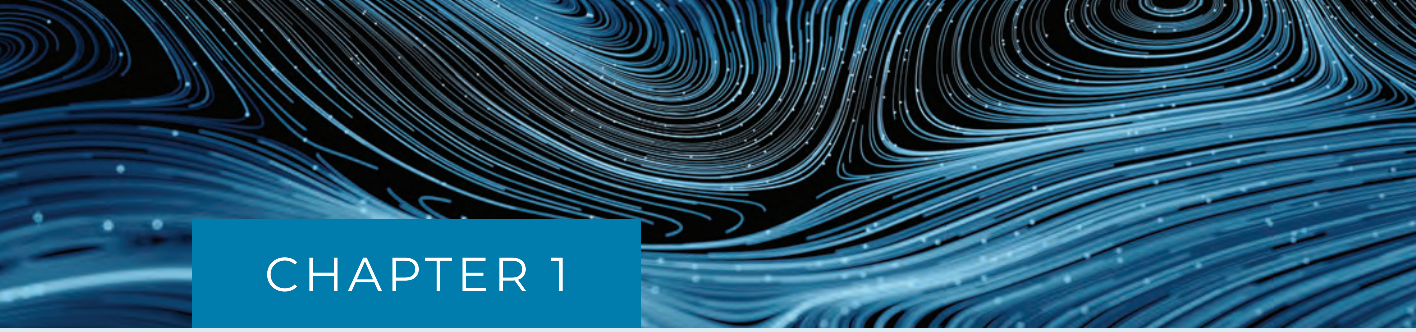
PART 1

Laying Out the Digital Health Foundation



CHAPTER 1

Charting a Roadmap for Digital Health Informatics (DHI)

Phillip Olla and Joseph Tan

LEARNING OBJECTIVES

- Chart the digitization of health care and review its transformative effects
- Overview the emerging DHI (digital health informatics) field and highlight the phases of the DH (digital health) evolution
- Identify key DHI components
- Highlight the organization of this DHI text

KEY TERMS

Digital health (DH)	Technological infrastructure	Regulation
Digital health informatics (DHI)	Data	Patient centric

1. Introduction

The digitization of health care has translated into new ways of preventing, diagnosing, treating, and monitoring human health conditions at individual, group, community, population, and even global levels. At the same time, newer and innovative technologies have emerged to expedite the development of new drugs, vaccines, and therapeutics. Arguably, these digital solutions have not only disrupted traditional approaches but will impactfully continue to create new forms of innovative therapies, such as digital therapeutics (DT), which are software-based solutions for treating specific disease or disorder (Park et al., 2019).

Even so, **digital health (DH)** is fostering the shift from pay-for-service to value-based systems. In the pay-for-service model, healthcare providers are compensated vis-à-vis the number of patients seen and the volume of tests and/or procedures ordered. In this model, wasteful behaviors are often encouraged with providers getting paid more with more tests ordered and more procedures performed, even if such activities may be somewhat redundant. In contrast, value-based care emphasizes high-quality, lower cost, and preventive patient care typically achieved via innovative DH tools.

The term **digital health informatics (DHI)** refers to the many ways in which informatics and technology may be aggregated to enhance the support for multiple aspects of the healthcare system. DHI encompass various disciplinary and practical domains including e-health, mobile health (mHealth), wearable devices, telemedicine, and personalized medicine or PM (Dhingra & Dabas, 2020). As technology develops, DHI continues to expand to include artificial intelligence (AI), machine learning (ML) algorithms, and big data analysis (BDA) from which large-scale monitoring of the effectiveness of healthcare policies on public health may be sustained, aside from enhancing communication and collaboration between healthcare professionals and improving ways in which patients can implement self-care (Balasubramanian, 2021).

Notably, DH technologies and applications have the potential to fundamentally overhaul the way health care is delivered locally, nationally, and globally.

2. The DHI Evolution

In the United States and developed countries such as Canada, DH is the central focus of ongoing health care expansion. Recently, the U.S. Department of Health and Human Services has moved to invest in an expanding workforce development program to help build a solid foundation for healthcare informatics (HCI) and data science in the United States (Balasubramanian, 2021). This initiative has likely been pushed in response to the COVID-19 pandemic; meanwhile it has both created and exposed the growing disparities in public health care among the haves and have-nots. Expansion of DH implementations such as e-health record infrastructure and public health data reporting, sharing, and analysis may help address such disparities.

In the private sector, the rising focus on DHI is also reflected. Indeed, the DH industry is becoming increasingly crowded and well funded, with almost 300 private DH companies receiving venture funding (Safavi et al., 2019). In 2016, the total funding for those companies exceeded $4 billion, and for 2017, it approached $6 billion. In an analysis of 20 highly funded private DHI companies, it was found that they mostly focused on data analytics (including AI). Indeed, the most well-funded companies tended to be companies specializing in biosensors, including wearable devices such as fitness trackers.

