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Promising Blockchain Technology Applications and Use Case Designs for the Identification of Multinational Victims of Mass Disasters

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In mass disasters with multinational victims, it is critical to identify the deceased for judicial, ethical, religious, and human rights reasons, as well as to allow the next of kin to complete the grieving process. Disaster Victim Identification (DVI) process is a complex procedure where postmortem (PM) identifying data, essentially fingerprints, DNA, and dental, are collected to be compared with equivalent antemortem (AM) data related to the missing persons list. Although there are solutions used in the field of human identification, they all fall short of equipping them with the tools needed for achieving human identification in a timely manner. Initially, it is significantly challenging to manage missing person lists containing years, and sometimes decades, of family AM data resources' updates. Furthermore, there is currently no record of any holistic technical solutions for managing both AM and PM for human identification to support collaborative multinational and interjurisdictional processes. Blockchain technology provides the tools to facilitate building trustworthy, secure, and holistic ecosystems, and it can disseminate siloed AM and PM data across systems, protecting data breaches, redundancies, inconsistencies, and errors. As such, blockchain technology can revolutionize the human identification process worldwide in terms of managing missing person lists, AM data repositories for living people, PM data repositories of recovered unidentified victims, and contribute to the comparison of compatible biological profiles for definitive identification. Using real-world scenarios, the authors propose a number of promising use cases to attain a holistic understanding of the challenges, and present how blockchain technology meets such challenges and facilitates multi-jurisdictional data information-sharing in conjunction with the forthcoming circulation of patients' electronic medical and dental records.

Keywords: blockchain technology, digital health, dental, globalization, human identification, forensic odontology, disaster victim identification, missing persons

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INTRODUCTION

Blockchain technology was conceived in 2008 as a distributed ledger technology, and there has been growing optimism in this new innovation since then. Although it is popularly known as the backbone of the Bitcoin cryptocurrency, in recent years, we have witnessed an increasing wave of interest in its application beyond cryptocurrency (Al-Megren et al., 2018). To date, there is no evidence of its application in forensic science for human identification. Indeed, it is critical to deploy advanced technologies and innovations to enhance traditional, tedious, costly, and ineffective human identification processes in order to optimize resources and reduce costs. Blockchain is proven to build trustless systems with no single dominant authority, while providing an immutable ledger that is transparent to all participants, and producing an auditable data provenance that can automatically track every change that is made to the data (Hardjono et al., 2016; Al-Megren et al., 2018). Although there are some solutions applying blockchain in cyberspace digital identities and digital sectors (Al-Megren et al., 2018), this technology has not been applied to date for human identification in meatspace. Therefore, the authors in this article aim to be pioneers in the deployment of blockchain technology in the field of forensic science to advance human identification practices beyond traditional means, as well as demonstrating blockchain technology's capability of building trusted identification ecosystems beyond our digital realm. This paper introduces blockchain technology to forensic science practitioners and presents using real-world scenarios what blockchain technology can offer in terms of bridging the technology adoption gap in the field of human identification using key promising use cases, and in particular, it provides a roadmap for future interdisciplinary research that can help revolutionize traditional disaster victim identification (DVI) process.

INFORMATION CHALLENGES FOR INTERJURISDICTIONAL DISASTER MANAGEMENT

Disaster Victim Identification Process

In our global society, mass disasters rarely have a singular national impact (INTERPOL, 2018). The DVI process is the facility management of disaster or incident that results in a loss of lives that exceeds a community's resources as well as its ability to respond. These include unintentional man-made disasters, natural disasters (hurricanes, floods, tornadoes, volcanoes, wildfires, earthquakes, and tsunamis, etc.), and intentional man-made disasters (Nuzzolese and Di Vella, 2007; Senn and Weems, 2013). Authorities in many countries use a placeholder name (such as "John Doe" or "John Smith") for people whose true identities are unknown and/or cannot be established, and thus, DVI plays a great role in law enforcement criminal investigations, also from judicial and human rights perspectives (Nuzzolese, 2012). The DVI process is a complex procedure where postmortem (PM), the after death, primary identifying data, essentially fingerprints, DNA, and dental data, are collected from the deceased or human remains to be compared with equivalent antemortem (AM) data, the before death data, related to the reported missing persons involved in the disaster. On the one hand, these primary identifiers are the most reliable means of identification, meaning each one can determine and identity or exclude one. On the other hand, secondary means of identification are also collected to support the identification process; these include tattoos, jewelry, scars, and so on (See Khoo et al., 2016).

