



The Role of IoT, Blockchain, Artificial Intelligence and Machine Learning in Maternal Health

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Abstract: Ingeniously, the innovations taking place in current medical era, where technology plays a dynamic role in pregnant women care taking both inside hospital and outside. Integration of Internet of Things (IoT), Artificial Intelligence (AI), Machine Learning (ML) and Blockchain technologies is deemed to ensure the effective and efficient care of pregnant women in any environment because intelligent tiny devices like Radio Frequency Tags (RF-Tags), Sensors are attached with pregnant women, and all the activities of pregnant women can be monitored by professional medical staff from anywhere and anytime. The usage of these advanced destructive technologies in pregnant women care environment, absolutely eradicates the pregnancy complications and harmful incidents, but also promotes privacy, integrity and availability of maternal health systems. The purpose of this paper is to discuss the usage of IoT, artificial intelligence, machine learning and blockchain in pregnant women healthcare environments and articulates endorsements to promote future research and also guarantee the pregnant women's data privacy is preserved. The study further seeks to unveil the potential benefits of integrating the four medical digital technologies into a single maternal healthcare application to reap their singular benefits. The study will apply an exploratory research design to review the existing literature on the destructive technologies and the results will be used to develop a conceptual framework that would be used to guide future research in maternal healthcare.

Keywords: Maternal Health, IoTs, Blockchain, Artificial Intelligence, Machine Learning

1. Introduction

Internet of Things (IoT), Blockchain, Artificial Intelligence (AI) and Machine Learning (ML) are key digital technologies that have great potential to improve the current business processes and business models in healthcare. Patients now have access to some of the best diagnostic tools, new and cutting-edge treatments, and a myriad of minimally-invasive procedures resulting in less pain and quicker healing via use of these emerging digital technologies. IoT drives the automation of industries and user-friendliness of business processes that is essential for the healthcare industry. In maternal healthcare IoTs can be used in real-time maternal stress monitoring (Oti et al., 2018).

Blockchain technology which is a distributed ledger technology can be used to secure the electronic medical records (EMRs), maternal patient monitoring and other health related processes by increasing privacy, transparency, trust and immutability through providing a shared and decentralized distributed ledger (Zhuang et al., 2018).

Artificial Intelligence (AI) techniques can be used to improve processes by detecting patterns and optimizing outcomes of these business processes in healthcare (National Academy of Medicine, 2018). Additionally, AI techniques can be used to develop clinical decision



support systems to help with medical diagnostics. AI technologies can also be deployed in various medical devices, trackers, and information systems. A huge amount of patient data is recorded in the electronic medical record (EMR) database, including diagnosis, medical history, medications, and lab results. Through the process of extraction, transformation, and loading (ETL), researchers can generate a patient dataset worthy of analysis by AI techniques. In addition to the data analysis using structure data, AI techniques are now used for medical image recognition, medical text, semantic recognition, and molecular biological testing. The analysis results can be used as a reference for the evaluation of maternal patients by the medical team (Mitchell & Kan, 2019). AI has the capacity to surpass human doctors and help them detect, predict, and diagnose diseases more accurately and at a faster rate. Likewise, AI algorithms have proved to be not only accurate and precise at specialty-level diagnostics, but also cost-effective in terms of detecting diabetic retinopathy which is crucial for maternal health (Puri et al., 2021).

Finally, Machine learning (ML) applications consist of algorithms which are a collection of instructions for performing a specific set of tasks. The algorithms are designed to learn from the data independently, without human intervention. Machine Learning which is a subset of artificial intelligence plays a key role in healthcare, including the development of new medical procedures, the handling of patient data and records and the treatment of chronic diseases. Today, Machine Learning is helping to streamline administrative processes in hospitals, map and treat infectious diseases and personalize medical treatments. Other most common healthcare use cases for machine learning are automating medical billing, clinical decision support and the development of clinical care guidelines (Ahmed et al., 2020).