By 2025, the global DHI market is purported to exceed $500 billion (Halminen et al., 2021). This growth in the DHI market is thought to be driven by multiple trends, including inflation, aging populations, and the shift toward more value-based practices in healthcare management. Although the DHI market is growing, compared to other industries the uptake of DH systems and strategies by healthcare providers is slow.

Over the last century, health learning systems have now experienced a century-long history of evolution (and revolution). Indeed, we may broadly categorized the historical evolution for DH into four graduating phases. Although there may not be as clear a distinction among these four phases as with other technological evolutions in the manufacturing areas, some authors have likened this evolution to the industry transformation using the transition concepts from Health Care 1.0 to Health Care 4.0 (e.g., Chen et al., 2020; Li & Carayon, 2021). See **Table 1.1**.

2.1 Phases of DH Evolution

Health Care 1.0 (or Phase 1) epitomizes the basic patient–clinician encounter. In this first phase, the typical encounter involves a patient visiting a health facility such as a clinic or hospital to see a doctor along with other members of the physician's care team. By means of a combination of in-person consultation, testing, and diagnostics, the physician or a member of the care team provides a prescription to the patient to receive medications along with a care plan for treating the disease. At the same time, follow-up plans

Table 1.1 Trends in the Digital Health Evolution

Domain	Health 1.0	Health 2.0	Health 3.0	Health 4.0
Human interaction	Patient–clinician face-to-face encounter	Medical Equipment Monitoring devices Internet groups	EHR CPOE Telehealth Remote monitoring	Smart health Connected care Personalized medicine AI
Benefits	Paper-based records	Digital data	24/7 mobility and connectivity between patients and caregivers	Personalization and intelligence
Challenges	Inefficiencies	Lack of connectivity	Interoperability but lack of intelligence	Security

such a laboratory testing, imaging, or referral to a specialist are often issued.

Health 2.0 (or, Phase 2) emerges with the advancements in health, life science, biotechnology, and information systems (IS). These advances lead to the invention of medical equipment such as imaging test equipment, including the magnetic resonance imaging (MRI), ultrasound, and computed tomography (CT) scan. Monitoring devices have also advanced to become more portable with digital connectivity such as pulse oximeter, blood pressure meters, and glucose, as well as surgical and life support equipment such as the da Vinci robot.

Moreover, innovations in data processing and IS have characterized Phase 2, leading to the development of electronic medical records (EMR) being championed and used to manage the care plans of patients across various hospital departments, which are typically called health information technology (Health IT or HIT). Ongoing advances and developments in health IT have had a major impact on clinical and operational processes. In addition to the internal hospital information systems (HIS) being implemented successfully, a social shift on how information was being accessed and used by patients on the Internet begins to revolutionize healthcare systems. New models soon appear to educate patients, providers, health managers, and community support groups.

Health Care 3.0 (or Phase 3) evolves with the emergence of HIT infrastructure that allows most activities and medical encounters to be time-stamped and recorded in an electronic health record (EHR). Eventually, many manual processes can be computerized as ancillary components to the EHR, for example, the computerized provider order entry (CPOE) component, digital imaging, and e-prescription systems.

In Phase 3, one of the more noticeable advancements is the creation of virtual care models, which soon proliferate with the diffusion of telecommunication networks. The adoption of this model also fosters the creation of systems for remote care and telemedicine (or telehealth). This has now led to asynchronous communication between a patient and their physician via a patient portal, as well as evolves to synchronous communication to replace some face-to-face encounters. The recent COVID-19 pandemic has further increased the demand for telehealth and virtual visits. All these advances have soon led to multifarious revolutionary changes in conventional healthcare services delivery.

Healthcare 4.0 (or Phase 4) transformation adds an intelligent cyber-physical system that is primarily maintained by the Internet of Things (IoT), RFID (radio-frequency identification), wearables, connected medical devices, sensors, robots, and more such connected DHI components. These components are integrated with HIT infrastructure comprising cloud computing (CC), BDA, AI, and clinical decision support (CDS) techniques to create a healthcare learning system that is both smart and interconnected. This current phase of healthcare transformation did not just occur within the confines of the medical settings such as hospitals, clinics, and long-term care facilities; instead, it is characterized by the infrastructure being connected to medical devices and sensors that are also linking individuals, homes, and communities. This transformation also led to a more proactive approach to medicine by incorporating AI to provide early treatment, new disease diagnosis, prognosis, prevention, even personalized medicine.

The Phase 4 transformation may be conceived as pervasive and smart, resulting in an interconnected healthcare system. Studies of this transformation (Chen et al., 2020; Li & Carayon, 2021) have determined that healthcare service delivery has shifted from simple medication delivery to a multifaceted and intelligent disease treatment system.