In the process of DVI, there are set guidelines to be considered based on Interpol protocol and local standards that must be adhered to (INTERPOL, 2018). According to Interpol DVI, there are five phases in managing a disaster and identifying the victims and these are explained in finer detail (AlQahtani et al., 2019), and illustrated below in **Figure 1**. Excluding the debriefing phase, they are phase 1 accident or scene site: recovery of human remains and properties; phase 2 temporary morgue or PM: where forensic DVI specialists examine human remains to determine the cause of death and collect all primary identification data and forensic evidence related to the case; phase 3 AM data collection: where the police collect all historic information to aid in the identification process (to be matched with the PM data). This phase includes the collection of the missing person's medical and dental records, physical characteristics, such as build, hair and eye color, scars, tattoos, and also DNA from their home or family; and most importantly, phase 4 data reconciliation: where data from phases 2 and 3 are compared to find correspondences, matches, but also exclusions, to achieve a positive identification. This process can be very time consuming, depending on the complexities of human remains and the availability of AM data (Morgan et al., 2006); phase 5 debriefing: in this phase, all the DVI activity is evaluated and checked for quality control.

Information Requirements for Interjurisdictional DVI Teams

Disasters, whether natural, accidental, or even intentionally man-made, are witnessed every day and anywhere around the globe (INTERPOL, 2018). Tragically, they are very difficult to predict and, in most cases, cannot be prevented. The number of casualties involved in such disasters varies depending on a number of factors, including the type and location of disaster. Such disasters can leave behind thousands of victims from all over the world, making multinational victims' identification a challenge that demands an interjurisdictional effort among multiple DVI teams representing nations where the involved victims are from, to bring justice to those victims and closure and relief to their families, regardless of their nationality. Using various real-world disaster examples with multinational victims, this section presents the information challenge DVI teams face to achieve a successful human identification process in a timely manner and identifies the gaps in existing technology in traditional human identification processes.

Hajj is the world's largest gathering where approximately 4 million pilgrims from more than 50 countries around the world travel to the holy city of Mecca, Saudi Arabia, to complete specific religious rituals (Alsalamah et al., 2018). Such overcrowded conditions have resulted in a number of crowd disasters witnessed during Hajj over the years (Manoochehry and Rasouli, 2017). The existing DVI process in such crowd disasters is an elusive, complicated, and time-consuming task. Many crowd studies have recognized that the forces of a massive gathering are almost impossible to control; fatal incidents occasionally

