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Potentials of Blockchain for Healthcare: Case of Tunisia

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ABSTRACT

Tunisia is a growing economy and in the midst of social, political, economic, technological and epidemiological transition. As a developing economy, Tunisia encounters related concerns in their healthcare sector. Opportunities include the mitigation of risks associated with counterfeit medicines including vaccines ("drugs"). Moreover, significant issues include drug availability and wastage, a fragmented healthcare information system. Overall, these issues are compounded by a lack of collaboration between healthcare stakeholders in setting priorities and moving the sector towards a patient-focused model of healthcare and preventative medicine. Many of these issues may be suited to the adoption of new technologies such as Blockchain and multiple case studies will be outlined within the scope of this paper. The present study aims to address the current issues and challenges pertaining to the healthcare sector in Tunisia and to contextualize the role of new technologies in providing better patient care, improved financial management and improved patient safety.

***Keywords*:** Blockchain technology, Healthcare, Collaboration, Pharmaceuticals, Tunisia

1. INTRODUCTION

Generally, the healthcare sector is characterized by its complexity [1], diversity [2], and dynamism [3, 4]. The effective management of the sector is one of the most significant

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challenges since any compromise in healthcare supply chains can directly affect patient safety and population health level outcomes [5]. The risks endangering the patients' lives transcend the borders due to the globalized nature of pharmaceutical supply chains [6, 7]. It has been estimated that millions are potentially at risk of being subject to falsified and substandard medicines. The impacts of counterfeit, fake and illicit medicines are enormous since they inflict many problems. These include, namely, the pernicious consequences for communities and healthcare systems [8, 9], the documented patients' deaths, waste, diversion, fraud and abuse in medicines access and healthcare financing [10], and the lack of trust in healthcare amongst local people. The World Health Organization (WHO) reported that counterfeit drugs were almost ten percent worldwide and 30% in developing countries [11].

The abundance of forged drugs coming from suspicious sources is not only limited to the so-called lifestyle products (e.g., drugs to treat weight loss, impotence, and the wrinkles of the skin, etc.) but it includes the treatment of cardiovascular disorders, cancer, antibiotics, painkillers, contraceptives, and other prescription drugs. Moreover, the healthcare sector is plagued in most cases by governance inadequacies [12], the lack of necessary infrastructure [13-16] and collaboration among different stakeholders (i.e., patients, clinicians, government bodies, pharmacies, health insurance companies, etc.) [17-19]. The reasons for this are traced to the numerous isolated Medical Information Systems (MIS) [20, 21], the heavy reliance on paper-based systems [22] the prevailing corruption [23] and bureaucracy [24-27], etc. As a result, there is a need for innovative technology-based solutions to protect patients and alleviate possible concerns [10].

The emergence of various forms of technology and digital health platforms has been a surge of interest in addressing supply chain problems and vulnerabilities in the healthcare sector. Admittedly, the advancement of Information Technology (IT) and related standards and has had a significant positive impact on data capture, communication, and analysis in the healthcare industry [28]. Despite this reality, there is still insufficient utilization of cutting-edge technologies and innovations for ensuring optimal patient safety and effective management of health supply chains (Clauson et al. 2018). Thus, healthcare technologists should consider several alternatives and move beyond the existing modus operandi. Emerging technologies are necessary to identify and operationalize practical solutions to healthcare problems. In this context, blockchain technology is viewed as a promising innovation which is extremely valuable for reinventing the healthcare procedures and solving entrenched issues.

Blockchain has gained significant attention in recent times. Its current journey began with the use of the technology as the backend for Bitcoin, a decentralized cryptocurrency [29]. A blockchain is generally defined as a decentralized network or distributed digital ledger of transactions which cryptographically links chains of data into immutable and time-stamped blocks [30]. A blockchain eliminates the need for a centralized third-party and facilitates the trusted exchange of assets between parties which do not trust each other. Blockchains can be architected in various forms including a centralized and curated distributed ledger technologies (DLT) and have been adapted to a variety of market verticals, incorporating its fraud-tolerant data-sharing capabilities into their operations [31].