In the past, patient care has mostly been offered via in-person interactions with a single physician. DH has made it possible to evolve care for a single patient to encompass multiple clinicians, team members, disciplines, and communities that are empowered with connected data via networked information exchange systems.

3. DHI Components

A variety of components of what can collectively be referred to as "digital health" exist, which are highlighted next.

3.1 Data and Information

Data collection and analysis are a basic part of science and technological progression. Many of the cutting-edge technological systems operating today use data to improve their functionality. One of the most prolific of these is AI, which refers to any program or algorithm that uses incoming data to simulate intelligent behavior and critical thinking by modifying its computational framework (Amisha et al., 2019). A step further than ML, AI doesn't just use data to make increasingly more accurate decisions within a specified framework but instead uses data to modify the framework in which decisions are made.

In the field of medicine, AI can serve many different purposes. A recent example is when AI was deployed to evaluate a range of existing medications to see if one could be usefully applied to combat the Ebola virus crisis (Amisha et al., 2019). This would have taken too much time to process via other methods. Related to AI is the use of Big Data in health care. Although there is no unanimous definition of Big Data, it is generally accepted that three major characteristics encapsulate Big Data: (a) large data volume, (b) variety, and (3) fast access rates (Dimitrov, 2016).

In health care, Big Data are used in many contexts to determine medical trends and make healthcare-related predictions. One of the most ethically contested uses for Big Data in medicine is the use of data by insurance companies to set rates based on medical risk factors (Dimitrov, 2016).

Informatics are like, yet distinct from, Big Data in digital medicine. Informatics refer broadly to using methods, combining data and technology, to improve medical interventions and positively affect patient outcomes (Clack et al., 2017). Informatics may thus be conceived as the realization of data collection and analysis, serving as the overall model for the development of improved medical interventions and predictive systems. Predictive systems can be seen as a product of bioinformatics in that they attempt to make predictions regarding patient health via data trends. Predictive systems serve as part of robust clinical decision-making processes and assist in identifying potential diseases, responses to treatment, and disease prognosis (Clack et al., 2017; Dimitrov, 2016).

3.2 Technological Infrastructure

Given the rapid pace at which technology progresses, it can be incredibly challenging to integrate new devices into different societal sectors safely and efficiently. However, through comprehensive rules, **regulations**, and standardizations, new technologies may be implemented in a way that causes minimal disruption to the daily workflow.

In terms of the medical field, given that patient safety may be at risk, the **technological infrastructure** required for the use of various devices must be even more comprehensive. The first part of this infrastructure is security. Security in medical technology refers to the ability of digital infrastructures to prevent themselves from being accessed or negatively affected by unauthorized parties (Esposito et al., 2018; Taitsman et al., 2013). This includes unauthorized access and manipulation both onsite and remotely. Security infrastructure such as firewalls, routine password changes, and biometric logins can all assist in the prevention of unauthorized data/device access and control. If security fails in medical technology, a patient's health could be at direct risk.

Blockchain technology currently stands at the forefront of digital security technology as it provides a framework to prevent data loss and manipulation (Esposito et al., 2018). Closely linked to security is privacy, which refers to the ability of patients exercising control over who can access their data. In essence, this means that a patient has the right to identify or know any parties who may be able to or will be accessing their data and should also have the right to revoke and/or give such access privileges at any time. Honoring this privacy is the responsibility of both the healthcare personnel and those overseeing the digital infrastructures for which the patient data have been transacted.

Over the years, the medical field often attempts to integrate cutting-edge devices to improve patient care and efficiency. Paramount to this integration, however, is the assurance that newly integrated technology will work well with preexisting systems (Lehne et al., 2019). If novel technology cannot integrate, cooperate, and share data with preexisting technological structures, forcing healthcare personnel to adopt it will only make the workflow even more inefficient, expensive, and problematic. In other words, all the technology present in a healthcare setting should be compatible and work well when used in conjunction (Lehne et al., 2019). This will ensure unison among all parts of the digital infrastructure and will minimize technical issues associated with compatibility. Similarly, medical technology and data must also meet the technical standards set by modern regulations (Health Canada, 2021). Any device or data structure used should not be obsolete and should function according to government-approved standards. Medical technologies have changing standardizations that must be routinely evaluated to ensure these standards are met.

3.3 Patient-Centric Care

Patient satisfaction and well-being are central to patient-centric care. Many aspects of the modern medical process are designed such that the patient is at the center of the service. Much of the infrastructure and protocol in place at medical centers focuses on satisfying patient needs. One of these needs is the patient's safety. From a DHI perspective, patient safety means that the patient should not be exposed to personal risk after releasing their data (Taitsman et al., 2013; Wade, 2007).