In maternal health these emerging digital technologies and techniques can be integrated and used to tackle problems of excessive stress during pregnancy which could cause adverse effects for the mother and her unborn baby, disrupting the normal maternal adaptation throughout pregnancy. Such conditions could be tackled to some degree via traditional clinical techniques, although an automated healthcare system is required for providing a continuous stress management system (Oti et al., 2018). Technology is a promising alternative for such real-time stress monitoring in the efforts to improve maternal health. In conventional IoT-based stress monitoring, stress-related data is collected, and the stress level is determined using a pre-defined model. However, these systems are insufficient for pregnant women whose physiological data are changing over the course of their pregnancy. Therefore, an adaptive monitoring system is needed to estimate stress levels, considering the maternal adaptation such as heart rate elevation in pregnancy (Azimi et al., 2019).

Lack of application that integrates these four digital technologies in a single maternal digital health application causes delayed and inaccuracy decision-making processes, poor medical service delivery, insecurity, untimeliness and inefficiency in access to medical data. The adoption of these digital technologies and innovations aims at addressing the challenges that hinder the full implementation of maternal digital health. These innovations will lead to solutions that improve maternal healthcare.

2. The Problem

Advancement in the use of digital technologies like Internet-of-things (IoT), blockchain technologies, AI, and machine learning have attracted substantial interest in maternal health. These innovative digital technologies have been intelligently and singularly applied with various applications in networking, medical diagnosis and healthcare systems, to build efficient,



sustainable systems and intelligent solutions to medical and healthcare Systems. Up to this point, the interconnection and integration between these four innovations in a single application is often neglected, and IoT, Blockchain, AI and machine learning are typically used separately. However, these innovations can be applied jointly and will converge in the future to maximize their potential in maternal health. One possible connection between these technologies could be that IoT collects and provides data, blockchain provides the infrastructure, security and sets up the rules of engagement, AI optimizes processes and rules while machine learning provides data analytical tools to analyze thousands of different data points and suggest outcomes, provide timely risk scores and precise resource allocation. By design, these four innovations are complementary and can exploit their full potential if combined and will improve the security and quality of maternal health services. Lack of integration and a merge of these digital technologies causes delayed, inaccuracy and untimeliness, delayed decision-making processes, poor medical service delivery, insecurity and inefficiency in access to maternal historical medical data. The adoption of these digital technologies in a single maternal health digital application will aim at addressing these challenges that hinder the full implementation of maternal health. These innovations will lead to solutions that improve healthcare quality, support health professionals to access good quality evidence and digital data needed for decision making and open new channels to help overcome the geographical inaccessibility barriers of maternal healthcare. This paper aims at reviewing existing literature to identify the roles, potential benefits of merging and challenges of integrating Internet-of-things (IoT), blockchain technologies, AI, and machine learning in a single maternal healthcare application with an aim to enhance the pregnant women and baby healthcare environments. The adoption and implementation of these digital technologies in a single maternal health application will guarantee the pregnant women's data privacy is preserved, timely and quality services are provided to lower the maternal related mortality rate. The results are used to propose a conceptual framework that can be used in the adoption of digital technologies in digital maternal health.

3. Objectives

1. To assess the current state of art of digital medical technologies used in maternal health
2. To explore the potential benefits of integrating Internet-of-things (IoT), blockchain technologies, Artificial Intelligence, and machine learning digital technologies in a single maternal health application
3. To analyze the challenges that hinder full potential of the integration of Internet-of-things (IoT), blockchain technologies, Artificial Intelligence, and machine learning digital technologies in a single maternal health application
4. To propose a conceptual framework that can be used in the integration of Internet-of-things (IoT), blockchain technologies, Artificial Intelligence, and machine learning digital technologies in a single maternal health application

4. Methodology

This paper employed the exploratory research methodology in reviewing existing literature in the health sector with an objective to analyze the potential benefits and challenges associated with the integration of Internet-of-things (IoT), blockchain technologies, Artificial Intelligence (AI), and machine learning (ML) digital technologies in a single maternal health application.



The systematic review included a review of the following 10 electronic databases and electronic libraries.

