The Digital Transformation of Seoul National University Bundang Hospital

DIGITAL HEALTH CASE STUDIES

EDITION 07

Acknowledgments: We, the IDB team, would like to express our gratitude to all the individuals who participated in interviews and provided valuable information for the development of this document. Our appreciation also extends to the SNUBH team for their efforts in organizing the interviews and conducting the necessary research.

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CONTENTS

ABBREVIATIONS & ACRONYMS

AKI	Acute Kidney Injury
CDSS	Clinical Decision Support System
CDW	Clinical Data Warehouse
CI	Clinical Indicators
CLMA	Closed-Loop Medication Administration
CP	Clinical Pathway
CT	Computerized Tomography
CTCs	Community Treatment Centers
DNR	Do Not Resuscitate
EHR	Electronic Health Record
EMR	Electronic Medical Record
ERD	Entity-relationship Diagram for a Hospital Management System
HIE	Health Information Exchange
HIMSS	Health Information and Management System Society
HIS	Hospital Information System
ICU	Intensive Care Unit
IT	Information Technology
MAE	Medication Administration Error
OECD	Organisation for Co-operation and Development
ONC	Office of the National Coordinator for Health Information Technology
PACS	Picture Archiving and Communication System
PHR	Personal Health Records
R&D	Research and Development
RFID	Radio-Frequency Identification
RRS	Rapid Response System
SNUBH	Seoul National University Bundang Hospital
SNUH	Seoul National University Hospital
TFT	Task Force Team
US	United States

EXECUTIVE SUMMARY

The Latin America and the Caribbean region can achieve an increase in average life expectancy of up to three years while maintaining current health and medical spending—if it can achieve an efficiency in the health care sector comparable to that of the average OECD (Organization for Co-operation and Development) nation. Thanks to its well-developed IT sector, the Republic of Korea has achieved a high level of digitalization in the health care realm, improving the quality and efficiency of various clinical services, especially through the implementation of electronic health record (EHR) systems.

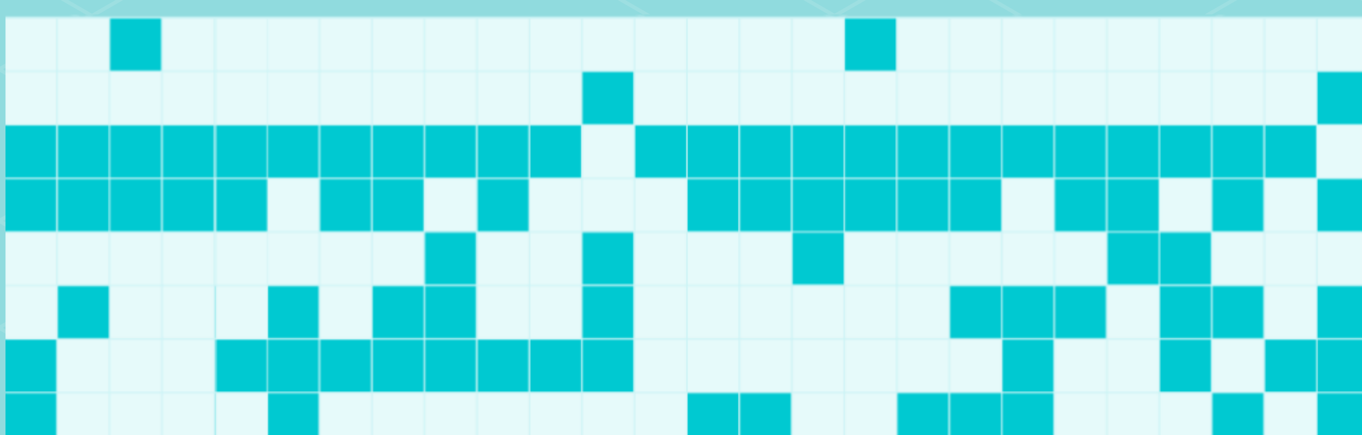
The SNUH health care group consists of four hospitals: SNUH, SNUBH, Gangnam Center, and Boramae Hospital. Seoul National University Bundang Hospital (SNUBH) is a national, multispecialty academic medical center that integrates hospital care with research and education and has led the foray into digitized health care by creating a fully-fledged digital system at a sizable, reputable tertiary hospital in Korea. SNUBH is one of the largest and most respected hospitals in the country, with 783 physicians, 1,603 nurses, 1,393 beds, and 38 operating rooms.

For this case study, SNUBH conducted focus group interviews to capture the first-hand experiences of field-deployed staff members. The interviews revealed the decision-making process for and motives of the transition as well as the implications of the internal and external contexts and key performance indicators chosen during the project's life cycle.

BESTCare, the hospital's interoperable EHR system is the backbone of the digital transformation of the hospital. Successful digital transformation in SNUBH with the implementation of BESTCare required both a top-down and bottom-up approach: decisive investment decisions by the leadership and key inputs of end-users from the initial phase onward. Short-term outcomes were not expected, as the benefits have grown gradually but surely, eventually compounding improvements in cost efficiency and clinical quality. Additional periphery subsystems have been and can be devised and used in a modular fashion and repurposed—which was a key feature that has proved vital for rapid development in times of crisis, such as during pandemics and the COVID-19 pandemic in particular.

In addition, SNUBH has invested in rigorous evaluations of the various digital tools implemented. The documented impacts of BESTCare, the integrated EHR system and the various electronic alert subsystems deployed for the quality and efficiency of care are detailed in the close-up studies in section 4.1.

1. INTRODUCTION



Source: The Republic of Korea's Tools for fighting COVID-19. Page ??

1. INTRODUCTION

Korea's health sector has achieved a high level of digitalization, quickly adapting the globally growing IT and Communication infrastructure at the outset of the 21st century —more than 90 percent of its medical institutions and, as of 2021, 100 percent of its tertiary hospitals used EHRs (Park and Han, 2017; MOHW, 2021).[1]

As of 2019, there were about 120 EHR software vendors in Korea, with the top 10 accounting for nearly 90 percent of the EHR market. In tertiary hospitals, 7.1 percent of the EHR systems are self-developed, 50 percent are commissioned to an EHR company, 32.7 percent are a joint product of the hospital and an EHR company, and 10.2 percent are purchased from commercial vendors. In secondary hospitals[2], no EHR system has been self-developed, 58.8 percent were developed by software companies, 2.9 percent are a combination of self-development and partial support from outside vendors, and 38.2 percent were purchased from commercial vendors (HIRA, 2019).

SNUBH is part of the SNUH health care group, which consists of four hospitals: SNUH, SNUBH, Gangnam Center, and Boramae Hospital. Since its successful opening as a digital hospital in 2003, SNUBH—a national, central, multispecialty academic medical center that integrates hospital care with research and education—has led the foray into digital health care. The hospital used health IT as part of its efforts to improve quality of care and created its own EHR system (BESTCare 1.0 in 2003 and BESTCare 2.0 in 2013), which is one of the most sophisticated EHR systems in the world.[3] As of June 2021, SNUBH was one of the largest and most respected hospitals in the nation, with 783 physicians, 1,603 nurses, 1,393 beds, and 38 operating rooms. It also conducts over 7,000 daily outpatient visits and more than 80,000 radiological exams a month.

In 2006, SNUBH became the first hospital in Korea to establish a health information exchange (HIE) system, to exchange information within its network while simultaneously implementing a real-time asset tracking system, and closed-loop medication administration, utilizing radio-frequency identification (RFID) and other barcode technology. These changes led to greatly improved work efficiency and medication safety, along with other marked achievements as showcased by the close-up studies introduced in section 4.1.

SNUBH was also the first non-US medical institution to be accredited at Level 7 by the Health Information and Management System Society (HIMSS) in 2010, and it was recertified in 2016 and 2019. Furthermore, a clinical data warehouse (CDW) is linked with SNUBH's hospital

[1] In accordance with Article 3-4 of the Medical Service Act, titled "Designation of Tertiary Hospital," the Ministry of Health and Welfare is responsible for designating a general hospital that offers highly specialized medical services for the treatment of severe illnesses as a tertiary hospital. To qualify for this designation, a hospital must fulfill the following criteria: (1) maintain a minimum of 20 specialized departments, (2) function as an institution that provides training for individuals aspiring to become medical specialists, (3) possess the necessary human resources, facilities, and equipment, and (4) adhere to the standards stipulated by the Ministry's Ordinance.

[2] Hospitals with between 30 and less than 100 beds. https://journals.lww.com/md-journal/fulltext/2022/10140/current_status_and_trends_of_pulmonary.120.aspx.

[3] SNUBH is the first hospital outside of North America to achieve the HIMSS Stage 7 designation and was the only hospital in Asia to do so by 2010 (Mehler, 2010). By 2015, only 0.5 percent of hospitals in the Asia Pacific region (n = 770) achieved the HIMSS EMR adoption level 7. By 2017, only 5.3 percent of US hospitals achieved stage 7 (n = 5,498). SNUBH recertified its HIMSS stage 7 in 2016 and 2019. SNUBH's EHR became the first solution certified by the Office of the National Coordinator for Health Information Technology outside of North America in 2015, and got numerous awards including the HIMSS-Elsevier Digital Healthcare Award, the IT Innovation Presidential Award, and the SAP SAPPHIRE NOW IT Innovation Award. Harvard Business Review mentioned SNUBH's EHR in the article "How Big Data Impacts Health Care" as a successful IT platform (Harvard Business Review, 2016).

information system (HIS),[4] which enables the hospital to analyze data with ease. SNUBH also has a training program through which about 300 people from 20 nationalities participate annually in the areas of internal medicine, general surgery, obstetrics, and gynecology.