Put simply, patient data should be used only in accordance with beneficence and nonmaleficence, meaning that the data can be used only to improve medical interventions/care and cannot be used to the detriment of the patient. Part of this process involves the ethical use of data. What is meant by this is that data should be seen and used only by authorized parties and that patients should have control over where their data go (Taitsman et al., 2013). Nevertheless, medical centers can experience and/or have experienced data leaks, the movement of captured and stored data without clear authorization, and the potential to sell accumulated information to outside companies. These activities are completely unethical as they expose patient data to unauthorized parties. Only physicians and other approved personnel should have access to the accumulated data (Taitsman et al., 2013).

Another facet of patient-centric care in digital medicine is the usability of medical devices and services. Any technological interface that a patient must use should be user friendly, culturally competent, accessible by different populations, in depth, and intuitive (Karsh, 2004). Patients should be able to control various aspects of their health care (data usage, appointment booking, hospital check-ins, and more) digitally, enabling them to access various services from the comfort of their homes or chosen locations. This will ensure that services may be available, accessible, and affordable; importantly, these services will be used by a greater subset of the patient population.

3.4 Emerging Technology

Although many components of DHI are derived from well-established systems and technologies, many areas of DHI that will likely give rise to entirely new fields in the next few decades have emerged, for example, the IoT wearable monitoring devices (Jayaraman et al., 2020).

IoT wearable monitoring devices encapsulate remote patient monitoring services, smart home device integration, in-hospital patient monitoring, rehabilitation, self-monitoring, and child and elderly care. When incorporated into IoT wearable monitoring devices, AI-driven data processing techniques can detect physiological and behavioral changes early, as well as help to identify clinical episodes of different types of chronic diseases.

Another IoT-related example is the use of ambient IoT devices both at homes and in healthcare settings (Jayaraman et al., 2020). IoT sensors can also be installed in various unobtrusive locations in a setting to monitor the daily behavior of the people in that setting. Such a set-up would be ideal for older individuals or for those with disabilities, as the constant monitoring would allow the IoT system to track for abnormal events such as a fall or emerging symptoms of a chronic disease such as Parkinson's.

A third significant DHI emerging technology is nanorobotics, an avenue in which humans can remedy biological problems on a scale magnitudes smaller than has been possible in the past (Soto et al., 2020). Nanomachines, for example, may be used for applications such as drug delivery and biological data collection. Although promising, the implementation of these devices in a healthcare setting still involves several challenges. One such challenge is the design of nanomachines such that they can leave the body in a safe, minimally intrusive manner. Additional challenges include the risk of producing an inflammatory response when foreign particles contact or build up on nanomachines, regulatory issues associated with implementing nanorobotic medical procedures, and the expenses associated with nanorobotic development and upkeep.

A final emerging DHI technology is 3D printing. In health care 3D printing currently includes building customized biomedical components vis-à-vis individual patient specifications, improving manufacturing efficiency, and creating detailed 3D models of organs to assist in training operating teams prior to surgery. However, the ability of 3D printing to produce biocompatible organ tissue and prostheses that can function like their organic counterparts is still limited. As well, widespread implementation of 3D printing technologies as a supplement to or replacement for organ-tissue donation is still far in the future (Schubert et al., 2014).

3.5 Regulatory Issues

The regulations and guidance surrounding DHI technologies are rapidly evolving and ever changing. Although several organizations such as the World Health Organization (WHO) and the U.S. Food and Drug Administration (FDA) have released guidance regarding best practices in developing and evaluating DHI technologies, the rapid pace of such developments requires more targeted and comprehensive guidance as to appropriate avenues for evidence generation (Guo et al., 2020).

Although the traditional approach to evidence generation for new healthcare interventions is the randomized controlled trial (RCT), the developmental speed of shifting innovations and integrative technologies as well as the relative lack of RCTs available in the literature for new DH interventions indicate that the traditional approach may not be best suited for these types of interventions.

Major regulatory bodies governing the implementation of DH practices include the FDA in the United States, whose jurisdiction notably excludes software (Kadakia et al., 2020). In Canada, the

Digital Health Review Division of the Therapeutic Products Directorate's Medical Devices Bureau in Canada (Government of Canada, 2018) has oversight on such practices.

Having set a roadmap for DHI development in changing the landscape of healthcare services delivery, we now introduce the various parts and topics of this text as it has been envisioned for undergraduate teaching and learning primarily in digital health informatics.

4. Organization of This DHI Text

In this section, we overview the organization of this DHI text written primarily for a primer course in HI education; what follows is a survey of the content.

Essentially, this text offers DHI students a broad range of DHI themes and topics, subdivided into five major parts with a total of 14 chapters as well as over 19 short case studies. All chapters begin with specific learning objectives and a list of keywords and are organized as well as integrated on selective DHI topics, followed by a series of questions raised at the end to motivate further critical thinking and research. In contrast, the short case studies are intended to provide deeper insights into practical problem-solving and thinking about real-world DHI scenarios and practices.