Blockchain has been identified by management consulting organizations such as Deloitte and PWC and Academia as having capabilities to disrupt the healthcare sector [32, 33]. Life sciences, and the pharmaceutical industry have also shown interest in using the technology to improve the transparency of their supply chain [34]. Blockchain-based supply chain systems have been used to provide traceability in the food and beverage sector as well as drug and

medical device supply chains [35]. As such, the supply chain trading partners will be able to track each stage of the supply chain at individual drug, package or palate levels [36, 37]. Equally important, a blockchain provides an option to address the increasing risk posed by counterfeit drugs based on the proof of ownership protocols using private keys and smart contracts. With regard to the many problems related to record keeping, medico-legal issues, and ethics in the healthcare sector, blockchain technology provides the opportunity for self-sovereign, decentralized medical records [38]. In addition, this technology is expected to provide a new model for health information exchange by making electronic medical records more efficient, disintermediated and secure [39].

Even though many blockchain initiatives and efforts in health supply chains are still at the proof of concept or pilot stage at present [40], the healthcare system is highly subject to disruption in many countries. For instance, in Tunisia the healthcare sector has experienced steady double-digit growth at between 10% and 15% a year as a result of increased domestic demand for drugs, emerging export markets and the implementation of a favorable business environment [41]. After the radical political change that occurred in Tunisia in 2011, a social dialogue was initiated by the government and civil society to underline the importance Tunisians attribute to healthcare institutions and the government engagement in providing affordable, accessible and quality healthcare. In the same vein, the main objectives of their revised strategy consist of the continuous improvement of healthcare services through programs aiming at the use of new technologies [42]. In doing so, Tunisia has the ambition of improving their economic development and the productivity of health entities. They aim to improve the quality of healthcare services delivered and thus the overall health and well-being for their citizens.

New technologies can gain recognition in a government's change orientation. Tunisia is no exception and they have paved the way for a new era of digital technology introduction in different sectors in general and in the healthcare precisely [43]. This study aims to propose a blockchain-based solution for the drug supply chain of the Tunisian healthcare system. The authors have not located any previous work on the exploration and benefits of blockchain as a critical enabler in Tunisia's healthcare sector. As a result, the next section presents a literature review on the IT-enabled healthcare. Section 3 presents an overview of blockchain technology and its possibilities healthcare. The subsequent section will introduce the healthcare sector in Tunisia and highlights some of the challenges that could be addressed using blockchain technology. The last section provides several conclusions and suggestions for further research.

2. LITERATURE REVIEW

2. 1. IT-Enabled Healthcare

- *Cost Effectiveness*

The soaring administrative and operational costs of healthcare institutions have created tremendous pressure on world economies [44] to consider the use of information and communication technology (ICT) techniques in the management of healthcare facilities [45]. According to a report by Transparency Market Research, the global market opportunity in the IT-enabled healthcare is expected to rise from US$120.20 bn in 2015 to US$210.32 bn by 2020. This figure reflects the fact that ICT represents a workable solution and an effective substitute for conventional systems. As has been argued in previous studies, the software applications and

IT systems have improved the quality of healthcare services [46-49] and created opportunities for promoting and supporting the active participation of people in their health management [50]. In the increasingly complex and data-intensive domain of healthcare facility management [51], the IT-enabled healthcare could drive more cost-effective and efficient healthcare services. In accordance with prior studies, the appropriate use of technological developments (e.g., electronic medical records) has significantly reshaped the healthcare service delivery led to considerable cost savings alongside enhanced quality of care for patients [52, 53]. Similarly, the efficient implementation of digital radiology imaging systems could provide system-wide cost savings and increase the patients' satisfaction with care [54]. Assessing the impact of home telehealth (i.e., the use technology in health care delivery for a specific patient involving a provider across distance or time) and nurse case management for patient with chronic heart failure, Noel et al. (2004) [55] found that healthcare costs decrease by 58 per cent for the home telehealth group while only 47 per cent was recorded for the non-intervention group. In an attempt to perform a cost comparative analysis of a technology-enabled service for frail older people and their family carers compared with usual care services in Sweden, Magnusson and Hanson (2005) [56] showed, based on the evaluation of a case study analysis of five families, that significant cost savings were achieved in all cases and the benefits to older people and their carers were also considerable. The gradual replacement of the paper-based records by the electronic medical records could enable to generate substantial healthcare-wide cost savings. For example, Hillestad et al. (2005) [52] approximate that extensive use of interoperable electronic medical records (EMRs) would enable Medicare to save $23 billion per year while private payers could save $31 billion. The same authors noted that over fifteen years the cumulative potential net efficiency and safety savings from hospital systems could be almost $371 billion, potential cumulative savings for physician practice EMR could be $142 billion.