SNUBH's success in achieving the highest level of digital transformation can provide lessons and recommendations for the rapid adoption of EHRs in other countries. For example, the role of the government can be important in the promotion of EHR systems and digital hospitals (IDB, 2019). Governments can provide financial resources for digitalization projects, the regulations required for the standardization of EHRs and interoperability incentives to promote EHR implementation, and, most importantly, a long-term commitment to the success of digital transformation. The private sector, however, can also lead innovation at the national level. In Korea, it was the digital transformation of SNUBH that led to the spread of EHRs and digital hospitals across the country.

One downside of Korea's rapid digitalization of health care has been the lack of interoperability between the EHRs developed at individual hospitals. The government has been aware of this problem for quite some time and has been working to resolve the interoperability issue using pilot programs and regulation of EHRs and HIEs. In 2016, Korea legalized the creation of a national HIE to be used among medical institutions. Because the EHR system employed at SNUBH (BESTCare 1.0 and 2.0) has been designed to meet international interoperability standards (HL7, DICOM for example) from the beginning, SNUBH essentially established the framework for nationwide interoperability through its active role in the decision-making process for the government's regulation of EHR systems and HIEs.

This paper offers SNUBH as a case study for building a digital hospital and seven close-up studies on the impact of the tools being implemented to improve quality and efficiency in the hospital. The information for the paper was gathered through a focus group interview for field staff tasked with the digital transformation of SNUBH to get a glimpse of their first-hand experience, opinions on the digital transformation process, and lessons learned. Second, we gathered information from internal studies that have been published in international journals. These highlight the long-term results of SNUBH's digital transformation. This paper shows that the digital transformation of hospital management is not simply a decision about technology, but rather one that involves organizational and cultural elements, strong leadership, and the commitment and dedication of physicians, as explained in our flagship document (Bagolle et. al, 2022).

[4] An EHR system is the part of an HIS that contains medical records, such as past diagnostics and medications.

2. SNUBH’S ORIGINS AND DEVELOPMENT

3. SNUBH'S ORIGINS AND DEVELOPMENT

In the 1990s, Seoul National University Hospital (SNUH), the leading public hospital in Korea at the time, decided to build a new hospital in Bundang, a newly planned city to the south of Greater Seoul, to cope with the increasing demand for health care in the region.

SNUH leadership decided that the new hospital should be devised as a fully digital hospital to lead into the 21st century. It was to be a slip-less, filmless, paperless, and chartless hospital,[5] fully digital to the core. The EHR project at the new hospital was conceived to keep up with the growing speed and size of data in an ever-increasing information society. Doctors at SNUBH were keen to develop it and began to consider how to incorporate IT into health care processes.

Even before SNUBH, SNUH had introduced computerized hospital processes in stages starting in the 1980s. The most burdensome task, and the most important to the hospital, was and still is in the speedy and accuracy of processing bills and payments. Financial management is a priority for keeping the hospital afloat and was the first to be tackled. Next was R&D: laboratory processes were computerized by implementing advanced diagnostic equipment that automatically produced lab results. Previously, diagnostic processes such as blood tests were recorded manually, causing huge workloads and bottlenecks in the process. Then, the most important transformation for physicians was the establishment of an EHR system to manage the clinical records that are the basis of health care. These records contain all necessary information on a patient, such as a patient's diagnostic, medication, laboratory testing, and surgical history.

Starting in the late 1990s, SNUH worked to implement a home-grown EHR system. The hospital worked with one of the most prominent IT companies in Korea for this purpose, but the company failed to produce the results that the doctors had expected for two years in a row because of a communication failure between the computer engineers and the physicians. Software engineers at the IT company could not understand hospital processes nor transform the way doctors do their jobs to create an integrated HIS. Therefore, SNUH leadership decided to create its own IT company, ezCaretech, to facilitate communication between medical professionals and IT developers. The vice president of SNUH also served as the president of ezCaretech. Employees in the Center for IT and Services at SNUH were transferred to the newly established IT company. For SNUH leadership, it was better to retain its software employees who had the experience of introducing and installing the picture archiving and communication system (PACS) and order communication system in the hospital in the past. These employees also understood hospital processes much better than external developers. Moreover, to secure excellent employees who were experienced with HISs, an independent company was more useful for providing better work conditions and material rewards. This decision might have been influenced by SNUH having been established as a university hospital under the Ministry of Education, leading its employees to hold a public servant status with a relatively fixed salary range. Nearly 87 percent of

[5] Slip-less means physicians' orders are transferred to a pharmacy or lab through a computer network. Filmless refers to the digital process where x-ray, CT, and mid-infrared images are recorded, retrieved, and read electronically. Paperless means all the hospital documents are stored electronically and shared by authorized personnel. Chartless means that all care processes are recorded according to international standards, such as SNOMED-CT. SNUBH spent extra money to purchase medical equipment that is compatible with its EHR and PACS (picture archiving and communication system).

SNUH's IT software engineers transitioned to ezCaretech, a private entity, where they could enjoy enhanced material rewards, acknowledging the considerable risk they undertook in developing the new hospital system.

The actual preparation for the creation of SNUBH began in November 2001, when the Opening Preparatory Committee, composed of 32 members, began to work 18 months before the planned opening in March 2003. The committee hired 40 physicians and 70 nurses in 2002. At this time, SNUBH leadership organized a task force team (TFT) that would work with ezCaretech to create the EHR system. The team was staffed by rather young medical personnel who were tech-savvy and willing to embrace radical changes toward instituting a digital HIS, and a professor in the Department of Psychiatry who had used an EHR system in a US hospital was designated as the TFT leader. The newly hired physicians, most of whom were quite young and 30 of whom came from SNUH, were required to participate in the EHR development process. The leaders of SNUH wanted to hire medical staff who were tech-savvy and willing to embrace a new HIS to reduce resistance to change. The premise was that they would participate in the EHR development process and be willing to embark on a journey to create the first EHR system in Korea. The TFT initially consisted of 15 doctors and 50 software engineers, but when the coordination problem between the physicians and software engineers persisted until just two months before the opening of SNUBH, the TFT leader reinforced the TFT by adding 35 additional doctors to achieve the agreed-on solution by matching one physician with one software engineer, thus facilitating the completion of the EHR system. The first function of this EHR, which is now known as BESTCare 1.0, was porting over all paper-based records to a digitized format.

Professors at SNUH were not offered any financial incentives or promotion opportunities to move to the new SNUBH, and most professors at SNUH were already working on several projects with many assistants. Moving to a completely new work environment and preparing for the opening of the departments in a new hospital could have prevented the successful implementation of their ongoing projects, which was required to ensure continued financial support for their research. In most cases, one professor per department moved to SNUBH. When SNUBH opened, most of the physicians were in their forties, which was rather young for medical school professors. The only incentive, if any, was the power of freedom to design and manage their departments in the new hospital according to their vision of medical care. A new department head would be in charge of designing the care processes, purchasing medical equipment, hiring new medical staff, and setting up specialized clinics. For example, Dr. Ha,[6] the head of the TFT, instituted Korea's first open ward system. Before this, psychiatric patients had been admitted to locked wards. The open ward system was found to work well for patients, so all psychiatric departments at other medical schools in Korea followed suit.

The TFT led the EHR development process. Physicians in the TFT explained to ezCaretech software developers what they needed to monitor results. When ezCaretech employees produced prototypes or drafts of how a service would be implemented, the TFT reviewed them and asked for revisions if they were not satisfied. This process was not easy and created conflict, even in this purpose-built company. Another point of conflict was how to incorporate the different tasks of each department into an integrated framework for the EHR system. In 2000, most EHR systems on the market were for specific departments or functions, such as EHR systems for internal medicine, surgery, and outpatient departments or intensive care units (ICUs). No EHR system covered all areas of hospital care, and it was very difficult to combine different care procedures from different departments into an integrated system. For example, a detailed record of tests and examinations is crucial for the internal medicine department, while the surgery department is much more concerned with radiology and the documentation of surgical processes.

[6] Kyoo-Seob Ha, professor at the Department of Psychiatry, is the former head of the EHR TFT at SNUBH. Section 3 of this paper is based on a July 5, 2021, interview with Professor Ha conducted by the SNUBH research team.

Implementing an EHR system involves changing work processes, but every department prefers its own version of work processes.

To coordinate different ideas into a framework that everyone agreed with was the most difficult part of the implementation process. This was resolved by the ruthless pursuit of an agreeable solution on the part of the TFT, which was strongly backed by the hospital leadership. This approach was possible because all the members of the TFT shared a strong bond and took on the job as their own.