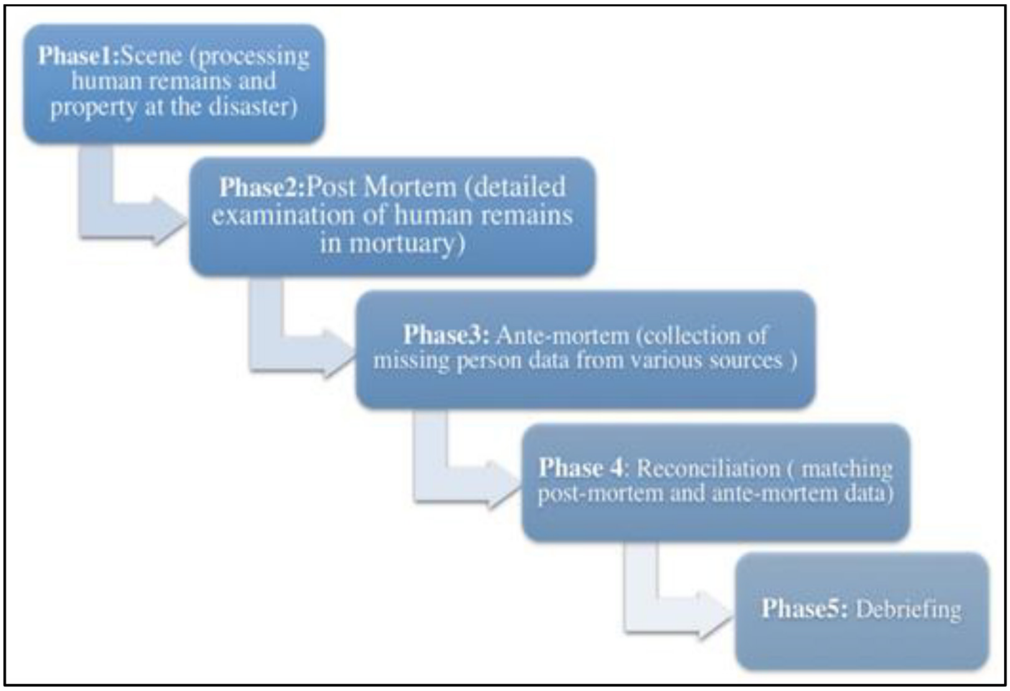

FIGURE 1 | Disaster management and victim identification phases (AlQahtani et al., 2019).

TABLE 1 | Classification of information requirements for DVI teams, type of information, and forensic specialist responsible for its collection.

Information required	Data type (AM/PM)	DVI team member
Victim's registered information (clothing, personal belongings, medical and dental information and records, fingerprints)	Both	Police/DVI team members
Basic information of the victims	AM	Police
Body description (weight, height, eye color)	Both	Police/pathologist/anthropologist
Autopsy	PM	Pathologist
DNA sample (depending on the status of the cadaver: deep muscle tissues, bones or tooth)	Both	DNA specialist/biologist/pathologists
Skeleton sketch	PM	Anthropologist
Original medical/dental record, medical practitioners and dentists consulted by missing person	AM	Police/DVI team members
Blood samples from parents/children of missing persons	AM	Biologist/pathologists

occur, and the emergency response has faced challenges. The information requirements for DVI process in multinational disaster has been classified and summarized in **Table 1**; it lists classified information and data type and maps it to the DVI team member responsible for collecting this information.

Another example is the terrorist attack Bali bombing that occurred in 2002 leaving 202 victims of 21 nationalities (Purwanti, 2013). The identification of victims in this attack was performed using 56% dental, 23% DNA, 12% fingerprints, and 9% with other circumstantial evidence. The presence of several nationalities required time for the collection of AM data. After such disasters, normally the process of identifying victims is rarely possible by visual recognition, and thus, DVI work requires an interdisciplinary approach, engaging the services of experts in various disciplines, comprising forensic pathologists, anthropologists, odontologists, radiologists, ridge logists (i.e., fingerprint specialists), and DNA experts, along with law enforcement agencies to work collaboratively toward the identification of victims (Nuzzolese and Di Vella, 2007; Senn and Weems, 2013; INTERPOL, 2018). Therefore, a mass disaster with multiple nationalities demands an interjurisdictional DVI process that involves a collaborative effort by various DVI teams, each representing the nationalities of victims involved in the disaster, especially if the hosting country is ill-equipped.

The Gap in Traditional Human Identification Technologies

Although there is a global movement toward digitization of dental practices through the adoption of Information and Communications Technology (ICT), forensic experts are still unable to access critical AM dental data needed for human identification. A unified communications and telecommunications integration would be of great benefit not only for the health system but would also enhance human identification practice. However, most existing technology solutions available today for human identification practitioners have key limitations. First, the police are faced with the significant challenge of managing missing persons lists containing years, and sometimes decades, of family AM data resources' updates. Second, there is currently no record of any holistic technical solutions for managing both AM and PM for human identification to support collaborative, multi-national, interjurisdictional DVI processes. Even though some limited PM data management solutions exist, they are fragmented and designed as discrete data silos to manage AM and PM repositories independently (Senn and Weems, 2013). Therefore, the team cannot be proactive and are left with no option but to start manually collecting AM data once a missing person is reported. Such solutions are ill-equipped to disseminate such siloed data across a firewall-protected repository system, and thus the data have to be shared offline with other forensic practitioners residing outside the controlled premises. This, however, hinders sharing, causes tremendous delays in the identification process, and puts the data at great risk of data breaches, redundancies, inconsistencies, and errors. Therefore, the aim of this article is to bridge this gap by studying the possibility of building holistic proactive blockchain-based tools that can be trusted to enhance the human identification practice as a whole. Such solutions should be effective in managing missing persons lists, AM data repositories for global living people, PM data repositories of recovered unidentified victims, and contribute to the comparison of compatible biological profiles for definitive human identification.