Accordingly, the early sections of this text entail the Foreword, Acknowledgments, and short biographies of all editors and authors who have contributed significantly to the development of this text. Aside from the Preface, Chapter 1, authored by the two primary editors (Drs. Phillip Olla and Joseph Tan), provides an overview of the rest of the text while specifying how it is organized. It therefore initiates Part 1 and echoes the title, "Charting a Roadmap for Digital Health Informatics," acknowledging that the field of DHI is still evolving as it continues to alter the landscape of the traditional healthcare services delivery. The entire text is subdivided into five major parts, encompassing diverse connected themes.

The general theme for Part 1 is on laying out the digital health (DH) foundation and that of Part 2 focuses on identifying key DH developments, methods, and challenges. Parts 1 and 2 are coedited by Professor Joseph Tan and Dr. Phillip Olla. Part 3, which dives into core DH technologies, has an added coeditor, Dr. Mountasser Kadrie; here, Dr. Kadrie collaborated actively with Drs. Olla and Tan to focus the theme for Part 3 on the multifaceted aspects of clinical decision support systems (CDSS) and consumer health informatics (CHI).

Parts 4 and 5 are again jointly coedited by Drs. Olla and Tan. Part 4 branches out into the theme of exploring DH emerging technologies, emphasizing today's DH innovations such as robotics and nanorobotics, wearables, medical sensors and devices, 3D printing, and more (e.g., genomics and personalized medicine). Finally, Part 5 closes the text with a broad series of over 19 short case studies, touching on practical scenarios and real-world instances of DHI activities, events, and services to supplement and enrich one's thinking and learning about the many facets of the DHI field.

4.1 Part 1: Laying Out the Digital Health Foundation

Specifically, Part 1 includes four chapters. As noted, Chapter 1 as contributed by Drs. Olla and Tan reviews the developmental phases of DH technologies over the years as well as introduces the diverse topics discussed in the text. Most important, it highlights how all the pieces of the different parts of this text are connected. Health Informatics (HI) Overview, Chapter 2, which is authored by Drs. Khuntia, Mustapha, and Tan, explores the emerging field of HI in the context of its historic evolution, its established domains and key issues vis-à-vis the modernization and digitization of health care. In view of current DHI developments, this chapter therefore dives into an increasingly in-depth discussion of the need for workflow alignment for future HI success that defines true healthcare digitization and transformation.

Contributed by Dr. Michael Hall from Roger Williams University, Chapter 3 surveys the topic of HI databases as the foundation of information for decision-making, research, and trends. In this chapter, challenges facing HI databases and strategies as well as leadership solutions to meet these challenges are also detailed with a conscious effort to align the area of HI databases to the broader perspective of management information systems (MIS), a well-established field that has driven the ongoing digital data connectivity developments. The final chapter of Part 1, Chapter 4, is a work of Dr. Debra M. Wolf and Ms. Sue Evans. Here, they review the topic of digitizing the medical record infrastructure by first exploring the historical development of medical records (MRs). They then highlight the different types of MRs such as EHR, eEMR, and personal health records (PHR), discuss the interconnectedness of health-related IS, and outline the different forms of standardized languages and the impact on system interoperability. More important, they also lay out the key issues linked to building a sound and rigorous DHI infrastructure, illustrating the presentation richly with currently implemented health information exchange (HIE) and health information networks (HIN), a DHI hot topic for the last several years.

4.2 Part 2: Identifying Key Digital Health Developments, Methods, and Challenges

Expanding on Part 1, Part 2 comprises three separate but critical DH developmental and methodological chapters. Chapter 5, contributed by Drs. Olla, Biswas, and Tan, covers BDA and AI in health care. This important chapter lays out the underlying methodologies driving DH adoption, namely, BDA, ML algorithms, and AI expansion.

Chapter 6, contributed largely by Joanne Kearon, Nancy Pham, Turna Chowdhury, and Joseph Tan, extends DH applications to the field of public health informatics (PHI) with key considerations for equity, ethics, and privacy. Indeed, the advent of the COVID-19 pandemic has ushered in significant opportunities for DH developments vis-à-vis the PHI discipline; essentially, it is challenged by the acceptance and adoption of PHI approaches by a broader community, the public, making the integration of these innovations ethically complex. Moreover, adding to the topic complexity and challenges, these authors highlight some of the barriers to applying information technology (IT) in public health, including privacy concerns, the need to become aware of the potential impact of IT on health equity, disparities, and the need to strategize intelligently on how IT in public health may be implemented appropriately and used more meaningfully.