When the TFT was formed to create SNUBH's EHR system, the first thing they did was persuade senior members of the university hospital of the usefulness of EHR systems. They emphasized that it was not difficult to use EHRs, and once they were used to them, it would be much easier and more convenient than filling out forms by hand. This perspective was important during the late 1990s because there was no pervasive understanding of the need for or the possibility of digitalization in patient care processes. Many physicians thought that the standardization of the care process, which required the implementation of an EHR system, was impossible. There were many different approaches to care, and many physicians thought that a standardized format for care was a sign of ignorance and incompetence. Moreover, physicians tend to be very independent-minded and not easily persuaded when it comes to the subject of how to provide care to patients, and these views need to be respected. No one should challenge their independence and autonomy as experts in their field of care. In Korea, those in senior positions carry more influence over junior members of the faculty, which reflects the traditional culture of seniority still prevalent in the country. **This culture of independence with seniority means that without the support of medical staff, especially its senior members, the introduction of an EHR system would be almost impossible.**

The support of the senior faculty members of SNUBH was crucial when the first rehearsal, held just a month before the opening of the hospital, failed in many aspects, especially in hospital management functions. Some professors were doubtful of the EHR and demanded a return to the old work processes using papers and charts, and others were worried about the financial burden that the possible postponement of the opening might cause. SNUBH had hired many physicians and nurses starting a year before opening, and a large sum of money in salaries had to be paid if it failed to open on time.

In a departmental heads meeting, two of the most senior professors came to the rescue of the troubled EHR TFT by quelling the opposition and giving a green light to the project. This was possible because the heads of the departments that attended the meeting were from the same medical school at Seoul National University, and they shared a strong senior-junior relationship—a dynamic that was particularly strong within the medical school, where seniority meant superiority and authority. The move also proved that the two senior members had a strong belief in the TFT. The TFT had been working hard and was committed to the success of the EHR project, and their efforts were recognized. This is when, as a last resort to resolve the communication problems, each physician was assigned one software engineer as a partner, and they had to come up with agreed-upon solutions at every step of the decision-making process.

The partners worked day and night, studying hard to overcome challenges that arose and visiting US hospitals using EHR systems to learn how they worked. Just one month before SNUBH's scheduled opening, the TFT fixed the problems they had discovered at the rehearsal, allowing SNUBH to open on time. The system launch was an extraordinary feat given that the doctors in the TFT had no prior knowledge of software development. Dedication, concentration, and collaboration were the driving forces behind the construction of the EHR system.

When SNUBH opened, its president made it clear that all hospital processes would follow the TFT guidelines. Support of the nurses proved to be another major factor in the successful implementation of the new EHR system. The nurses liked that the EHR system reduced their workload, and thus their time and energy. The extra time and energy could then be used to provide better patient care. “Though physicians play a key role in diagnosing, ordering, and surgery, it is nurses who spend a whole day with the patients and enter the data into an EHR system.”[7]

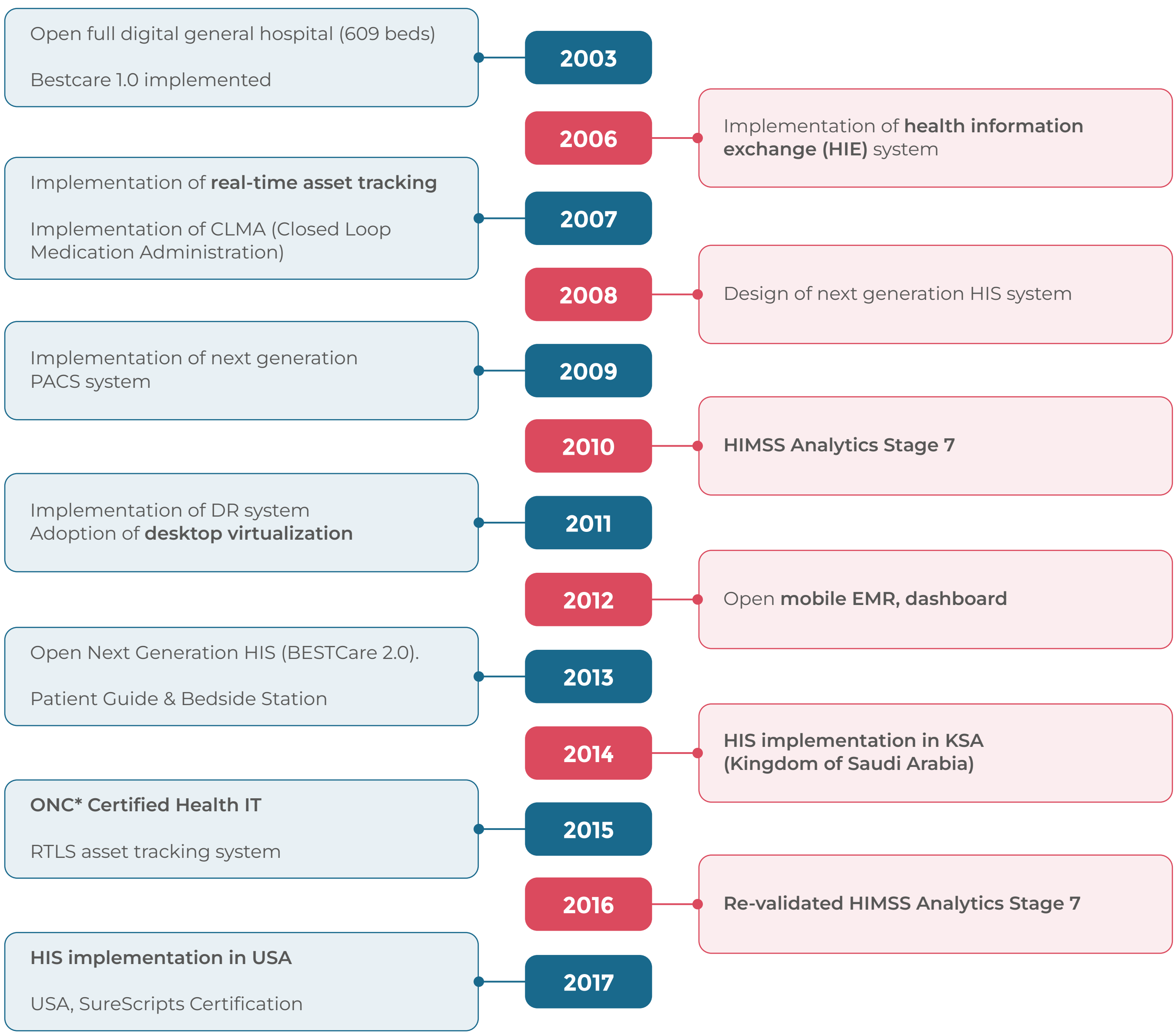
After the opening of SNUBH, the implementation of the EHR system contributed to enhancing the quality of care by providing various types of care information (such as the ICU readmission rate, complications rate, and operation waiting time) that could be retrieved from the CDW. Initially, physicians were given incentives to create clinical indicators (CIs) for measuring and monitoring the medical quality of care. The department performance as measured by these CIs affected budgetary allocations to each department, which could be used to buy equipment that the department wanted or for any other specific purpose, so tech-savvy young physicians were active in devising CIs for their departments. The number of CIs, thus increased from 19 in 2005 to 335 in 2012. The use of CIs and other indicators led to “better patient safety, improved health care quality, and increased efficiency of hospital administration” (Yoo *et al.*, 2014).

Because satisfying the needs and demands of the physicians is vital to ensuring the successful introduction of an EHR system, there is no such thing as a one-size-fits-all EHR system. An EHR system needs to be user-friendly by reflecting the demands of the physicians and nurses using it. For example, at SNUBH it was important to develop an EHR system that assisted physicians in making diagnoses and issuing orders quickly. The first step toward the adoption of any EHR system is ensuring the medical staff’s confidence in its ease of use. No matter how good an EHR system is, it will be useless if medical staff find it difficult and uncomfortable to use or if it provides little help in improving the quality of care.

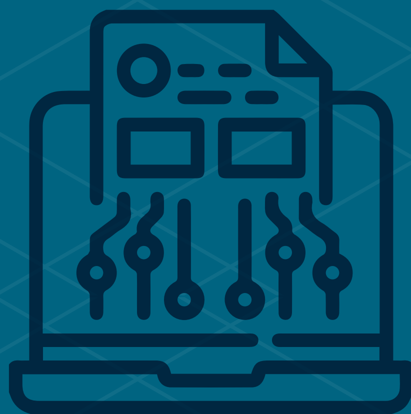
BESTCare was developed so that the medical staff at SNUBH liked working with it, so it appealed to staff and reduced the resistance to its adoption.

[7] Quote from the interview with Professor Ha, conducted on July 5, 2021, by the SNUBH research team.

FIGURE 1:
Development of BESTCare



Source: updated from Yoo *et al* (2012), Yoo, Hwang and Jheon (2016).
Notes: EMR = electronic medical record; HIE = health information exchange; HIMSS = Health Information and Management System Society; HIS = health information system; ONC = Office of the National Coordinator for Health Information Technology; PACS = picture and archiving communication system. The ONC provides the Health IT Certification Program in the United States.



3. CONSOLIDATING DIGITAL TRANSFORMATION: THE CREATION OF BESTCARE 2.0

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In 2010, SNUBH looked at the past five years of trend data on yearly requests for next-generation EHR improvements and concluded that the existing architecture harmed the speed and soundness of BESTCare.