BUILDING TRUSTED ECOSYSTEMS FOR FORENSIC CASEWORKS USING BLOCKCHAIN

There are many types of blockchain systems in the literature, but the following granular matrix can mainly classify them into four widely deployed blockchain groups based on their accessibility and visibility (illustrated in **Figure 2**).

Although advanced technology deployment in the fields of forensic sciences is notably limited, this article is the first to date to investigate the application of blockchain in the field of forensic sciences in general and human identification in particular. According to a recent study by Al-Megren et al. (2018) in 2018, most blockchain applications beyond cryptocurrency are focused on government services, healthcare delivery, Internet of Things applications, and supply chain management. Although some preliminary blockchain-based solutions are being rolled out for managing digital identity (Al Omar et al., 2017; REUTERS, 2019) and electronic medical records (Azaria et al., 2016; Yue et al., 2016; Hou, 2017; Sullivan and Burger, 2017; Xia et al., 2017), they are designed mainly as patient-centered or citizen-centric solutions to only manage AM data of the living and not PM data of the deceased. Therefore, there is no record of any blockchain-based solutions to date for human identification.

Promising Blockchain Use Case Designs for Human Identification

Blockchain technology can address the outlined challenges by contributing to the identification of missing persons in a disaster using both AM and PM data records of both primary and secondary identifiers. This section presents the block anatomy and use case designs for four real-world scenarios that provide answers to the following 3 Ws:

- ***Who*** *are the direct users in the blockchain network?*
- ***What*** *information resources are being tracked at each of the blockchain units?*
- ***Why*** *is this blockchain use case important?*

All use case designs share the same block anatomy for each information (i.e., asset) transaction. The anatomy consists of three sections, a header, content, and signature (illustrated in **Figure 3**). First, the *Block Header* includes all common details about the blockchain use case including *Block ID* and *address* (i.e., for off-chain data storage reference), *previous block address*, *Proof-of-Work* (selected consensus protocol that best suits the use case design), and the transaction's *timestamp*. Second, the *Block Content* includes all fundamental use-case-specific information details to be tracked in the blockchain (defers from one use case to another). Finally, the *Block Signature* includes private key(s) for content decryption, and public key(s) to track it back to the block originator for integrity and ownership.

Managing Cross-Jurisdictional Disaster-Centered Missing Persons Lists

Once a person is reported missing, the police collects the victim's historic information from families and friends, including, but not limited to, finger prints, personal belongings containing DNA samples such as toothbrushes, dental x-ray images or other dental data, retainers, and photos obtained such as selfies or others showing the victim's teeth. This information is collected, tracked, and updated over decades. Normally, such information is limited to a specific local jurisdiction where the reporter lives. Therefore, it is stored in a siloed police department's information system where access is limited to the physical boundaries of the national police department perimeter. This results in fragmented lists of missing persons across multiple discrete systems that makes it extremely challenging for the police to have a holistic view to provide forensic experts with the required information in a timely manner. This would make it difficult to have victim-centered data reports or manage disaster-related victim AM data across jurisdictions. Therefore, a blockchain-based solution for global disaster-centered missing persons would be needed to help achieve this. This use case builds a distributed ledger where all victims related to a disaster who are reported missing along with their information and details are recorded in a blockchain unit with a time stamp. This ledger should be distributed among DVI members across jurisdictions so that the missing person's list can be instantly updated. Any updates related to a particular victim can be added at any time to the blockchain with the victim's unique allocated number and the new timestamp to reflect the updates. This should facilitate matching reported missing persons