- Google Scholar
- IEEE Xplore
- Elsevier Science Direct
- Springer Link
- ACM Digital Library
- Web of Science (WoS)
- PubMed – NCBI
- PNAS
- Tayol & Francis
- Mendeley

The systematic review only includes research that introduces Internet-of-things (IoT), blockchain technologies, Artificial Intelligence (AI), and machine learning (ML) digital technologies in maternal health, shows a new solution in using these digital technologies in enhancing service delivery to improve maternal health, benefits and challenges associated with the application of these digital technologies in maternal health, using the query string(s) defined below:

(Maternal health) AND (Internet-of-things (IoT), blockchain technologies, Artificial Intelligence (AI), and machine learning (ML) OR digital technologies)

Steps followed in the review; first, a comprehensive review was carried out to find out what is meant by maternal health, Internet-of-things (IoT), blockchain technologies, Artificial Intelligence (AI), and machine learning (ML) digital technologies and the influence of these digital technologies in achieving maternal health. Second, an in-depth review of the existing literature was performed to explore the current state of digital technologies applied in maternal health. Further, the potential benefits and challenges associated with the application and integration of these digital technologies in maternal health were reviewed. The results are used to guide the development of the proposed Conceptual Framework for integration of Internet-of-things (IoT), blockchain technologies, Artificial Intelligence (AI), and machine learning (ML) Digital Technologies in a single maternal health digital application.

5. Results

This section discusses the digital medical technologies, potential benefits and challenges of digital medical technologies and proposes a conceptual framework for the integration of Internet-of-Things (IoT), blockchain technologies, Artificial Intelligence, and machine learning digital technologies in healthcare including maternal health.

5.1. The Current State of Art of Digital Medical Technologies

In 2020, the Covid-19 pandemic forced healthcare into the future, and, as a result, several promising medical technologies were tested on a massive scale. In 2021, the question is how those technologies can be used together in a post-pandemic world. Medical technology has come a long way since the invention of eyeglasses and the stethoscope. The broader availability of mobile internet, the expansion of a more affluent middle class, and an aging global population are all driving change in the healthcare industry, and the associated technology is changing faster than ever before. The rise in the number of wearable sensors, the digitization of patient records and expansion of virtual healthcare services are key improvements in achieving affordable health services and universal health coverage. Gone are the days where medical staff had to go through heaps of paperwork in order to find relevant information about individual patients. Currently, the digital transformation allows the use of computers and digital data, pulling out a patient's medical history is a matter of seconds.



The integration of digital medical technologies into the primary maternal healthcare includes a variety of electronic methods that are used to manage information about people's health and health care, for both individual patients and groups of patients. The use of digital medical technologies can improve the quality of maternal healthcare, even as it makes health care more cost effective. Digital transformation in healthcare is going to be an exciting step for society as it automation of the processes, better management, diagnosis, and treatment of mother and child. The digital medical technologies are supported by Internet-of-things (IoTs), blockchain technologies, Artificial Intelligence (AI), and machine learning (ML) digital technologies among others. According to a report by infomineo (Saidi, 2021), the study revealed that various digital medical technologies have been adopted since the year 2015 and the adoption continues to increase as shown in the figure 1 below:

Adoption of Digital Medical Technologies in healthcare as from 2015-2020

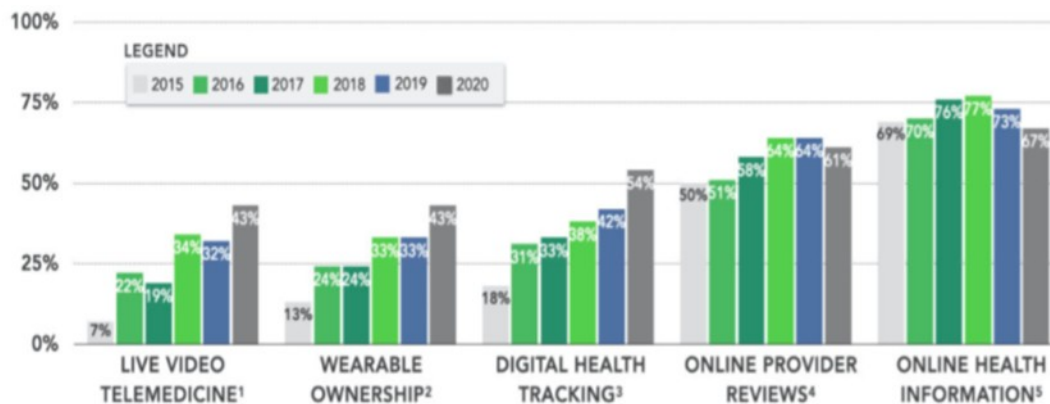


Figure 1: Digital Medical Technologies

Additionally, the Covid-19 pandemic accelerated the dependency on technology where the digitization of healthcare drove investors' and funding bodies interest in supporting and funding digital health companies raising a record \$14.8 billion in funding in 2020 and increased the support of startups and new innovations in healthcare. According to rockhealth report (Krasniansky et al., 2021), the graph below shows a summary of top funded digital categories in the year 2020 in US dollar, figure 2 showcases the considerable funding interest in Telemedicine which increased by 140% compared to 2019.