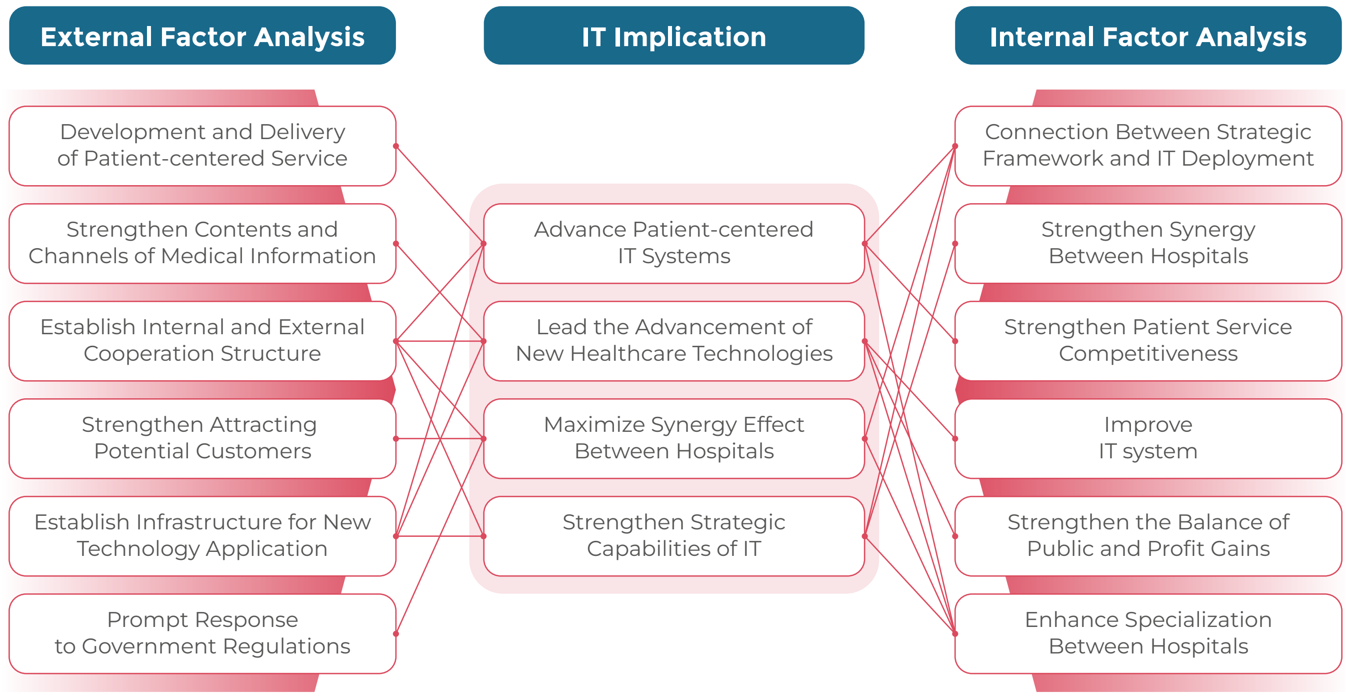
The big question was whether the medical informatics team should continue maintaining the system or strategically devise a new technical solution for a more advanced system.

BESTCare 1.0 was based on .NET infrastructure, which was inherently limited in its throughput. In a way, BESTCare 1.0 was a reflection of the way SNUH did things in the predigital world, so many of the data tables were poorly mapped, such as electronically implemented CIs or medication administration systems. As data accumulated, a more efficient system was needed to quickly access and visualize patient's history. In recognizing the shortcomings of BESTCare 1.0, the chief information officer and executive directors decided to develop the next generation, known as BESTCare 2.0. The **TFT team received a lot of support and funding from SNUH to upgrade to the next-generation EHR system.**

In preparation for the 2.0 system implementation, SNUBH received an on-site consultation from a global firm from September to November of 2010 about the hospital's strategic IT directives and approaches, the outlines of which are shown in Figure 2. Topics of the consultation included specific IT environments, business directions, internal capacities, and future key roles.

BESTCare 2.0 needed to have proper, consensual leadership. Therefore, strategic planning meetings for consultation and information were conducted continuously from September 2010 to April 2011. **All four hospitals of the SNUH healthcare group: SNUH, SNUBH, Gangnam Center, and Boramae Hospital were potential users of the newly developed BESTCare 2.0 system and were part of the consultation**. A feasibility study was also done by the same firm, done through 29 metrics, grouped into 16 categories and three overall stages.

FIGURE 2:
IT Implications of Internal and External Environment Analysis



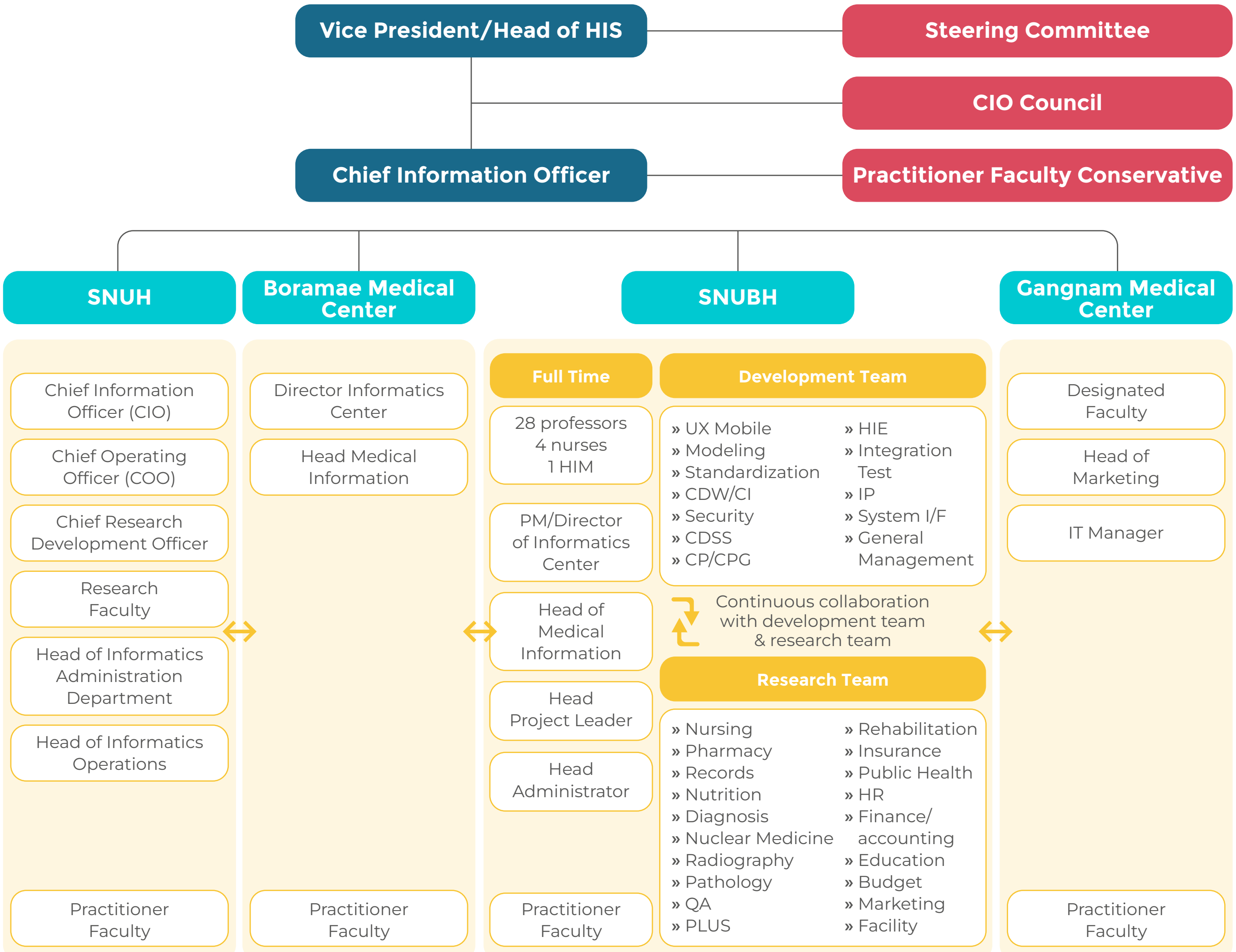
In order to respond to the changing internal and external environment, Seoul National University Hospital plans to 1) lead the advancement of new technologies in healthcare, 2) expand balancing of public/profit gains, 3) advance in IT infrastructure, and 4) maximize synergy effect between hospitals.

Source: own work by the SNUBH.

By the early 2010s, through the consensus of all four hospitals, a direction and blueprint for the next EHR was decided. The head of Medical Informatics (chief information officer) for each of the four hospitals joined in quarterly meetings. Also present were the chief financial officers, chief operating officers, and chief R&D officers. Each hospital accounted for the needs of their institution from the bottom up, gathering the requests and advice of all staff and faculty. Resources were divided and task forces formed, as shown in Figure 3. The next-generation system would also benchmarked upon global standards, such as HIMSS.

The new hospitals did not have some of the advantages that SNUBH had. Starting from a clean slate, not depending on previously developed data tables that were poorly mapped, was very helpful for SNUBH, when it was created. Because there was no previous paper based system many, especially younger employees, easily and gladly picked up the digitized systems. On the other hand, pre-established hospitals whose resources may have been 20 to 30 years old had a very hard time convincing and assimilating their employees, including the older doctors, to drop the paper and pen and pick up the mouse and keyboard.

FIGURE 3:
Organizational Chart for the development of BESTcare 2.0



Source: own work by the SNUBH.
Note: Head-level positions and subordinate C-suite positions for the four hospital centers of SNUBH are shown.