- *Information Sharing & Collaboration*

Aside from the cost considerations of IT-enabled healthcare systems, there are also tremendous benefits in terms of healthcare process efficiencies. A particular benefit of IT that has been cited recurrently in the academic literature in general and in the healthcare field in particular is the ability to facilitate the information sharing and the interaction between different stages, departments and parties [57, 58]. Today, health information systems involve, without limitations, physicians, staff, nurses, laboratory analysts and technicians, and administrative operators etc. who use the sharing and interactive capabilities of the technologies to foster integration and increase collaboration [59]. Moreover, studies on the IT-enabled healthcare models have proved that the synergistic communication and seamless health information sharing between patients and medical service providers are capable of improving health diagnoses, enhancing patients knowledge and education, and furthering self-care as the result of digital monitoring capability [60-63].

Quality medical services would typically signify the presence of a technology infrastructure that preserves the continuity of care and guarantees the efficient transfer of information across all the layers of the health system. For example, IT applications architecture spread (ITAAS) is able to positively impact on healthcare operational performance [64]. The resulting impacts of these applications are the better coordination of activities within and across hospital boundaries, the increased efficiency of transactional processing, and the intelligence development and decision making [65]. In a similar vein, the data mining techniques and medical informatics have led also to a situation where information is effectively shared and

integrated among healthcare entities and patients. Not only they contribute to driving down the healthcare delivery costs but they improve the patient care by way of well-informed choices and decisions [66-68]. Of course the IT-enabled healthcare has optimized health outcomes and facilitated the value-driven care because patients would be more knowledgeable about the available healthcare services [69, 70] and healthcare providers would be able to effectively respond to patients needs and cater their service delivery accordingly. Therefore the possibilities of IT-enabled healthcare systems can go a long way to renovating the definition of care delivery by allowing to break down the existing functional siloes [71] and to create healthcare-integrated platforms among the dispersed entities.

- *Automation & Efficiency of Care Services*

A major reason justifying the application of IT to the healthcare field is the automation of care delivery services [72–77]. The decision of embedding the IT into the organizational processes of healthcare organizations has led to an efficient and effective hospital system that covers all operations ranging from clinical procedures, management and administrative functions, to office automation and communication [76]. IT helps to streamline healthcare operations and to make the execution of care delivery services more practicable, coherent, and hence more effective. To sustain the workflow of medical organizations, the global IT-enabled healthcare market involves several types of systems such as EMR [75], nursing information systems (NIS) [78], pharmacy information systems (PIS) [79], and computer-aided systems [80] etc. At a more detailed level, the deployment of EMR has been commonly touted by healthcare providers as a way to improve the care delivery through providing simple accessibility, retrieval, and storage of medical documents [75].

Similarly, EMR and interactive decision support tools could allow hospitals to gain up-to-date knowledge of patients medical history [81] , thus improving health diagnoses and reducing errors [82]. The high level of automation and digitization of these systems supports the mobility of patients and healthcare professionals [83]. As such, the patients would receive consistent and steady healthcare services irrespective of their geographical locations. Having been considered as one of the significant issues of the non-hospitalized hospital, the waiting time could be significantly reduced by the full computerization of hospitals [84]. The digitization of health services also enables to reduce the length of patient stay and the processing time of patient discharge [76].

Indeed, preliminary findings by Kumar, Swanson, and Tran (2009) [85] show the excellent potential for RFID technologies to decrease the patient waiting time by 94 percent and increase the discharge time by 48 percent. The crux of the argument seems to reside in the authors' claim that RFID technology induces better scheduling, delivery room, equipment availability, decreased paperwork, and improved information flow [85]. Another study by Augestad et al. (2014) [86] underlines the role of electronic surgical referral system to reduce the waiting time for surgery by 101 days. Potential results of speeding the surgical treatment are the decrease of the length of sick leave and societal savings of approximately 1809 £ for each patient receiving an expedited one-stop surgical service [86]. Consequently the benefits of process optimization and increased responsiveness in medical procedures are not only bound to a single healthcare provider but they could be also transferred to other stakeholders and cross-organizational processes [87].