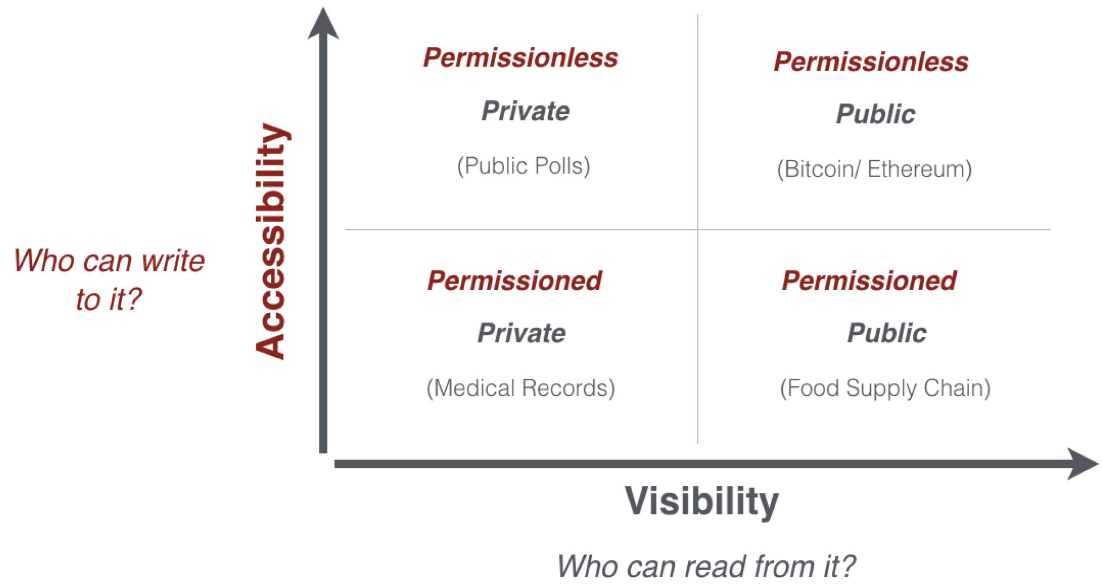

FIGURE 2 | Blockchain systems accessibility and visibility matrix.

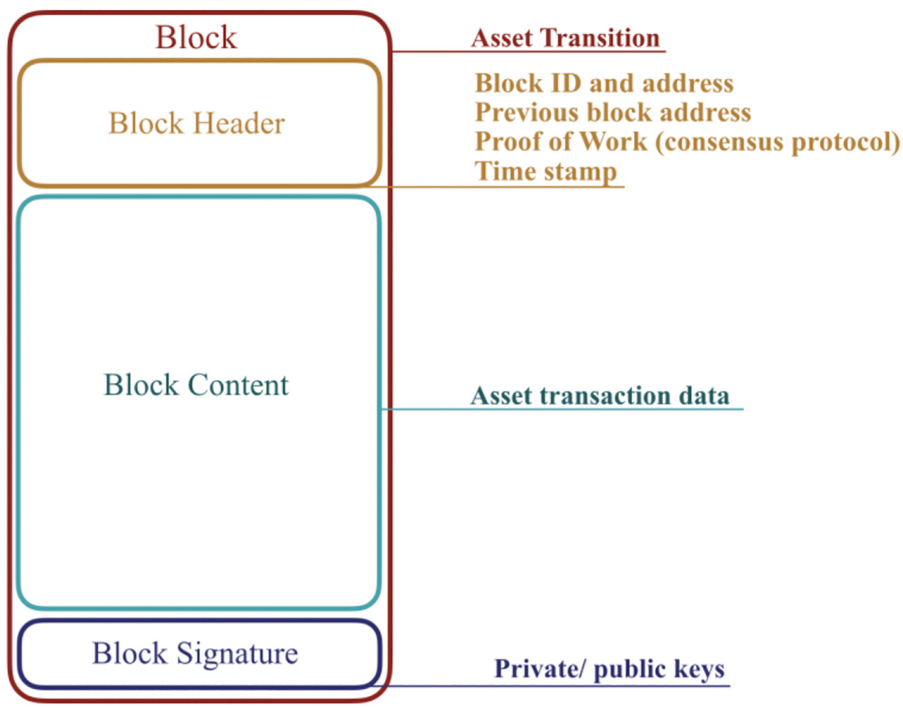

FIGURE 3 | Common block anatomy for all blockchain use case designs.

by families with authorities found missing persons to identify found victims from multiple jurisdictions.