The last chapter of Part 2, Chapter 7, reviews security and privacy issues. As contributed by Olla, Tan, Elliott, and Abumeeiz, this chapter emphasizes the key challenges with DHI in terms of personal data capture, storage, and exchange. First, the authors distinguish privacy from confidentiality and review key terms linked to privacy issues. Following this, the historical perspective of privacy is reviewed. Next, the basic security measures for health data preservation are delineated. Finally, the authors envision the future developments of privacy concerns and policies vis-à-vis potential breaching of health data privacy in the DH era.

4.3 Part 3: Emphasizing Digital Health Core Technologies

For Part 3, which concentrates on DH core technologies, including CDSS and CHI, four chapters have been allocated. Interestingly, all four chapters have been contributed by Dr. Mountasser Kadrie, one of the coeditors for Part 3 of the text. In Chapter 8, Mountasser focuses on knowledge-based CDSS, noting that CDSS is conceived to be the backbone of DH as these systems connect all technology patient care systems, health consumers, and business-based applications. Not surprisingly, the author explores the use of CDSS to improve patient care and business processes while highlighting the complexities and challenges of integrating CDSS into health care. Finally, he projects the future roles of CDSS for DH.

In Chapter 9, Mountasser shifts focus to CHI. Basically, he explains the role and impact of CHI on promoting patient engagement in the medical care continuum with rich illustrations cited throughout the chapter. As well, the benefits of integrating CHI in health care are discussed with a survey on the primary uses of CHI and their impact on addressing consumers' (and patients') needs. In Chapter 10, the focus is still on CHI, but this time from the perspective of using CHI tools to support healthcare access and patient engagement. In this manner, both Chapters 9 and 10 are well-connected chapters surrounding the same CHI theme. The impact of CHI tools on digital communication, information acquisition, delivery of care, and clinical decision-making cannot be overly emphasized, and it is the intent of the coeditors of this part of the text to demonstrate how COVID-19 has allowed CHI to move to center stage vis-à-vis an evaluation of telehealth care within the context of distance care delivery.

In the final chapter of Part 3, Chapter 11, Mountasser jumps focus into privacy-security issues for CHI, a core DHI technology. Key factors affecting the compliance and privacy of health information are assessed and privacy policy practices in healthcare information are evaluated. Additionally, the complexities of health information privacy regulation and challenges related to such regulations are highlighted to educate practitioners on how compliance of DHI systems may be ascertained.

4.4 Part 4: Exploring Digital Health Emerging Technologies

Moving forward, just as with Part 2, Part 4 comprises three chapters. Together, these chapters offer insights into DH emerging technologies such as, but not limited to, robotics, wearables, digital therapeutics, 3D printing, genomics, digital mental health, and PM. Chapter 12, contributed by El-Masri, Abu-Libdeh, Nazemi, Olla, and Emadi, explores sensors and wearable electronics in health care. Specifically, these authors first review diverse forms of wearable electronics and sensor types, including the IoT as part of the proliferating DH technologies. The benefits of implementing such technologies in medical practices to enhance patient care and healthcare services are then discussed, followed by a recognition of the challenges involved in deploying these newer technologies as innovative solutions within the DHI space. The chapter then closes with a projection on the impact of these innovations on healthcare future.

Chapter 13, submitted by Olla, Elliott, Abumeeiz, and Tan, highlights precision medicine, 3D printing, and digital therapeutics. Broadly, precision medicine refers to all aspects influencing disease intervention and prevention efficacy from genetic markers to behavioral tendencies. More specifically, it relates to the proteomic-genomic implications of individual variance, which focus more on population data and outcomes than on individual genome. Accordingly, precision medicine typical activities can include the integration of genetic dispositions into pharmacological interventions, pre-/postnatal genetic counseling, and genome-based screenings to assess a patient's particular disease state, such as in the case of genetic screening done on tumor cells.

DT generally refer to the technologies and applications that deliver evidence-based treatments online to aid improvements in the accessibility and efficacy of those treatments. Distinct from other general wellness applications and technologies, DT are evidence-based programs designed to treat specific health issues, not key applications for general health monitoring. DT may be conducted remotely, reducing costs associated with visiting a care facility, allowing for continuous monitoring with the doctor–patient communication being streamlined.

Additionally, 3D printing can create physical objects via the use of layered fabrication. Unlike traditional manufacturing, such objects may be produced more efficiently, cheaper, with more detail and complexity, and with more consumer input. In health care, 3D printing may be used to customize biomedical components vis-à-vis patient specifications, improve manufacturing efficiency to help meet high product demand, create detailed 3D models of organs to assist in training operating teams before surgery, and to produce biocompatible organ tissue and prostheses that function similarly to their organic counterparts. In drug printing, 3D printing may be used to ease the drug manufacturing process, making it more flexible, efficient, and inexpensive. Recent advances allow for the manufacturing of active pharmaceutical ingredients via 3D printing to help make medication more accessible in rare cases.