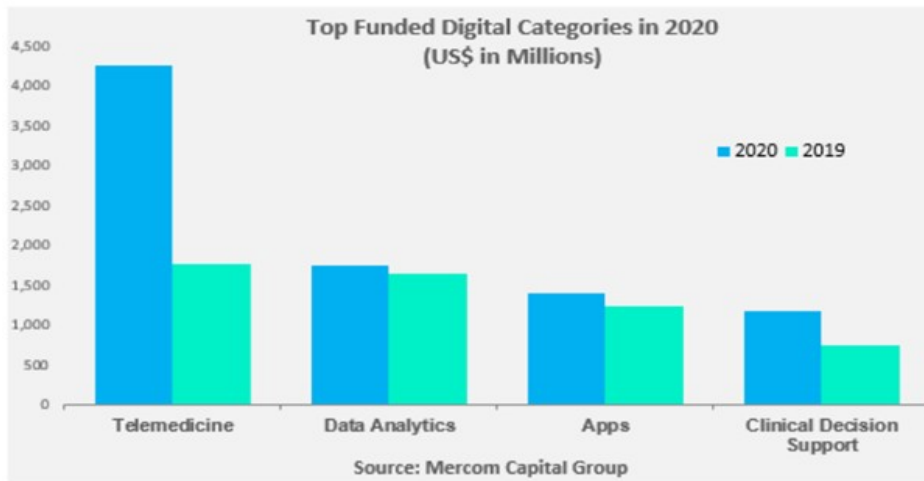


Figure 2: Funding of Digital Medical Technologies

This implies that as technology companies move into healthcare, it is necessary for legacy players such as hospitals and pharmacies to adapt their strategies and embrace new digital medical technologies like telehealth, telemedicine and remote patient monitoring tools supported by Internet-of-things (IoT), blockchain technologies, Artificial Intelligence (AI), and machine learning (ML) digital technologies. Products and solutions from technology companies will increasingly become more distributed and sophisticated as the quality and volume of data improves in the healthcare industry. It goes without saying that the future of healthcare will be told outside the hospital.

5.2. Potential roles and benefits of Internet-of-things (IoT), blockchain technologies, Artificial Intelligence, and machine learning digital technologies in maternal health

5.2.1. IoTs in Maternal Health

Remote health monitoring systems broadly extend the boundaries of everyday healthcare access particularly for at-risk population groups including pregnant women and senior adults who may require additional observation. These systems are very promising in the healthcare domain as the individuals can be continuously monitored for early detection, preventive care, and early intervention. The key function of such healthcare systems is to ubiquitously observe and analyze users' health conditions, and subsequently deliver medical early-warning as well as health and wellness coaching (Akbulut et al., 2018). Fortunately, recent advances in Internet-of-Things (IoT) technologies have paved the way for enabling such monitoring services with 24/7 availability with their challenges being the security of the IoTs devices that are used to support the ehealth systems which can be controlled (Bundi & Nelson, 2019). IoT is a growing network of interconnected objects that envision a shared knowledge for smart and autonomous decision-making and actuation. In the healthcare domain, IoT systems leverage different sensing, computing and communication resources (Khan & Hameed, 2018).

There is a major concern about pregnancy-associated stress and anxiety, which are key risk factors for various pregnancy complications involving the health of mother and fetus. Maternal adaptations to decrease the stress level are important to enable a successful pregnancy although various maternal difficulties and environmental stressors can disrupt these adaptations. Several studies have tackled this subject, managing stress level during pregnancy with different



medications and techniques. However, to support the conventional clinical methods, a personalized and automated healthcare system is highly required, providing stress monitoring for not only in-hospital environment but also everyday settings. Fortunately, recent advancements in Internet of Things (IoT) technologies have enabled the deployment of remote health monitoring systems in real-time applications, of which maternal patient's health-associated parameters are continuously collected and analyzed to deliver health services (Oti et al., 2018).