From project launch to implementation of BESTCare 2.0, the development took 1.5 years. The official figures for the cost of development of BESTCare 2.0 indicates 24 billion Korean won (approximately 20 million US dollars), however this figure does not include all the expenses associated with individuals involved in the development but not formally part of the development team—given that project development necessitated widespread institutional participation. To get a better idea of the level of effort that is not contaminated by differences in inflation and wage levels between the time of system development and the present day, the total hours per month needed was 1,260 for full-time physicians and 2,300 for full-time IT engineers.

The project was largely separated into four stages:

- **Analysis**
- **Design**
- **Implementation**
- **Testing**

The first stage, analysis, outlined the tasks for each role, the project's scope, and formalized detailed requirements. **The second stage** was the **design stage,** which detailed the requirements and architectural outline of the development standards. This stage also included the design for the service side, along with data modeling, data migration plans, and basic user interface and user experience outlines. **The third stage, implementation,** was mainly concerned with the actual migration of data. **Last, the testing** stage oversaw various tests from specific modules to comprehensive integrated testing and the formalization of proper procedural guidelines and protocols. **All four stages equally contributed to the development of the final product as we know BESTCare 2.0.**

By the time BESTCare 2.0 was released in 2013, a substantial volume of patient data had accumulated in BESTCare 1.0. This made the system update crucial for rapid and correct diagnoses and medicinal orders. In addition, a logical interface in the form of a dashboard was constructed, where all the important patient information could be seen in a single glance. The update included data standardization to enable the use of accumulated data for research. This feature convinced many professors who were initially skeptical of using the EHR system to find it convenient and beneficial for patient care and research.

TABLE 1: BESTCare 2.0 Project Stages

Results at the Analysis stage

Sept. – Oct. 2011 (2 months)

- Initiate launch briefings.
- Determine requirements for each role.
- Determine ongoing tasks and interface.
- Project implementation plan, scope comparison table.
- Documented definitions and statements of requirements.

Results at the Design stage

Nov. 2011 – Jan. 2012 (3 months)

- User requirements, additional performance results summary.
- Formalize and refine requirements.
- Formalize architecture and determine development standards.
- Design service side.
- Data modeling.
- Establish data migration protocols.
- Basic and detailed user interface blueprints, basic and detailedservice-side blueprints.
- Logical and physical ERD (Entity-Relationship
- Diagram for a Hospital Management System), formalized entities jargon dictionary, domain dictionary; formalized common code
- Formalized architecture, user experience style guide, development environment guide.

Results at the Implementation stage

Feb. – Oct. 2012 (9 months)

- Data migration planning and activation.
- Data modeling.
- User interface design and development.
- Application design and development.
- Modular testing.
- Source code.
- Report on modular testing results.
- Data transfer mapping definitions.
- Data transfer results analysis.

Results at the Testing stage

Nov. 2012–Mar. 2013 (5 months)

- Integrated testing.
- Trial testing.
- Parallel testing.
- System overload testing.
- User training.
- Integrated testing and trial run protocols.
- Integrated testing and trial run results.
- Data implementation results.
- User manual.
- Administrator manual.
- Implementation and emergency procedures protocol.

Source: own work by the SNUBH.
Notes: The project was divided into four phases: 1) Analysis, 2) Design, 3) Implementation, and 4) Testing.

4. ACHIEVING RESULTS THROUGH DIGITAL TRANSFORMATION AT SNUBH

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How Was Success Defined?

The leaders of the development and implementation of BESTCare 2.0 defined the near-term success as the launch of the system. Determining the efficacy of the new EHR system was possible only a few years after its implementation.

The key metrics were a reduction in time spent on asset management, patient safety accidents in closed-loop medication administration (CLMA), and other error rates. A summary of other results published in international journals is shown in Figure 4 and a more detailed discussion of is shown in section 4.1.

FIGURE 4: Summary of SNUBH's Digital Transformation studies

Antimicrobial Prescription Intervention Program

Electronic Alerts with Automated Consultations Promote Appropriate Antimicrobial Prescription

(PLOS ONE, 2016)

Appropriateness use of antimicrobial

- Effective therapy rate → **7.5% INCR.**
- Optimal therapy rate → **26% INCR.**
- De-escalation therapy rate → **86% INCR.**
- Intravenous oral switch → **7.1% INCR.**

Clinical Indicator

Clinical Benefit of Electronically Implemented Clinical Indicators Based on a Data Warehouse

(International Journal Medical Informatics, 2014)

Clinical Benefit & Effectiveness

- Surgical Antibiotic Admin rate → **90% DECR.**
- Avg. Hospitalization Days → **73% DECR.**
- ICU Mortality Rate → **18% DECR.**
- ICU Re-hos. Rate → **8% DECR.**

Close-Loop Medication Administration

Analysis of a Large-scale Closed-loop Medication Administration System using RFID and Barcode

(Health Information Research, 2015)

Prevention of MAEs

1. Patient Mismatch 0.73%
2. Drug Discontinuation 0.32%
3. Data Discrepancy 0.14%
4. Drug Overdose 0.03%

MAEs → Rate 1.22%

Acute Kidney Injury Alert System

Impact of Electronic AKI Alerts with Automated Nephrologist Consultation on Detection and Severity of AKI

(American Journal of Kidney Diseases, 2017)

Effect of Early Consultation

- AKI Overlooked Rate → **67% DECR.**
- AKI Incident Rate → **14% DECR.**
- AKI Recovery Rate → **44% DECR.**

Clinical Pathway

Analyzing the Actual CP Applications using BESTCare CP Support System

(Health Information Research, 2015)

CP Standardization/Adaptability

→ CP Application Rate: 75%

* Considering order code, date, and format

Rapid Response System

Successful Implementation of a Rapid Response System in the Department of Internal Medicine

(American Journal of Kidney Diseases, 2017)

ICU Patients Care using RSS

- LOS in ICU → **37% DECR.**
- Survival in ICU → **14% DECR.**
- Duration of Intubation → **10% DECR.**

Health information exchange

Can a health information exchange save healthcare costs? Evidence from a pilot program in South Korea

(Park *et al*, 2015)

Lower costs for charges for clinical laboratory tests (54%), pathological diagnosis (76%), function tests (73%), and diagnostic imaging (80%)

Sources: Kim *et al.*, 2016; Park *et al.*, 2018; Yoo *et al.*, 2014 ; Yoo *et al.*, 2015 ; Hwang *et al.*, 2016 ; Park *et al.*, 2015.
Note: AKI = acute kidney injury; CDSS = clinical decision support system; CP = clinical pathway; ICU = intensive care unit; MAE = medication administration error; RFID = radio-frequency identification; RRS = rapid response system.

4.1. Close-Up Studies on the Long-Term Outcomes of the Digital Transformation

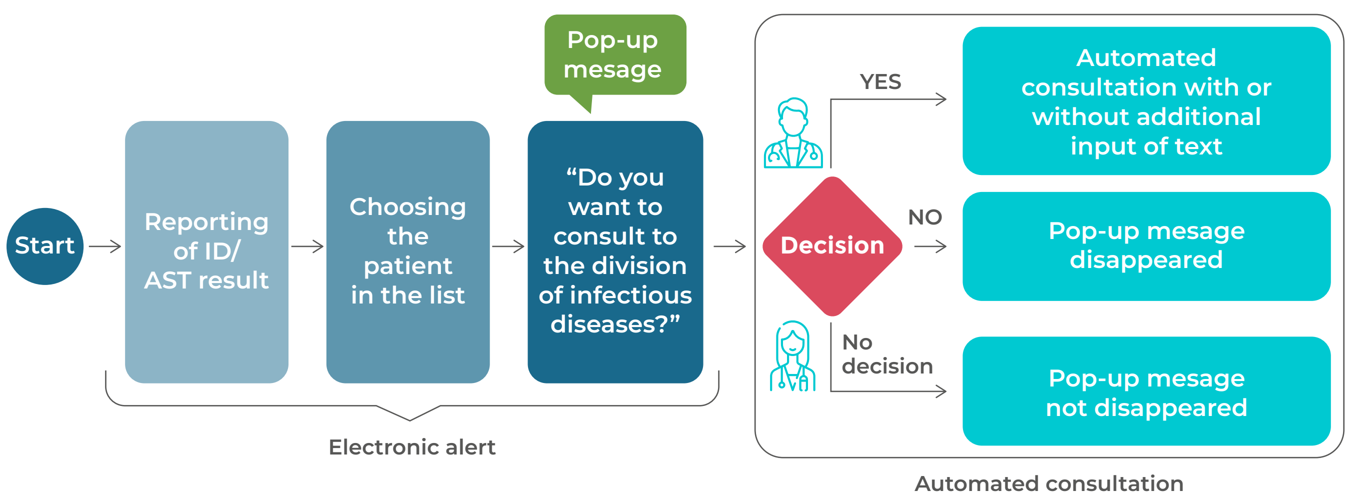
4.1.1. Close-Up 1 | Antimicrobial Prescription Intervention Program (Kim *et al.*, 2016)

To address what was perceived as a notable gap in addressing the prompt administration of appropriate antimicrobials, SNUBH initiated a program of electronic alerts and automated infectious disease consultations that was implemented for appropriate antimicrobial prescriptions to treat bloodstream infections in 2011. The intervention combined the work of infectious disease and IT specialists.