2. 2. Blockchain-Enabled Healthcare

Researchers note that the healthcare sector encounters several issues that raise concerns for healthcare providers [32, 35, 88]. For example, inefficiency is a known issue in healthcare globally and may negatively impact on patient care, directly or indirectly. In the context of the drugs supply chain, a significant complexity lies in the significant financial loss and human health and safety risk posed by counterfeit, theft and diversion of drugs [39]. A study conducted by PricewaterhouseCoopers (PwC) indicates that the illicit trade market for drugs is estimated at €188 billion (US$200 billion) annually. This ranks it as one of the most lucrative illicit trade markets in the world [33]. In fact, nearly 1,000 different drugs have been reported as falsified or substandard by the World Health Organization (WHO) across various categories [89]. Moreover, the WHO states "Unsafe medication practices and medication errors are a leading cause of injury and avoidable harm in health care systems across the world. Globally, the cost associated with medication errors has been estimated at $42 billion USD annually." [90]. This reality is attributed to a combination of non-compliance to Good Manufacturing Practices (GMP) for drugs, illegal imports of cheaper drugs to be sold at higher margins and infringements in intellectual property (IP) (e.g., registered trademarks or patent rights). From sporadic manufacturing and labelling errors to complex supply chain processes and pharmacy fraud (e.g. up/down dosing, generics replacing branded drugs at higher cost), drugs are subject to many issues. These different forms of compromised or fake drugs can manifest as a result; importation of substandard active ingredients without local approval which impacts the drug quality and efficacy. Furthermore, poor manufacturing practices as well as improper storage (e.g. some drugs require refrigeration) combined with cargo theft and diversion contribute to the overall problem [40].

As a result of the globalization of consumer markets, and the rise of electronic commerce, it is easier for counterfeiters to infiltrate the drug supply chain through purchase and delivery via the internet [9, 91]. The proliferation of online pharmacies has allowed drug counterfeiters to use digital channels to penetrate both developed and developing countries and to bypass the well-protected traditional physical drug distribution networks. As a consequence, securing the global drug supply and delivery networks, and taking defensive measures are necessary to combat illicit trade. The existing anti-counterfeiting procedures rely upon serialization (i.e., the unique identification of individual packs) and other differentiators such as covert or overt security images and features such as holograms or tamper-evident seals. These features are on top of existing forensic drug authentication completed in field surveillance testing or at an analytical laboratory.

Furthermore, the industry has widely digitized its supply chain in developed economies and increasingly so in developing economies. For example, traceability technology is widely used in combination with industry standards from GS1 [37, 88, 92-94]. Combined, these measures have helped to deter counterfeiters but not to eliminate them as legitimate businesses are occasionally the 'bad actors' in illicit trade. For instance, developed countries such as the USA have implemented 2D barcodes and RFID while the European trend is towards 2D barcodes [92]. By adopting various technologies and counter-measures, they facilitate the tracking (forward) and tracing (backward in a product safety recall) and help to manage the visibility of inventory flowing through the manufacturing and distribution process. Thus, these measures can contribute to the faster identification of genuine versus falsified, substandard, and adulterated drugs. In doing so, the influx of these faux drugs will be hampered and the risk to human health and safety reduced.

The adoption of new technologies is an important strategic decision taken up by several drug manufacturers and regulatory authorities [92]. Today, there is no single technology that can serve all the requirements for detecting counterfeit and substandard drugs. Moreover, there is an opportunity to bifurcate the technologies into specific niches to respond to well-defined needs within the workflow process of detecting medical products [88]. When it comes to the sensitivity of the production process and the critical reputational and liability issues associated with the final product, blockchain technology stands out as a valid option to increase transparency and enhanced trust in the drug supply chain. This new and emerging technology can be aligned with the GS1 system of supply chain standards. Together, they enable the identification of trading parties (e.g. producers, distributors, pharmacies) as well as products and pallets of drugs across the supply chain. Likewise, it can be used at all the stages of drug movement from manufacturer to patient [95]. This will be crucial in controlling and monitoring the authenticity of the active pharmaceutical ingredients during all phases of raw material sourcing, production and manufacturing of the active pharmaceutical ingredients and packaging of the final products [96]. Besides, blockchain ensures a secure supply chain protected against fake drug infiltration, hence leading to more trustworthiness, accountability, and transparency [40]. It also facilitates the tracking of processes, the detection and/ or retrieval of counterfeit, stolen and parallel imported goods which contribute to costs reduction and patient safety [96] [40]. In their study [97] suggested a product ownership management system to prevent counterfeits once the goods are in the post supply chain thereby the tracking of origin can be easily ensured after buying the products.