5.2.2. Blockchain in Maternal Health

The world is changing exponentially like never before in the history of human kind in the application of technology in healthcare with the maternal health concerns continuing to be a priority of the health sector. There is an unprecedented opportunity to connect creatively disruptive innovations to transform the world for the better. One such creative disruption is blockchain technology. Blockchain is a decentralized distributed ledger, which is immutable and is hackproof (Thomason, 2017).

In August 2016, the World Economic Forum released a report calling blockchain technology a “mega-trend” that will shape society in the next decade, predicting that blockchains could store as much as 10% of global GDP by 2027. Blockchain can help leapfrog a number of challenges faced by poor women and children. Imagine a world where the poor have their own identity on the blockchain, which they can use to access essential services (Koigi, 2019).

Imagine a world where the two billion unbanked poor, can access the global financial system through a simple mobile phone and crypto currencies. Imagine a world where foreign aid goes directly to poor women and children under a smart contract. All this is possible with the advent of blockchain technology. If we seize the moment, blockchain can make a transformative contribution to ending preventable deaths in women and children (Kouicem et al., 2018).

Considerable gains have been made in reducing preventable deaths in women and children. The number of women globally who die each year during pregnancy or childbirth has dropped substantially from 523,000 deaths in 1990 to 289,000 in 2013. The global number of deaths of children under the age of five has dropped significantly as well, from nearly 12 million in 1990 to 5.9 million in 2015. However, unacceptably high rates of maternal and child deaths still prevail in Asia and the Pacific. China and India together accounted for 16.4% (China accounted for 1.46% and India the other 14.92%) of the global number of maternal deaths. The Lancet reported that 20% of underage deaths took place in India in 2015 (Creanga, 2018).

5.2.3. Artificial Intelligence in Maternal Health

Over the last 30 years, health professionals around the world have reduced the number of annual child and maternal deaths by half. This monumental achievement demonstrates that great progress can be made when the global health community works together to create positive change, but we have an opportunity go further, to accelerate research and scale new solutions. This is where AI for Health can help (Akbulut et al., 2018).

While great progress has been made in reducing child and maternal mortality, these improvements have not been equal across the globe. For example, Finland's child mortality rate is 43.7 compared to Somalia's at 1,899.2 per 100,000 live births, and the U.S. maternal mortality rate is 29.9 compared to Chad's at 383.3 per 100,000 live births. Even in countries



such as the U.S. that have made great progress in reducing child mortality, the probability of a child surviving to their fifth birthday depends heavily on the zip code where that child was born and varies dramatically by demographics. There are real health issues in which AI can play an important role, and it may be our best option to accelerate research or expand the reach of new solutions, especially in areas that may lack attention from the commercial health sector (Foundation, 2019).

For example, technology can help scale screenings for diabetic retinopathy – an issue facing 463 million people – to expand the reach of ophthalmologists, as there are only 210,000 in the world. Or in cases such as Sudden Infant Death Syndrome (SIDS), where it is tough for organizations to invest in research given the size of the affected population, but there are huge knock-on effects to better understand and mitigate against general infant death (Firoz et al., 2018).

For instance, Ugandan doctors are giving new mothers artificial intelligence-enabled devices to remotely monitor their health in a first-of-its-kind study aiming to curb thousands of preventable maternal deaths across Africa, medics and developers said. Doctors at Mbarara Hospital in western Uganda will give devices to more than 1,000 women who have undergone caesarean section births to wear on their upper arms at all times (Azimi et al., 2019).

The phone-sized gadget transmits patients' data such as respiratory rate, oxygen levels, pulse, temperature and blood pressure to a desktop or mobile platform. Algorithms detect at-risk cases and alert doctors. Joseph Ngonzi from Mbarara University of Science and Technology, which is conducting the study, stated that, it would help "improve monitoring in a resource-constrained environment". The World Health Organization says almost 300,000 women worldwide die annually from preventable causes related to pregnancy and childbirth - that's more than 800 women every day (Ahmed et al., 2020).