The key feature of this program has been integrated pop-up message alerts, which give the identification and antimicrobial susceptibility test (ID/AST) results with a note about whether a consultation with an infectious disease specialist is needed. The pop-up messages are generated for all categories of ID/AST results for attending physicians and allow them to make their own decisions on the use of antibiotics, after which they could directly consult on the results with infectious disease specialists. The use of EHRs has enabled faster and more accurate communication between physicians.

Because of this intervention program, attending physicians were no longer required to open the test results section of the EHR to view the results. The program also greatly reduced unnecessary antibiotic use and increased the proportion of optimal therapy in nonoptimal episodes: the proportion of effective and optimal therapy increased by 20 percent, and the median time to effective therapy was shortened by 19.5 hours in the same period.

FIGURE 5: Flow Diagram of Electronic Alerts and Automated Consultations



Source: adapted from Kim *et al* (2016).

4.1.2. Close-Up 2 | Acute Kidney Injury Alert System (Park *et al.*, 2018)

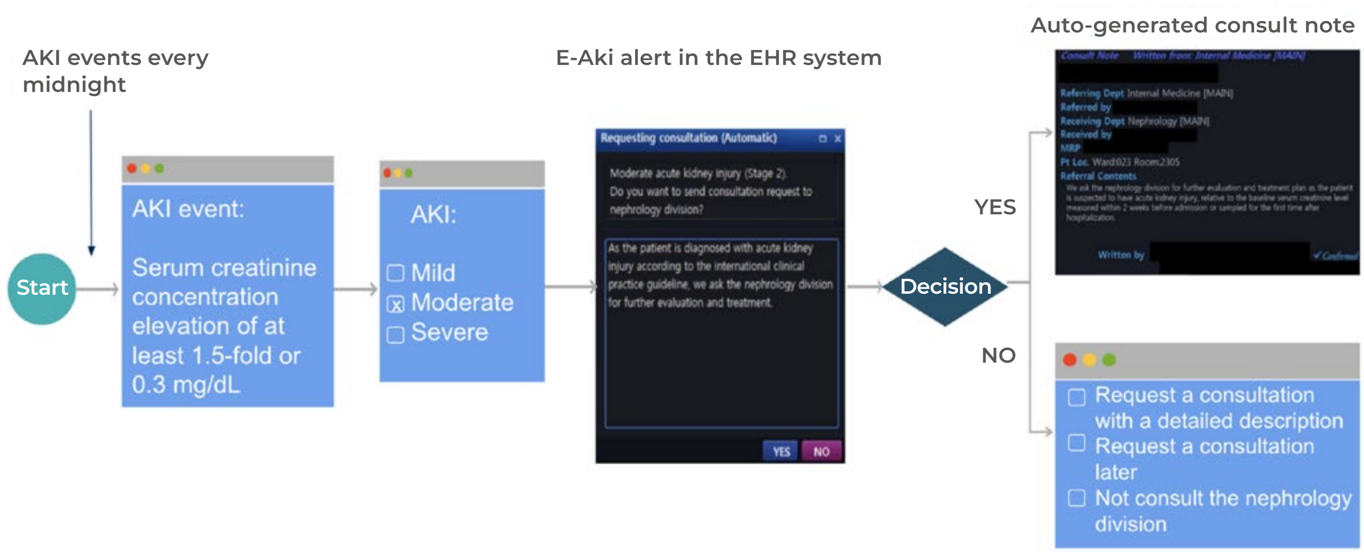
Many studies have addressed the necessity of improving acute kidney injury (AKI) outcomes, and its risk factors and prognosis have been widely investigated (Dreischulte, Morales, Bell, and Guthrie, 2015; Garg *et al.*, 2014; Mehta *et al.*, 2016). There is a consensus that early detection of AKI is crucial to improved patient outcomes. However, there are certain ways to electronically monitor the status of a kidney in real-time, which SNUBH has implemented through an electronic AKI alert system that fully integrates with the electronic health record (or EHR) system and includes an automated nephrologist consultation about the detection and severity of the AKI.

The AKI alert system automatically generates direct consultations for attending physicians with the nephrology division. The AKI alert system asks a physician the severity of the AKI and takes them to an automatically generated consult note in the EHR or **has them choose one of three options:**

1. Request a consultation with a more detailed description from the nephrology division.
2. Request a consultation later.
3. Decline to consult the nephrology division.

With the AKI alert system, early consultations with nephrologists increased by 21.4 percent. The likelihood of AKI recovery was improved in the alert group by 24.7 percent, while overlooked AKI events decreased by 1.6 percent after early AKI intervention and implementation of this specialized management system using AKI alert message.

FIGURE 6: Sample of an Automatically Generated Nephrology Consultation Request in the AKI Alert System



Source: Adapted from Park *et al* (2018).

The EHR-based AKI alert system altered the behavior of clinicians, increased the involvement of specialists, and improved AKI outcomes. Early nephrology intervention significantly improved patients' prognosis and rate of recovery from AKI, patients in the alert system exhibited a higher recovery rate (80.3 percent) compared with those receiving standard care (55.6 percent), and the alert system showed a consistent association with AKI recovery across all tested subgroups. Notably, the benefits were more pronounced in patients who had relatively preserved kidney function, had been admitted to nonsurgical departments, had no history of cancer, and were female.

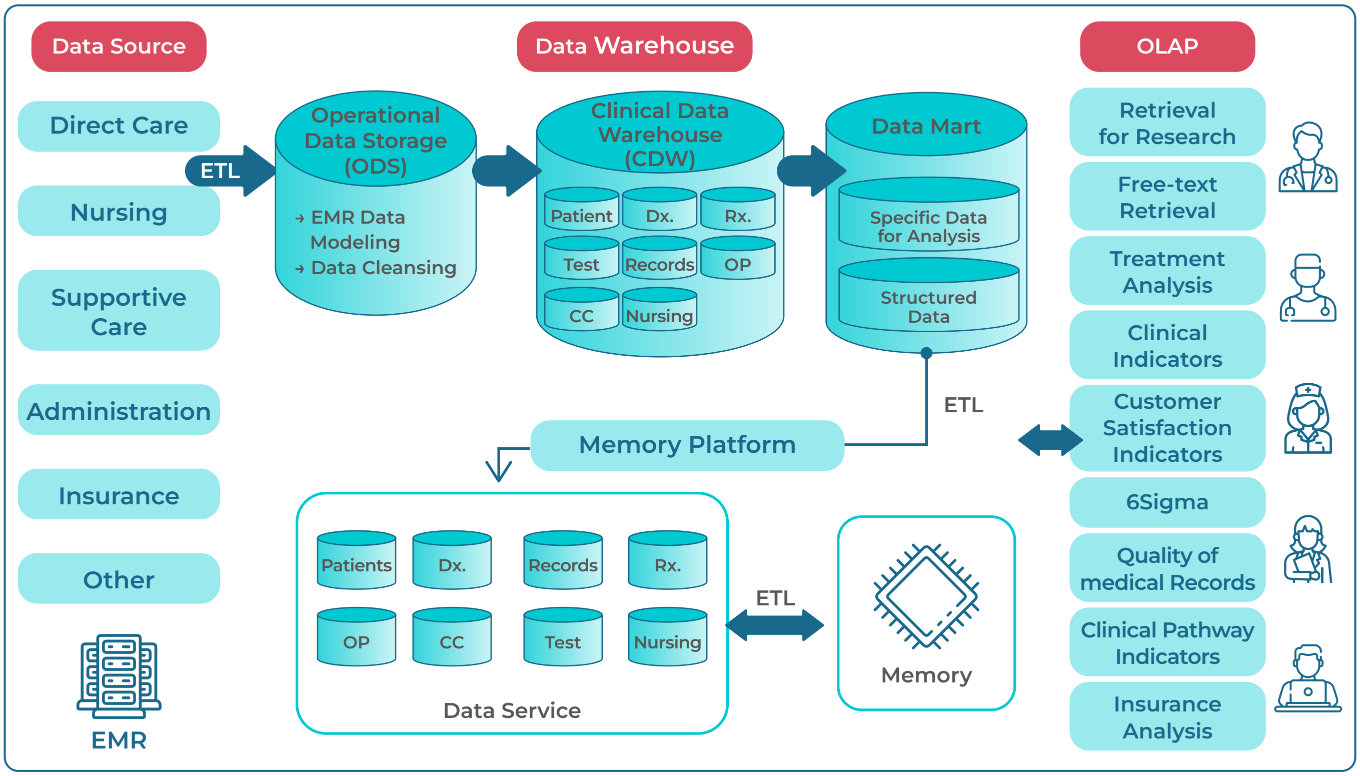
4.1.3. Close-Up 3 | Clinical Indicators (CI) (Yoo *et al.*, 2014)

A CI is any measure, process, or outcome used to judge a particular clinical situation and indicate whether the care delivered was appropriate and whether its measurement led to improvements in the quality of medical care (Huston, 1999; Shortell *et al.*, 1995). However, the proper management and maintenance of CI data has been difficult because of the manual input required for its collection and allocation. SNUBH has devised an automated implementation of a data-warehouse-based CIs system to carefully evaluate clinical benefits and performance for quality-controlled medical care.