Although traditional technologies, such as mobile technology, barcode scanning system and RFID, have been suggested for the tracking and tracing of drugs, counterfeiting still occurs on a global scale [98]. To respond to this matter, the combination of blockchain with the Internet of Things (IoT) services is regarded as a substantial transformative power across several industries [99]. The intervention through blockchain-enabled systems is esteemed to transform the potential and bridge the gap of device data interoperability while maintaining security, privacy and reliability around medical IoT applications [39]. In combatting the prevalence of counterfeit drugs, blockchain can be applied to the traceability of raw materials and finished product from manufacture to end user in an unalterable and shared e-pedigree-based digital ledger. For example, a system combining the RFID and blockchain could be useful in drug supply chain allowing the customer to reject the purchase of counterfeits even with genuine RFID tag information if the seller does not possess their ownership [97]. Moreover, blockchain technology allows to maintain adequate supply at the point of distribution (e.g., mitigating stockouts), mitigate health systems inefficiencies, fight the corruption in pharmaceutical procurement, and catalyze effective delivery of healthcare services and commodities [40]. The technology also drives better information sharing across separate databases and different partners in the drug supply chain [10].

Concerning the medical health records, blockchain technology shows high suitability in the fields of legal medicine, research, electronic medical records, medical data analysis (i.e., big data), teaching and the regulation of payment for healthcare services [100]. Recording medical data on a blockchain network makes it extremely difficult to tamper with because this technology provides a high level of confidentiality and selective access (i.e., the use of cryptographic algorithms and the permissioned blockchain network). Furthermore, due to this fact, blockchain will assist in bringing in a radical impact on future healthcare systems by allowing the standardization of medical record keeping across a vast geographical area [101].

In their studies, [38] described the benefits of using blockchain technology compared with traditional distributed databases for biomedical and healthcare applications. Among the key benefits are decentralized management, immutable audit trail, data provenance, robustness and availability, and the improved security and privacy. They also indicated that blockchain could improve the medical record management, enhance the insurance claim process, accelerate the clinical/biomedical research, and advance biomedical/ healthcare data ledger.

Several blockchain projects and initiatives are currently underway and many large pharmaceutical companies are cooperating on leveraging blockchain technology in healthcare**.** In fighting against the counterfeit pills, Pfizer- one of the world's largest pharmaceutical companies- is leading a group of firms to develop MediLedger Project. They aim to launch a blockchain network to circumvent the silos, to build bridges for secure record-keeping of transactions, and to stop counterfeit drugs from penetrating the supply chain. Similarly, Genentech and Chronicled spearheaded the Ethereum-based blockchain system to enforce solutions related to the traceability and identification of irregularly manufactured and fake medicine or pills. Another United Kingdom-based startup FarmaTrust has signed a partnership agreement with the Mongolian government to implement blockchain technology in order to prevent the distribution of fake medicines and help the government in monitoring and inspecting the pharmacies and pharmaceutical supply chain stakeholders.

Several organizations such as Deloitte and Accenture are involved in applying blockchain technology [102, 103]. A blockchain is aimed to improve data integrity, decentralization, and disintermediation of trust. The technology can reduce transaction costs, facilitate patient tracking, and identity assurance and validation among healthcare professionals, patients, and healthcare providers [102, 103]. In their review study, [104] noted that MIT Media Lab and Beth Israel Deaconess Medical Center launched a blockchain project called "MedRec" which aims at offering a decentralized approach to managing permissions, authorization, and data sharing between healthcare systems. The use of blockchain is intended to provide patients with transparency and visibility over access to healthcare data. Estonia's digital health infrastructure proves the usefulness of blockchain in securing the health records of one million of its citizens. The country collaborated with Guardtime- a Netherlands-based software security company- to establish a proprietary Keyless Signature Infrastructure (KSI) which constitutes of a healthcare platform based on blockchain technology. Since then, Estonian citizens, healthcare institutions and insurance companies have been able to quickly retrieve all information related to medical treatments carried out in the country. Another case of collaboration between Capital One and Gem Health (a US startup) yields to successful development of blockchain application platforms. Using the Gem Health network, different healthcare operators can access the same information, which consequently allows to unlock wasted resources and solve important operational problems in the sector.