Chapter 14, also contributed by Olla, Elliott, Abumeeiz, and Tan, closes Parts 1 through 4 of this text by revisiting the medical innovations transforming health care, including simulation, augmented reality (AR), virtual reality (VR), and mixed reality (MR), AI and robotics, as well as assistive technology and nanorobotics. With rapid advances in AI, ML, robotics, and simulated realities, the future of health care is bursting with possibilities. The functionality of robotics in health care has expanded and deepened over time with the benefits of using robots, recognizing that robots are not prone to fatigue and can be trained for any task, even though they do not have the emotional intelligence and decision-making skills, adaptability, and dexterity range of humans.

Use of robotics for medical training includes simulation technology, which has the benefits of being reusable, providing objective, in-depth statistical feedback to trainees, and enabling trainees to become more comfortable with essential skills and procedures in a risk-free setting before moving onto more complex procedures. Telementoring via robotics also allows for trainees and students to remotely observe or even participate in rare surgical cases, as well as collaboration among multiple experts when experimenting within niche or specialized fields. Nanorobotics offer an avenue by which humans can interact and remedy biological problems on a scale with magnitudes smaller than ever before. Nanomachines may be used for drug delivery, supporting molecular functions such as gas exchange, and biological data collection. Robotics can also be used to assist those with cognitive impairments due to stroke, dementia, age-related disease, or autism spectrum disorders (ASD). The primary functions of these socially assistive robotics include tasks such as monitoring and prompting medicine intake, assisting with bathing, and dressing, and providing interactivity and a sense of companionship.

Finally, VR simulations can be used to perform robust and diverse training that is risk free and cheaper and easier to perform than the real-life counterpart. However, there are downsides to VR training in that it does not always work to train every skill in VR.

4.5 Part 5: Supplementing Short Case Studies

In Part 5, we assemble a series of more than 19 short case studies that integrate concepts from the different thematic directions discussed in Part 1 through Part 4 of this text to comprehensively illustrate real-world scenarios of events, problems, approaches, and challenges surrounding the applications of DH technologies and connected devices.

The first case (SC-1) by Bayat, Olla, and Tan, for example, focuses on telemedicine in Canada during the COVID-19 crisis, a key development on the use of DH technology that is augmented and driven by the current pandemic. The next piece (SC-2) by Kearon, Pham, Chowdhury, Olla, and Tan relates to COVID-19 contact tracing and the piece that follows (SC-3) as authored by Pham, Kearon, Chowdhury, Olla, and Tan discusses awareness for technological malfunction in the context of EHR infrastructure and downtime. SC-4 submitted by Dr. Ileana M. Carillo-Crane focuses on improving health outcomes via DH technology. Clearly, the value of DHI has been recognized throughout the COVID pandemic and DHI applications are being applied generally to improve population health and well-being.

SC-5 by Cao, Olla, and Tan deals with DHI innovation to fight the opioid crisis whereas SC-6 written by Joseph Tan with Phillip Olla attempts to integrate wearable tracking devices toward nurturing a healthy lifestyle among older adults and the elderly in Singapore via innovative use of digital solutions. SC-7, compiled by Colling, Olla, and Tan, looks at preventing and treating diet-related disease via today's diet-tracking apps. SC-8, part of a series of compiled short cases by Elliott, Abumeeiz, Olla, and Tan falling generally into the broader theme of DH systems security issues, looks specifically at hospital systems security. SC-9, completed by Chestnut, Olla, and Tan, relates to a filtering system for greater accuracy within eating disorder diagnosis and SC-10 offered by Razvi, Olla, and Tan discusses the popular robotic system, PARO, as envisioned by Takanori Shibata at the National Institute of Advanced Industrial Science and Technology in Japan in 1993.

Continuing, SC-11 provided by Huynh, Wu, Armstrong, and Dohan from Lakehead University touches on an analytical approach to assess the accuracy of case-mix methodologies (CMMs) for residents with dementia at a long-term care facility in Ontario. SC-12, SC-13, SC-14, and SC-15, which are all part of a series of compiled case studies by Elliott, Abumeeiz, Olla, and Tan in the broader theme of DH systems security issues, emphasize various aspects of privacy and security; namely, SC-12 focuses on pacemaker and medical devices, SC-13 on genetic genealogy, SC-14 on wearable devices, and SC-15 on physical security and digital hygiene.

SC-16a,b,c assembled by Walter, Olla, and Tan discuss COVID vaccine passport issues whereas SC-17 by Biola Adenini is an interesting teledentistry case, focusing on emerging digital health innovations for dentistry in the coming era. SC-18 is presented by Emily Marron regarding digitalization of the milk room at Mott Children's and Women's hospital in Ann Arbor, Michigan to promote patient safety and sanitation. Last, but not the least, SC-19 as submitted by Deanna McCellan attempts to narrow "the digital gap" between the registered dietitians or nutritionists and the general health practitioners.