The data warehouse consists of a clinical Data Warehouse (CDW), operational data storage, and a data mart, and the inclusion of the electronic CIs in the data warehouse does not interfere with the EHR system's operations. Financial information, patient information, and medical data including diagnoses, prescriptions, tests, medical records, and nursing records are automatically updated daily from the operational EHR database to the data warehouse. In addition, online analytical processing was also implemented to develop functions to search, analyze, and visualize the data. SNUBH then created four types of electronic indicators: CIs, performance indicators, safety indicators, and patient experience indicators. Those indicators are decided on monitoring the performance of the operational EHR system.

The system helped end-users access the monitoring data and immediately use it to improve their quality of care, work efficiency, and patients' safety. For example, optimal dosages of preoperative antibiotics were improved by giving feedback on preoperative antibiotic prescription through continual monitoring, which led to an optimal selection of which preoperative antibiotics to prescribe. Also, the overall ICU mortality was reduced by 2.1 percent, and the average length of hospitalization was shortened by 5.8 days.

FIGURE 7:
The Architecture of SNUBH's Clinical Indicator System, Based on a Data Warehouse



Source: Yoo *et al* (2014).

4.1.4. Close-Up 4 | Clinical Pathway (Yoo *et al.*, 2015)

Effectively managing inpatients during hospitalization by providing a multidisciplinary treatment plan and step-by-step execution of clinical activities for a particular diagnosis is known as a clinical pathway (CP). As one of the leading digitized hospitals, SNUBH has conducted a study to confirm the conformance rate of CP usage through EHR log data from its tertiary general university hospital setting.

This study required the analysis of application and matching rates of clinicians' orders with predefined CP order sets based on data from 164 inpatients who received appendectomies out of all the patients who were hospitalized for almost a year. Then, EHR log data was collected on patient information, medication orders, operation performed, diagnosis, transfer, and CP order sets using the process mining technique.

The average value of the actual application rate of the prescribed CP order ranged from 0.75 to 0.89. The application rate decreased when the order date was factored in along with the order code and type. Among CP pre-operation, intra-operation, post-operation, routine, and discharge orders, orders pertaining to operations had higher application rates than others. Routine orders and discharge orders had lower application rates.

This analysis of the application and matching rates of CP orders suggests that it is possible to increase these rates by updating the existing CP order sets for routine discharge orders to reflect data-driven evidence. In this case, the CP adoption rate with BESTCare was as high as 89 percent when considering only the order code, and at least 75 percent when order date and type were factored along with the order code. The study does not compare adoption with a non-EHR comparison group, but it shows that it is feasible to improve the application and matching rates of the CP solely by using EHR log data.

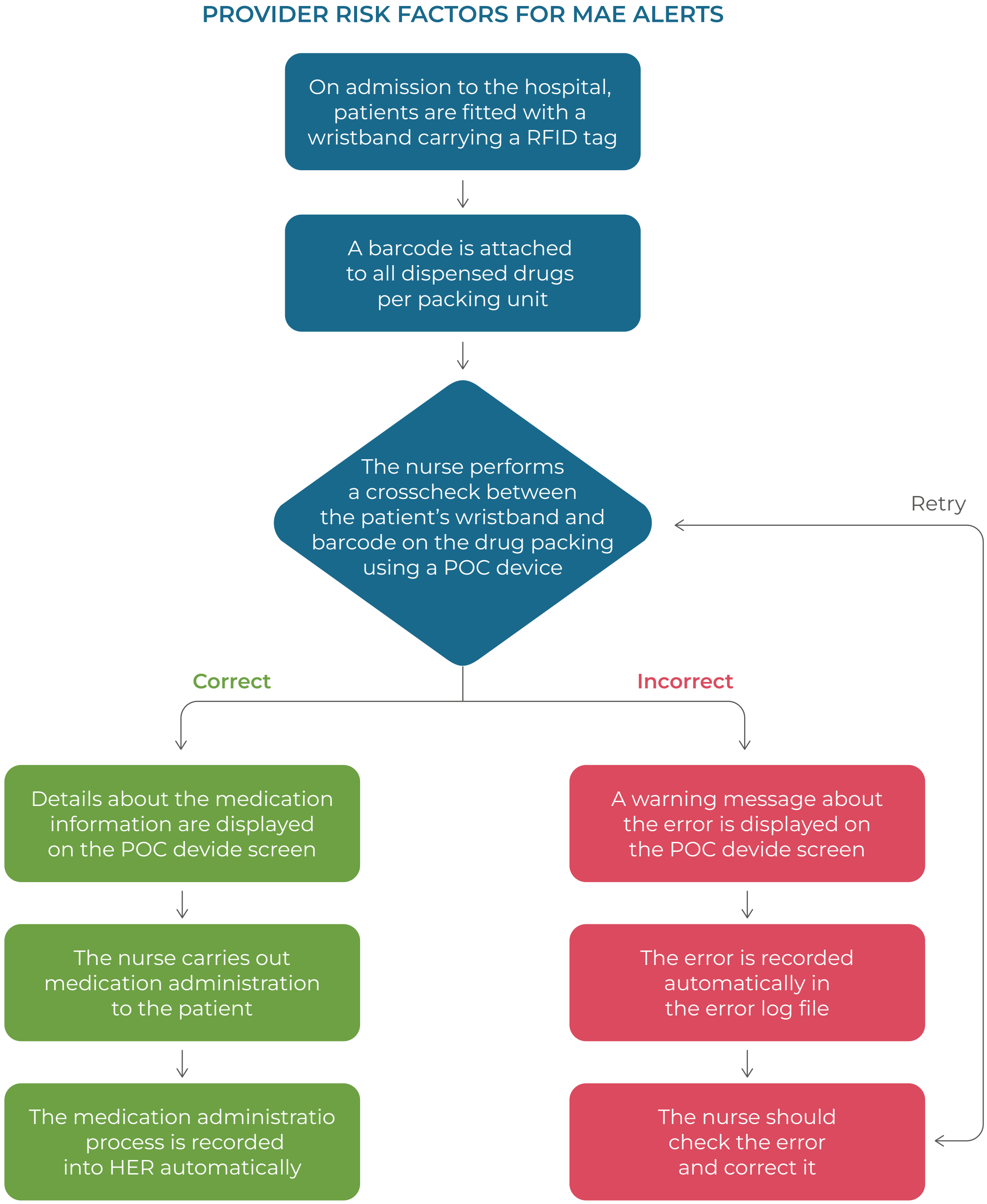
4.1.5. Close-Up 5 | Closed Loop Medication Administration (Hwang *et al*., 2016)

Proper administration of medication is one of the most vital processes in patient care.

About 1.5 million Americans go through injuries caused by medication errors every year, of which 25 percent could have been prevented (Institute of Medicine, 2007). To mitigate this error at all care stages, SNUBH devised a closed-loop medication administration (CLMA) system to determine the risk factors and rate of alerts from medication administration errors (MAEs). The risk factors considered for MAE alerts included administration time, order type, medication route, the number of medication doses administered, and factors associated with nurse practices, done through a logistic regression analysis.

All medication administrations in the general wards were automatically recorded in real-time using radio-frequency identification (RFIDs), barcodes, and portable point-of-care devices. The MAE alert logs were recorded for a full year in 2012 to gather the data for an in-depth trial analysis. The database was not trivial in size, with a total of 2,874,539 medication doses recorded from up to 30,232 patients. Of these, there were 35,082 MAE alerts identified (approximately 1.2 percent of total medication doses), most of which occurred during nonstandard hours or as part of emergency orders and were dependent on the total number of medication doses administered per patient. Other significantly related factors included medication route, assigned nurse's employment duration, and work schedule. All of these factors were used to tweak the alert system and lower false alerts to reduce MAEs for the safety of patient care.

FIGURE 8:
Schematic Illustration of the Medication Administration Process in the CLMA System



Source: Hwang *et al* (2015).

4.1.6. Close-Up 6 | Rapid Response System (Lee *et al*., 2014)

Unforeseen patient deaths are some of the most difficult situations to respond to in a clinical setting.

To mitigate this, SNUBH has devised a rapid response system (RRS) to prevent unexpected patient deaths from clinical errors, especially in the fast-paced environment of ICUs. For example, the RRS was used to identify and respond to patients with early signs of clinical deterioration in non-intensive care units, admitting them to the ICU as necessary. To assess the activity and outcomes of an EHR-based RRS for hospitalized patients in internal services, a total of 4,849 alert lists generated from 2,505 patients were analyzed. Of those, RRS was activated in 58 patients. 44.8 percent of those patients admitted to the ICU, and a "do not resuscitate (DNR)" order was initiated by the RRS physician in 12.1 percent of those RRS activated patient. It was also found that low oxygen saturation was the most common criterion for RRS activation.

Overall, ICU admission via the RRS resulted in a significantly shorter length of stay in the ICU than that with conventional admission (6.2 days versus 9.9 days, a 37 percent decrease). This finding is important because long-term stays in the ICU are adversely related to health outcomes because of the increased risk of infections, other complications, and even mortality (Lee *et al*., 2014).

An additional finding was that patients admitted via the RRS and the conventional methods had similar disease severity, but the former had a slightly lower likelihood of organ failures. This suggests that the early detection of at-risk patients in general wards and early intervention via the RRS can prevent the development of organ failure. **Also, the RRS might lead to a short length of stay in the ICU as well as possible improved clinical outcomes in long-term observation.**

4.1.7. Close-Up 7 | Health Information Exchange System (Park *et al*., 2015)

Many institutions and national governments have tried to proliferate and expedite the process of adopting HIE technology. As a common IT infrastructure, HIE can directly improve the quality and efficiency of many clinical facilities by allowing users on-demand access to health care information generated by all other providers. The Ministry of Health and Welfare funded a 3-year pilot program at SNUBH from 2007 to 2010 to assess the impacts and effectiveness of HIE in health care utilization and costs of patient episodes at a tertiary referral hospital environment.