Managing AM Data Repositories for Global Living Citizens

One of the key challenges DVI teams face is the collection of good quality AM data on their victims from their country of origin. To date, there are no proactive solutions in the literature, where AM data are only collected if a missing person is reported by someone. This hinders access to AM data in a timely manner for the DVI process. Therefore, building a universal dental data repository using blockchain can help family members and dentist practitioners globally to record AM data for the living and make it available so that distributed identification of

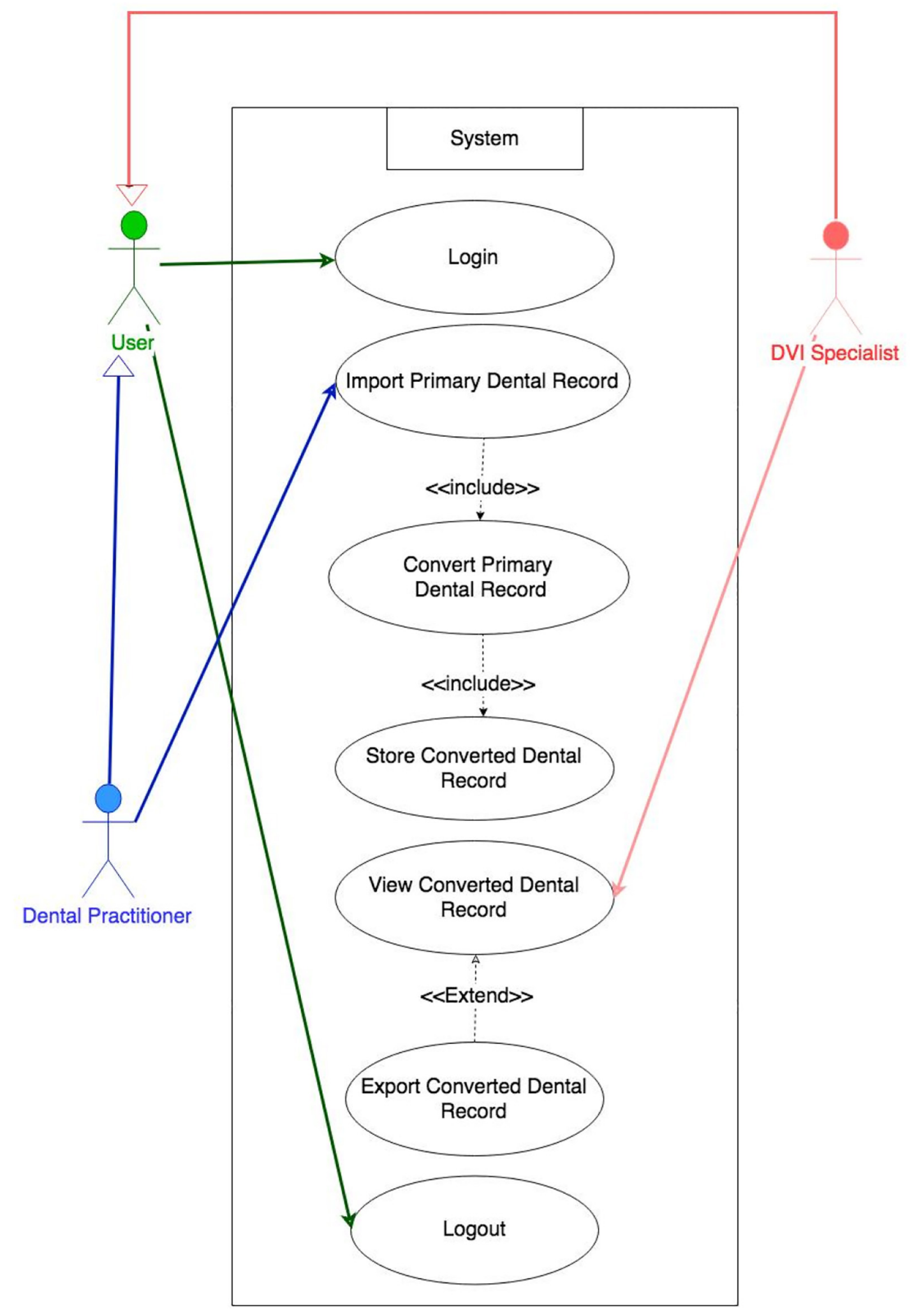

FIGURE 4 | AM data repositories for global living citizens system use case diagram (AlQahtani et al., 2019).

data can become automated, verifiable, immutable, distributed, and decentralized.

This use case has been fully designed using a mixture of UML tools [see (AlQahtani et al., 2019)]. The system Use Case Diagram, illustrated in **Figure 4**, presents the system's actors: *Dental Practitioner* and *DVI Specialist*, who both are inherent from the *User actor*.

First, both *Dentist* and *DVI Specialist* activities should be traced, and thus, should be identified in the system by logging in first. Second, the *Dental Practitioner* imports their primary dental record in XML format in the *Import Primary Dental Record* use case, which the system automatically converts into the standard code before storing it in a unified distributed ledger. Finally, the *DVI Specialist* views all converted dental records completed by the system in chronological order in the *View Converted Dental Record* use case and exports a reported missing person's AM dental record in the *Export Converted Dental Record* use case. This use case design would allow the DVI team to be more proactive and perform DVI process in a timely manner. Refer to (AlQahtani et al., 2019) for the full system design with use case activity diagrams.

Managing PM Data Repositories of Found Victims

All human remains recovered from any disaster scene are examined in a DVI center (Nuzzolese and Di Vella, 2007) where examination of the unidentified body is performed to collect PM data. Data resulting from primary identifiers are mostly well structured, whereas data resulting from secondary identifier are mostly free text, as they refer to personal belongings, tattoo patterns, jewelry, scars, and so on. Traditionally, secondary