New York-based software firm Current Health, which developed the technology, said the technology had the potential to improve postpartum healthcare for women across Africa. The CEO Chris McCann indicated that the devices - which require wireless internet and electricity - may not yet be practical for some African countries where connectivity and power is unreliable. McCann stated that internet and electricity coverage was rapidly expanding across the continent. Addressing concerns over patients' data privacy, it was further noted that the participants provided written informed consent to allow encryption of their personal health data. Uganda enacted data protection and privacy legislation in 2019 which also used to enforce the security and privacy of patients medical data (Foundation, 2019).

5.2.4. Machine Learning in Maternal Health

Machine-learning is a novel method of analyzing big databases, exploring meaningful information and developing models for prediction, clustering and associations. Machine-learning algorithms are methodologies used for big data analytics. These algorithms make data mining capable of mining information that commonly used statistical methods (logistic regression) fail to present. While statistical methods only quantify data, data mining develops models to identify hidden patterns and relationships in the data, usually from large volumes of database (Creanga, 2018).

Machine-learning is a widely used method in computing which is becoming popular in medicine and public health as well. Large number of studies have identified predictors of skilled delivery service use. However, they fail to present information that is unknown in advance. Applying data mining techniques is different from commonly used statistical methods (for



example logistic regression) as it extracts valuable information on the absence of any clear hypothesis (Ahmed et al., 2020).

Furthermore, large volumes of quality data, such as Demographic and Health Surveys (DHS), are being collected and recorded in the health sector. There is a growing need of applying better analytical techniques on those voluminous data to extract evidences that improve decisions in the health sector. The study by Zheng and others aimed at assessing determinants of skilled delivery use by applying a reliable predictive model using machine-learning methods (Zheng et al., 2018).

Much descriptive and diagnostic data exist to show the trends of social media monitoring (SMM), with visualizations depicting the staggering increase in incidence. These data used in hindsight are not enough to improve outcomes for mothers. It is time to manipulate these data to answer the questions of why SMM occurs and, more urgently, to identify these events before they happen. Within the Big Data in today's healthcare ecosystem, assembly of large, unbiased, clean and validated data sets can assist researchers to proactively determine what is happening to mothers before giving birth that may cause SMM or post-partum mortality (Dubey et al., 2017).

With a strong focus on racial and ethnic disparities, social determinants of health and health equity, datasets must represent populations at the highest risk for SMM, since rates of SMM were found to be greatest among mothers who are poor, over age 40, uninsured, on Medicaid, and residing in large urban areas (Famolaro et al., 2018). SMM occurred more often among black, Hispanic and Asian/Pacific Islander women than among white women in 2015. Also, black women were three times more likely to die in childbirth than white women (AHRQ, 2018), making a case for more inclusive data sets that accurately represent all maternal races and ethnicities (Akbulut et al., 2018).

5.3. Challenges that hinder full potential of the integration of Internet-of-things (IoT), blockchain technologies, Artificial Intelligence, and machine learning digital technologies in maternal health

Infrastructural challenges in healthcare sector. Healthcare systems around the world have been quite slow in using modern technology to revolutionize their sector as revealed by a study conducted by Organisation for Economic Co-operation and Development (OECD) on 23 countries (United Nations Conference on Trade and Development., 2019). The study indicates that many members of OECD have a high proportion of digitized health data but only a small percentage of them are regularly linked with other sources of information making vast quantity of data redundant as shown in the figure 3 below.