Over a 17-month duration from June 2008 to October 2009, a total of 1,265 HIE cases and 2,702 non-HIE cases have been studied from referred patients of 35 HIE and 59 non-HIE subtertiary clinics, respectively, to the SNUBH. This study examined nine measures of health care utilization and the magnitude of clinical information exchanged in four categories. Cost savings were calculated through linear regression models with dummy variables for HIE participation and patient classification codes controlling the case-mix differences between HIE and non-HIE cases.

The result showed that the mean total charges and mean number of orders were significantly lower in the HIE group than in the non-HIE group. By improving physicians' access to past Cis, thereby reducing diagnostic test utilization and health care costs, the total charges incurred by the HIE group were lowered by approximately 13 percent, while their charges for clinical laboratory tests, pathological diagnosis, function tests, and diagnostic imaging were more than halved, at times up to 80 percent. (Park *et al*., 2015). The government emphasized the inequitable benefit distribution between providers and payers (the payer benefits but the provider pays for the technology), as well as between tertiary hospitals and referring clinics. To rectify this imbalance, incentive mechanisms were recommended to compensate providers for implementing an interoperable HIE system.

In 2009, a new Medical Information Exchange System (MIES) was developed by SNUBH and the Center for Interoperable EHR of Korea (CIEHR) based on exchange standards. On its launch, this system allowed seamless access to heterogeneous systems. By adhering to international standards for information exchange, it not only enhanced connectivity for domestic medical institutions but also extended accessibility to international medical establishments (Han *et al.*, 2010). Since its launch in 2009 with SNUBH's 35 clinics, this HIE network has expanded by 2022 to 61 tertiary-level hospitals with 7,500 clinics—which covers all the tertiary-level hospitals in Korea, making the HIE network nationwide (MOHW, 2022).

5. HOW SNUBH'S DIGITAL TRANSFORMATION HELPED IN COMBATING COVID-19

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At the outset of the COVID-19 pandemic, Korea was taken by surprise.

To prevent the medical system from collapsing in early 2020 when cases spiked dramatically, community treatment centers (CTCs) were established starting in March 2020 across the country to take care of patients with mild symptoms awaiting hospital admission and those who seemed to be recovering. As part of these triage efforts, the faculty of family medicine team, dispatched from SNUBH led the CTCs to help create a digital field hospital to manage COVID-19. **SNUBH's IT preparedness played an essential role in designing and creating a fully functional digital field hospital in short time** maximizing the few resources to develop an architecture of telemedicine where intensivists and primary care doctors could monitor patients in the CTCs (Jung, Hwang, Lee and Baek, 2020).

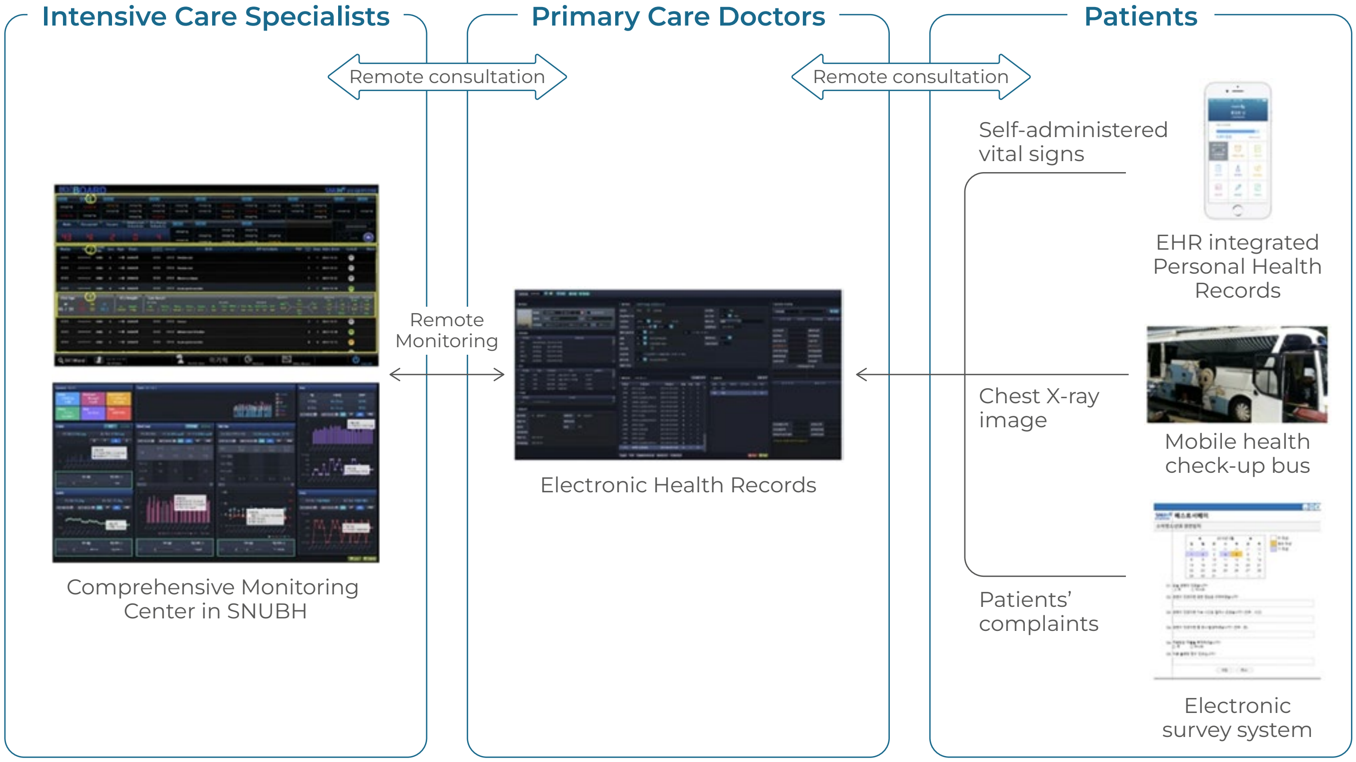
The CTC digital hospital was built in a short period thanks to SNUBH's advanced IT, and **digitalization was important for three main reasons:**

1. To minimize direct contact with patients.
2. To keep and record all the data and information electronically and incorporate it into EHRs.
3. To implement a telemonitoring system to interact effectively when necessary.

With BESTCare 2.0, SNUBH's EHR system, all patient data is integrated bidirectionally through an electronic monitoring system. At the CTCs, the system was utilized as an information hub to gather all the medical information from patients, including personal health records, and clinicians were able to communicate with the patients through video calls.

At the same time, a SNUBH personal health record solution called Health4U, which monitors a patient's vital signs (blood pressure, pulse rate, body temperature, etc.) was used in the CTCs. Moreover, physicians were able to analyze the symptoms they were seeing in their CTC patients, as well as from the risk alerts identified from the complaints registered via electronic surveys that SNUBH built to integrate the patient's survey result automatically into BESTCare.

FIGURE 9:
The Telemedicine Architecture for CTCs Supported by SNUBH



Source: Jung, Hwang, Lee and Baek (2020).

6. CONCLUSION

7. CONCLUSION

Digital transformation of SNUBH through the implementation of BESTCare 1.0 and 2.0 required both a top-down and bottom-up approach. It required a decisive investment decision by the high-level decision-makers, as well as key inputs of the end-users at inception. Continuous support from leadership was essential as it was understood that results would not be shown in the short term. The composition of the team was a key factor in building a common understanding between health personnel and IT personnel of what was required from the system, matching IT and health personnel one to one enabled the team to overcome obstacles at a critical time. Another important lesson is the need to redesign processes independently of the paper-based approach, a lesson that was learned for the development of BESTcare 2.0. Also important is listening to the users so that the designs end up facilitating their work and make it easy to use the system. Finally the system should create value for the users, enabling the use of the data for research was a key factor in EHR adoption in the SNUH group.

The effects of SNUBH's digital transformation can be assessed through the gradual improvement in the hospital's cost efficiency and clinical quality. In the last decade SNUBH was able to perform various studies of the different features that make up BESTcare 2.0. showing objectively that the system has enabled improvements in both quality and efficiency. These features, enable data-powered real-time preventive interventions, which was an unfeasible endeavor in the former print-out-based analog era of hospital systems. Each feature allows for easy reutilization and repurposing. Illustrated by SNUBH's response to the COVID-19 situation, the widespread establishment of the CTC field hospital became achievable through the modularity and repurposing of modules within the integrated EHR ecosystem. This adaptability facilitated a rapid response tailored to the specific circumstances.

SNUBH's close-up studies also show several areas of verifiable long-term benefits of the EHR system. Given that digital transformations cannot be expected to return numerous short-term gains, it is nonetheless clear that persistent, long-term investments toward fully digital hospitals yield long term returns, including in ways that are not foreseeable at the time a digital transformation is undertaken. It is important to invest in such studies to make sure there is a return on the investment in terms of quality of care and to ensure continuous support for the project.

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