identifiers are used by DVI specialists as an adjunct information, but their significance could be enhanced through the ability to search through free text. Building a blockchain-based system that can store secondary identifiers data with a unified and structured format with metadata can help better use secondary identifiers beyond traditional practice. This would facilitate more reliable human identification, using secondary identifiers along with another primary identifier.

IDENTIFYING HUMAN REMAINS IN A DISASTER

Human remains are recovered from the disaster scene and examined in a morgue to generate PM profile. The AM data are collected from the police, analyzed by the AM team, and aggregated before the reconciliation process. A blockchain-based solution would be capable of managing both AM and PM data in one platform, and support the human identification process by comparing AM primary identifiers tracked in a time-stamped ledger, with collected PM data and recorded on the blockchain. Regardless of the matching methods, whether manually or using artificial intelligence algorithms, this should cumulate all the necessary data for DVI process in a timely manner, leaving always to the reconciliation team the final certification of a positive identification, saving time and resources. Building a blockchain would enable specific disaster details to be tracked and distributed among multiple DVI teams to help them exchange disaster-related information across multiple jurisdictions seamlessly.

DISCUSSION

This article encourages openness to attain a holistic understanding of the challenges in human identification practice, and how ill-equipped traditional solutions are to facilitate the management of missing persons' AM data resources' updates, and integrating siloed AM and PM data resources. Furthermore, this article presents a roadmap that can transform human identification practice and empower DVI teams using blockchain technology, saving valuable resources and much needed time because in all disasters, there is a huge pressure from the government and the public on the DVI team to identify all bodies quickly, while they are stretched thinly because of the low numbers of the teams and the difficulty in acquiring the AM data. This is also to meet such pressing challenges and facilitate multi-jurisdictional data information-sharing in a timely manner to find missing people and help in the grieving process of the victims' families.