Notably, several of these cases appear to have been purposely shortened from longer contributed cases. This is done to not overwhelm students at the undergraduate level as longer cases often contain much more unnecessary information filler to distract the readers from the key problems to be addressed. Instructors and/or students, however, can freely choose to select cases within this Part 5 for their own reading and thinking about the case questions posed.

5. Conclusion

Today, the digitization of health care has unlocked value-added opportunities to improve healthcare services delivery from both clinical and administrative point of views, supporting remote and secure information exchanges among care providers digitally and globally. Unlike conventional means, DH will enable round-the-clock patient–physician mobility and health learning systems interoperability at reduced time and cost. Consequently, DH is having and will continue to have a profound impact on the delivery time, needed capital resources, and efficiency of care processes, while providing the impetus for an ongoing paradigm shift from treatment to prevention.

Broadly, the expanding field of DHI can include simple categories such as e-health, mHealth, technological infrastructure, and EHR as well as more complicated and wide-ranging concepts such as the use of CHI, CDSS, BDA, AI, ML, blockchain platforms, telemedicine, virtual clinical trials, 3D printing, and smart devices in health care (Senbekov et al., 2020). With DHI advancing innovative solutions for future health considering the significant technological and economic progress over the last decade, the promotion of new ways to do things has taken precedence to fit the new world order for better population (essentially, global) health control and management.

Strategically, key objectives of DHI for current health learning systems have been noted here and throughout the different parts of this text to include:

- Noticeable enhancement to the quality of healthcare outcomes and ongoing care services
- Noticeable enhancement to overall population health and well-being

- Time-proven improvements in the experience of navigating through the health learning system for patients, providers, and funders (e.g., the government)
- Time-proven improvements on how existing health disparities may be addressed (Ronquillo et al., 2021)

Alongside the transformation of Health 1.0 through Health 4.0, the role data play has also changed dramatically. At the beginning, few, if any, encounters generated digital data as most of the medical encounters have relied upon paper-based systems. Modern healthcare systems generate massive datasets in diverse formats, making BDA and intelligence necessary to unlock the hidden insights in these data. Another important consideration is that the patients and healthcare professionals are collectively involved in monitoring health indicators, reporting ongoing symptoms, and sharing decision-making to design optimal care plans personalized to the individual patients and their treatments.

As noted, the core DHI technologies of CDSS and CHI can support efficient care processes throughout today's health learning systems while connecting consumers who are concerned about their self-care with care providers empowered with digital information exchanges to be interoperated over different databases and networks. Moreover, the challenges faced in terms of cybersecurity and privacy issues over connected health systems are even more challenging and must be attended to if the DH experience for the consumers would be fully adopted and endorsed over time in comparison to the use of conventional approaches.

Today, multitudes of people in many countries suffer from mental illness without receiving the proper care. Hence, DH tools are becoming critical to fill in the gaps left by the lack of personnel and other needed resources, allowing more people to access the mental health services on demand especially in underserved areas. Such digital mental health tools can range from clinician-involved solutions such as live-streamed appointments to nonclinician involved solutions such as phone app-based treatments and diagnostic testing. Implementing ML and AI into these tools may further improve their usefulness in addressing mental health problems. Used in conjunction with robotics, AI in health care will enhance data analysis via ML methods as well as neural networks and natural language processing to advance research into diseases such as cancer and heart disease. Robotics-assisted surgery or teleoperation refers to the remote control of a robot to perform surgery and has shown great potential over the course of its development, with benefits including allowing surgeons to work in a more ergonomically friendly posture, providing enhanced dexterity, and providing enhanced technical accuracy.

With safety and security considerations in the face of COVID-19, teleassessment or the assessment or screening procedures performed remotely, can assist with both pre-/postoperative examinations, performing tasks such as clinical imaging analysis, digital triage, and monitoring pre-/postoperative vital signs. Telesurgery, a system incorporating wireless networking with robotic technology to enable surgeons to operate on patients who are inaccessible in person, has also advanced significantly with distancing requirements in today's COVID era. Benefits of telesurgery include convenient access to high-quality surgical care for patients remotely, providing enhanced technical accuracy, and protecting both surgeons and patients from infection.

Discussion Questions

1. How has digitization of health care transformed the way healthcare services have been delivered vis-à-vis the traditional approaches?
2. Offer insights and provide examples to illustrate activities that would achieve the strategic objectives of digital health informatics (DHI).
3. Differentiate among the characterization of healthcare services and processes in Health Care 1.0 through Health Care 4.0.
4. What are some of the key components driving DH trends?
5. How do you feel about the organization of this DHI text? Suggest any modification or improvements that could be easily implemented.
6. Why would case-based learning as offered in Part 5 of this text be important for understanding the content and discussions of Parts 1 through 4 of this text?

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