The practical and real-world application of blockchain to problems pertaining to the pharmaceutical supply chains is still not clear and requires further maturation [40]. Similarly, a certain level of complexity of data ownership and governance structure still exist between public-private entities [39]. Despite these facts, it is envisioned that blockchain will lead to impressive results in terms of drug safety savings in health-related follow-up costs. Therefore, motivated by the lack of awareness surrounding the blockchain applications to healthcare and the scarce of comprehensive studies examining the possibilities of the technology in middle and low-income countries, we discuss in the subsequent section how blockchain technology could solve several problems in the Tunisian healthcare sector.

3. POSSIBILITIES OF BLOCKCHAIN TECHNOLOGY IN HEALTHCARE IN TUNISIA

Besides the Ministry of Health and the international bodies such as the WHO, multiple actors were involved in many health programs including national legislators, regional councils, financiers, private health providers, researchers, the pharmaceutical industry, and mass media [105]. Although the health system has shown a good performance both in curative healthcare services and coverage and since Tunisia is on its way to achieve the health Millennium Development Goals (MDG) targets by 2030, it has yet many shortcomings that should be addressed and solved with the current advancement in new technologie. In developing countries, blockchain technology has the potential to support the healthcare sector in various ways.

Since the mid-1990s, Tunisia has adopted an industrial policy aimed at promoting Research and Development (R&D) and innovation in all domains, particularly in emerging and high added-value industries such as pharmaceuticals [106]. The Tunisian pharmaceutical industry is a highly evolving market with an approximate annual growth rate of 12% and a strong increase in expenditures. With its young age (created at the end of the 1980s), pharmaceuticals are subject to stringent regulations covering the imports (through the Pharmacie Centrale de Tunisie (PCT), a state monopoly), manufacturing, distribution, and sales [107]. Historically, the pharmaceutical regulation dates back to 1942 in the form of a decree on medical and pharmaceutical promotion and medicine control [108]. The reason for which all sales of pharmaceutical products in Tunisia are subject to a review committee and certification process.

Notwithstanding these facts, it is estimated that one in ten medicines in middle-income and low-income developing countries is counterfeit [95]. In this regard, a blockchain-based supply chain system can aid in curbing the danger of substandard and fake drugs. The technology can secure the pharmaceutical supply chain in the country and guarantee a verifiable circulation of safe drugs. Besides, all the actors of the supply chain (pharmaceutical manufacturers, laboratories, the Tunisian Central pharmacy, the Ministry of Health, third-party companies including shipping logistics and cold chain management companies, etc.) could interoperate in a universal blockchain platform to track pharmaceuticals to individual medicaments. In doing so, a high level of control of all elements of the chain of production, logistics, certifications, and sales of drugs could be achieved at singnificanly reduced costs. Any State budget exclusively allocated for quality inspection of manufactured drugs can be decreased. Moreover, real-world incidents such as the recent seizure of harmful drugs imported from Tunisia in Algeria and intended for slimming treatment can be eradicated by blockchain implementation. The system would help to identify any potential leaks of substandard medicines in the distribution system as well as helping to monitor the parallel trade flows between Tunisia and its export markets, viz., the neighboring and West African countries. If adopted across the industry, blockchain can leverage the marketing potential of companies interested in promoting their quality medical products. This will generate additional value in terms of increased export value, marketability, trust, and promotion of goodwill, etc.

Like many other countries, Tunisia depends on locally assembled refrigeration equipment in the cold chain of vaccines. Any improper storage and transport results in high wastage and inadequate immunization coverage. Fluctuations in temperature within the appliances entail the loss of potency in vaccine and subsequently to its inefficiency [109]. In a case study by [110],