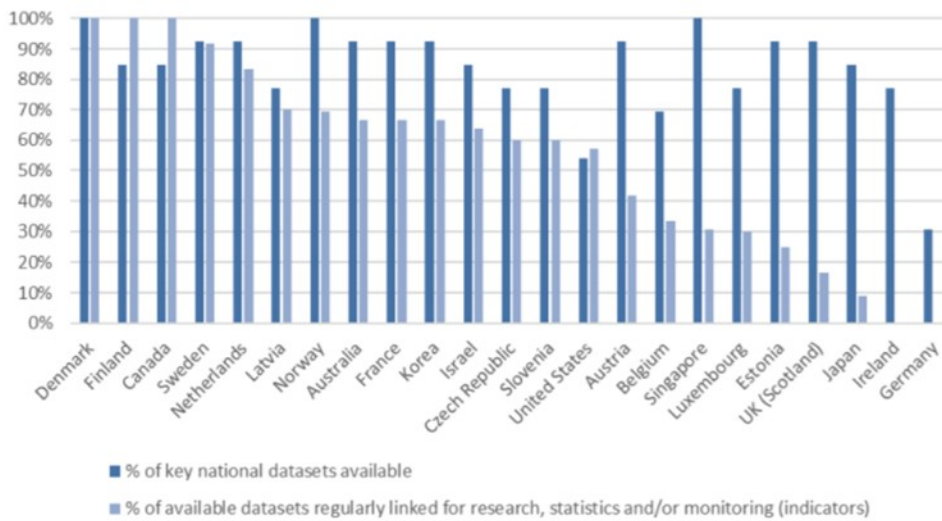


Figure 3: Infrastructural Challenges to Digitization

This implies that security and safety concerns have increased with the virtual interactions becoming a necessity exposing weaknesses in healthcare infrastructure. Hence, digitization of healthcare systems around the world is slowed by the technological readiness of some countries and lagging of regulatory legislation.

Privacy issues is also another challenge evidently, governments play a crucial role in facilitating Big Tech’s entry in healthcare especially allowing access to patients digitized health records, a very sensitive subject considering technology companies’ spotty track record regarding privacy and use of personal data. A survey conducted by Rock Health (Krasniansky et al., 2021) shows that patient’s willingness to share health data, with technology companies is predictably low with only 11% of respondents willing to do so. By contrast, patients were more willing to trust their doctor as the study indicates that 72% of patients are willing to share health data with their physician as shown in figure 4 below.

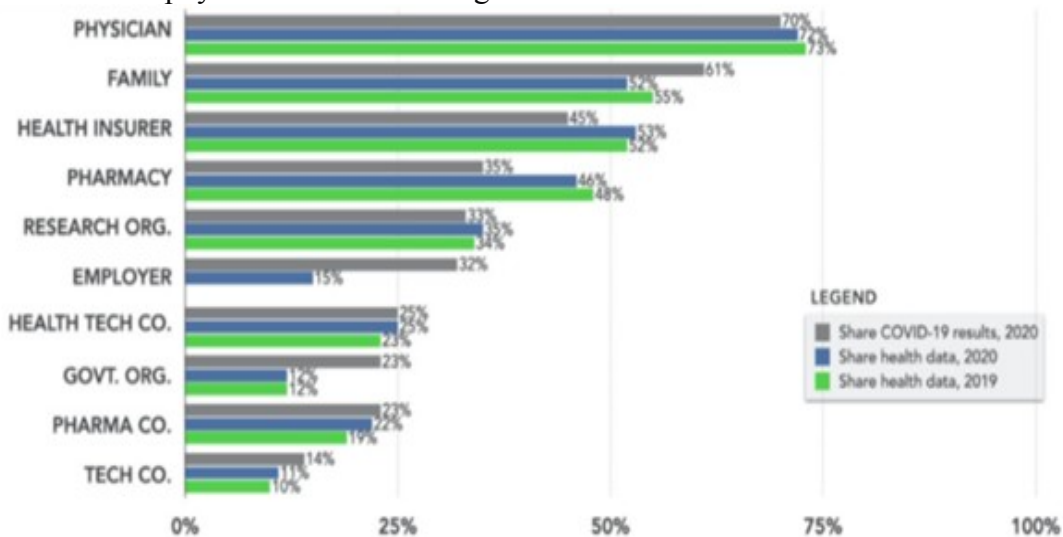


Figure 4: Patients’ Willingness to share health data 2019-2020

This implies that infrastructural, privacy, security and cost of implementation challenges are among the key barriers to full integration of digital medical technologies in healthcare. The healthcare stakeholders need to address the above names challenges inorder to reap full benefits of digital medical technologies.

5.4. Proposed Conceptual Framework for the integration of Internet-of-things (IoT), blockchain technologies, Artificial Intelligence, and machine learning digital technologies in maternal health

The proposed conceptual framework in Figure 5 below shows the integration of digital medical technologies like IoTs, Blockchain Technologies, Artificial Intelligence and Machine Learning tools and technique in aiding the provision of maternal services in healthcare using a single maternal healthcare application.