This article demonstrates how blockchain technology could help build proactive global cross-jurisdictional ecosystems that would allow the DVI team to have fair speedy access to usable AM data from around the globe at the event of disasters, and be able to perform their specific tasks regardless of where the disaster took place, its type, or even the diversity of victim's nationalities. However, the adoption of such technology will not be easy and can be challenging by some DVI teams more than others. This is because it could raise data governance, and laws and regulations' compliance in relation to interjurisdictional data. This may hinder its adoption by some DVI teams owing to compliance requirements with tighter jurisdiction-specific data protection laws and regulations, which are not applicable elsewhere, such as the General Data Protection Regulation, which is considered the toughest privacy and security law applied today (GDPR.E, 2019).

Finally, this article targets a multi-disciplinary community of forensic science practitioners and health informaticians. On the one hand, forensic scientists are exposed to novel applications of an emerging technology (namely, blockchain) to transform human identification practices and possibly other areas of their work (toxicology as an example) and should stimulate them to implement such use cases in their context using the knowledge presented. On the other hand, health informaticians learn how beneficiary the deployment of emerging technologies can be to health practitioners beyond traditional ones, understanding the challenges faces by an under-represented part of science that carries a huge social and humanitarian importance and can affect whole societies and human rights greatly. The key question is: Does the roadmap presented in this paper sufficient to draw the foundations for the next generation of DVI innovative solutions for human identification practices?

CONCLUSION

Blockchain is a distributed ledger technology that is notably generating optimism as a new innovation since its conception just over a decade ago, with an increasing wave of interest in its application beyond cryptocurrency and financial applications in recent years. Traditional human identification process is tedious, costly, and can be particularly slow, although it has a huge importance in society's wellbeing and in protecting human rights. Although there are some preliminary blockchain-based solutions and other traditional forensic technologies available today for human identification practitioners, they are mostly ill-equipped to simultaneously manage AM and PM data effectively for a number of reasons. Moreover, there has been a digitization shift of dental practice processes from paper-based patient's health records to digital ones to facilitate storage and sharing (Bakshi and Trivedi, 2018). However, digital data formats are human-readable and not necessarily machine-readable. In other words, such files cannot be recorded, manipulated, and processed with computer programs alone and would require manual human interaction. Besides, traditional human identification solutions are ill-equipped to meet the challenges DVI team face. Therefore, the distinctive features of blockchain for tracking data provenance and providing an immutable distributed ledger with no single authority give this technology the potential to revolutionize the DVI process if deployed correctly to address the real-world challenges. Therefore, the promising use cases for blockchain application proposed are believed to contribute to building electronic processes that are machine-readable. This is intended to fully manage the documentation of medical and dental data in all formats (in transit and rest), using programs that would allow for comparison and data mining. The utilization of advanced and emerged technologies, including blockchain, can help achieve an automated archiving system that can preserve privacy. Furthermore, the deployment of blockchain technology in forensic human identification and DVI should revolutionize this process worldwide, improving the management of missing persons, AM data repositories of living people, PM data repositories of recovered unidentified human remains, interactions with electronic medical and dental records, and helping to facilitate the comparison of compatible biological profiles for a definitive identification. The possible applications discussed in this review promise enormous benefits to authorities, victims, their families, and society in general. It should create a trusted ecosystem to help forensic science practitioners advance beyond traditional methods and stimulate innovative collaborations with computer scientists to improve procedures, especially in the area of forensic dental identification. This opens up new interdisciplinary areas of research to promote novel solutions for blockchain technology applications and use cases in electronic medical and dental records applied within the field of human identification.

DATA AVAILABILITY STATEMENT

This is a review article without any use of datasets or generated ones.

AUTHOR CONTRIBUTIONS

SA designed the blockchain use cases from the computer science perspective focusing on the solution, while EN contributed to the blockchain designs from the subject-matter expertise perspective, and focusing on the implication of the solution. Both authors contributed to the conceptualization and writing of this article.

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