it was found that a modification of methods to cold chain management of vaccines in Tunisia resulted in 20.16% reduction in energy costs for vaccine storage and distribution. A related work of [111] shows that the shift to a Vendor-Managed Inventory (VMI) system (a form of collaboration between the customer and the supplier in which inventory information is automatically sent and order replenishment will be done accordingly.) drives down the total logistics costs and phial wastage to 18% in overall program costs with increasing the per-unit cost of vaccine. While a temperature monitoring solution was implemented in Tunisia and successfully demonstrated the viability of electronic/ continuous temperature monitoring and freeze prevention technologies in reducing the incidence of inadvertent freezing of vaccines [109], blockchain could leverage these solutions and assist in addressing humanitarian logistics problems. The technology can ensure sound traceability of vaccines in a system consisting of refrigerators and temperature- controlled containers equipped with sensors which send real-time information to a shared blockchain platform between all participants. Smart contracts can set triggers or conditions and automatize the process of monitoring the vaccines. If the regulated temperature of vaccines is outside certain threshold, a notification alert will be sent to the responsible agent. Indeed, blockchain will guarantee the compliance of cold chain management with the WHO norms for vaccine storage. More visibility over vaccine forecasting, stock management, and order status can be achieved in a way to reduce the risks of understocking (i.e. stock-out and low immunization coverage) or overstocking (i.e., expired medications). Therefore, the goal of of a zero waste can be reached and a sustainable social policy of "The Tunisians are Tunisia's main natural resource" can be advanced by leaps and bounds.

Referring to the health information systems in Tunisia, the WHO states that they are the root causes of healthcare sector weaknesses. The subsystems for managing the different parts of the healthcare system are patchy and unconnected [105]. Furthermore, Tunisia exhibits inefficiencies in the management of health financing services, delivery systems and pharmaceutical expenditures [107]. The conventional hospital management systems are unable to solve the problems of cooperation and communication among medical service units (i.e., the absence of automatic management of any medical data, patient medical records, radiology, etc.) [112]. As a result, several problems still exist such as the shortage of medications, lack of adequate coordination, transparency and poor communication, the ineffective use of resources, the weak public service, and the patients' discontent with health services [113]. To encounter these challenges, blockchain technology can be a potential solution to improve the collaborative supply chain and ease the information flows between the healthcare stakeholders. It is possible to digitalize all related documents, facilitate their circulation, and secure their exchange across the network.

Based on these capabilities, problems related to the exaggerated requirements by nurses for drugs, the delivery of excessive quantities of certain medications, the mismatch between the supply and demand can be stamped out with the use of blockchain technology. The distributed ledger technology supports the synergistic communication and the close involvement of doctors in the management process and stock control of drugs [114]. In a blockchain network, all information related to healthcare is safely shared, distributed, communicated, and synchronized among the various medical units. The prevailing inefficiencies of health information systems can be solved by increasing the speed of information processing and the elimination of possible losses, damages or falsifications of documents. These outcomes can be justified by the immutability of stored data and event logs, their non-repudiation and their high integrity.

In the blockchain scenario, the centrally controlled decision making of Tunisian hospitals in placing drug orders will shift to a system wherein there are collaboration and consensus among the registered hospitals on the procurement dates. Thereby, any probable overload of the PCT can be mitigated resulting in a high satisfaction of orders, drug delivery in the right amount and at the right time, and the protection of patients' lives. Having proven to be a practical strategy, the order placements in different dates allowed 83.33% of hospitals suffering from drug shortage to be covered more than 100% of their needs [107]. This practice can be improved through the use of blockchain since the technology provides visibility over the orders placements and ushers in new opportunities for hospitals to borrow medicines from network members and to resolve drug shortage problems.

Although the private sector providers have been steadily participating into the healthcare delivery system because public healthcare sector cannot meet the decentralization of curative services, and that the healthcare sector is plagued by the progressively aging population and the increasing health needs, the public-private coordination is still limited [105]. As such, the communication gap is accentuated and the gulf between the private and public stakeholders is stretched more than ever before. To foster the effective coordination, there is a need to strengthen the inter-sectoral collaboration which is defined as the recognized relationship between part or parts of the healthcare sector with another sector to take action on an issue and achieve more efficient and sustainable health outcomes than could be achieved by the sector acting alone [115]. The stakeholders can deploy blockchain technology to minimize collaboration inefficiencies. Issues related to the duplication of efforts, ineffectiveness in processes, and higher operating costs for health systems can be well resolved by blockchain.