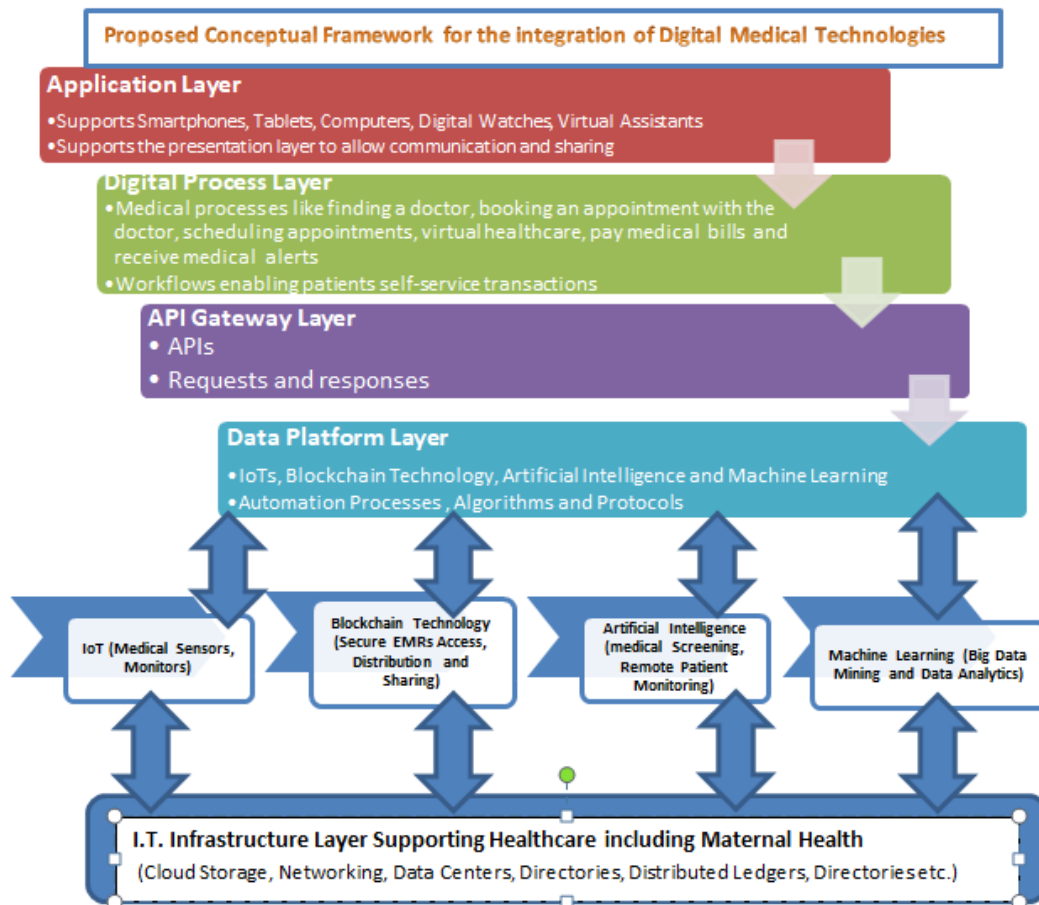


Figure 5: Proposed Conceptual Framework for the integration of Internet-of-things (IoT), blockchain technologies, Artificial Intelligence, and machine learning digital technologies in Healthcare including maternal Health



6. Conclusion, Recommendations and Future Work

Overall, digital medical technology has transformed healthcare. And this transformation is expected to continue in the years to come. Internet of Things (IoTs), blockchain technology, Artificial Intelligence, machine learning and many other such technological advancements and transformations will change the future of healthcare. As long as healthcare organisation and healthcare professionals keep their minds open and create the required infrastructure and systems, there is no limit of how far digital technology can go in healthcare. Innovative approaches using emerging technologies are key to improving equity in maternal health services delivery and in order for any innovative intervention to be scaled up in low-resource settings, evaluation studies need to consider cost, infrastructure, security, privacy, feasibility, and acceptability. The process of innovation does not end with implementation. Ultimately, innovative maternal health delivery approaches are only successful if they are sustainable and integrated into the health system. Innovative approaches in maternal and newborn health (MNH) care also will require innovative strategies for their evaluation. The potential of integrating the key digital medical technologies into a single maternal healthcare application, with an aim to reap their singular benefits, will be a great milestone towards enhancing maternal healthcare service delivery. This will allow programme and policy planners to assess the potential of interventions and ultimately determine which approaches may work, and why in maternal healthcare. Future research can be done to actualize the proposed conceptual framework.

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