The Ministry of Social Affairs, Solidarity, and Tunisians Abroad (MASSTE) and the Ministry of Finance play a crucial role in the healthcare sector through ensuring the proper practices regarding the eligibility conditions of potential beneficiaries for reduced fees or charges (i.e., defined based on the minimum wage rate) and free-care cards programs (i.e., exempted from healthcare fees and defined according to national poverty line and regional quotas) [113]. The blockchain can be utilized to empower health equity and prevent biased selection of beneficiaries for aid programs. Based on a blockchain platform that involves tax offices, it will be possible to have full transactional disclosure and a single truth for the network participants about the individual income and social status of the persons concerned with medical assistance. As Tunisia is currently striving to step forward in its war on the prevailing decentralized corruption, false prescriptions, illicit drugs, and faults in public procurement, the advancement of the innovation systems in the counntry cannot take place in the absence of a supportive legal and institutional framework [106]. For blockchain to be implemented in Tunisia, prerequisites should be established to host this new technology. The engagement between all healthcare stakeholders is required. This implies saying that all the players including public/ private hospitals, governmental bodies (PCT, the Ministry of Health, the Ministry of Social Affairs, the Ministry of Finance, the Ministry of Communication Technologies and Digital Economy, etc.), and health insurance entities must be ready to adopt blockchain. More so, a digital environment based on internet connectivity and digital literacy are required to shift toward this new trend [116] since awareness of the technology is still at a low level between health professionals as previously stated.

Currently, Tunisia has undertaken a strategic partnership agreement with the Locus Chain Foundation to implement blockchain technology in all construction projects and as a base technology and settlement currency for different industries, including the medical one. Through

this project, the country aimed to digitalize the public sector and businesses by establishing an urban development and a mega economic development project in the eastern region. Infrastructure partnerships including the government, international companies (e.g., IBM) and potential startups can work jointly to bring new solutions for the current problems pertaining to the healthcare sector [116].

Although blockchain technology contributes to the reduction of transaction processing time and costs by alleviating third-party intermediaries within the healthcare sector, its implementation is still challenging. Changes in the existing system require high capital costs and long adaptation time. Additionally, the Tunisian government may consider putting more attention to blockchain possibilities through building future capabilities, training, funding, and setting the suitable regulatory framework for blockchain adoption in the healthcare sector.

4. CONCLUSIONS

In developing and implementing a strategy for a patient-centered healthcare system wherein hospitals, health institutions, families and patients are closely involved in the healthcare sector, Tunisia aspires to step forward in its reform and recently launched anti-corruption drive in the medical domain. Although the country has witnessed an epidemiologic transition manifested by the substantial regression in the morbidity rate, namely, the remarkable decline in communicable illnesses, and the increasing burden of non-communicable diseases (e.g., cancer, diabetes, cardiovascular disease, and obesity) [117], the inequities in access to healthcare, the public mistrust in the state-owned health provisions, the deterioration of health sector, and the intensifying burden of expenditure for health treatment are the main debatable issues in Tunisia post-2011 transition.

Public investments in logistics and communicational infrastructure lead to the creation of a conducive environment for long-term endogenous growth [118]. In this respect, Tunisia has adopted a policy which aims at promoting R&D and innovations in all fields in general and in healthcare in particular. From attempts to spur R&D activities in the pharmaceuticals to the private initiatives for modernizing hospitals using a holistic approach to healthcare, digital records and high tech equipment, the country recognizes the critical role new technologies can play in its orientation.

The critical issues faced in the healthcare sector include among others the risks of counterfeit or substandard drugs infiltration in the supply chain, the parallel trade in medications, the drug shortage, the lack of collaboration and transparency, and the corruption, etc., appear well suited for the adoption of blockchain technology. Some researchers describe blockchain as being as important as the Internet due to its transformational impacts on business and society [119]. While blockchain technology is not considered as a panacea for all the problems and issues related to the Tunisian healthcare sector, we highlighted in this study a wide range of promising possibilities and benefits that could remarkably reshape the delivery of health services in the country.

On the one hand, blockchain technology can consolidate the pharmaceutical supply chain by allowing a high level of control of all elements of the chain of production, logistics, certifications, and sales of drugs as well as a sound traceability system for drug authenticity and vaccines potency. On the other hand, empowering more disintermediation, processes efficiencies, and collaboration among healthcare stakeholders are the main advantages of a

blockchain system. Overall, this new emerging technology has the potential to instill trust in the healthcare sector, solve various sectoral pain points, and significantly improve the quality of healthcare services. Future research may focus on designing a theoretical framework for blockchain-enabled systems targeted to different processes in the healthcare field. Research endeavors have yet to consider cost-benefit analyses of applying blockchains in the healthcare sector.

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