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Revolutionary Dentistry through Blockchain Technology

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Abstract: Multitudinous health data are continually being produced as our activities, including medicine, evolve into the digital age where data plays a decisive role. Challenges come along as well, concerning the collection, secure storage, verification and secure access to the continuously growing data at such a broad scale before valuable information can be extracted to contribute to medical advancement nowadays. With the decentralization feature, huge successes of blockchain technology in overcoming similar challenges in the finance and cryptocurrency sector brought us the confidence to investigate and reveal its immeasurable potential for the health sector, specifically in dentistry. Dentistry is an important area of healthcare, but there is relatively little research focusing on its interactions with blockchain technology. Given the limited amount of existing research on this specific subject, this paper focuses on blockchain in dentistry and aims to provide a conceptual framework for the possible applications of blockchain in dentistry. The framework is organised by different areas of dentistry operations so that dental professionals can easily refer to and identify areas of interest. This contributes to increasing the awareness of blockchain technology among dental professionals and promoting blockchain-empowered revolutions in dentistry. This paper also discusses how blockchain fits alongside other emerging technologies, the challenges that have to be overcome to maximise the functionality and efficiency of this technology, as well as future research directions concerning blockchain implementations in the dental industry.

Keywords: blockchain; dentistry; big data; AI

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1. Introduction

The ongoing human endeavour to shape and utilise a more innovative world, which has resulted in interminably increasing advancements in all kinds of technologies, will, of course, have profound modifying impacts on various healthcare fields, including dentistry, undoubtedly maximising efficiency in this sector [1]. Technology's infiltration into healthcare generally provides a more enabling environment for education and knowledge exchange, as well as promotes personalised healthcare information based on the needs of the individual patient [2]. Moreover, there are more areas of data utilisation in healthcare that also benefit significantly from the fast-expanding digitalisation process, including but not limited to assessing prognoses, revealing diseases' hidden correlations, supporting ingenious treatment concepts, population-based clinical research and health assessments, as well as reviewing the whole healthcare system [3].

One powerful component that drives the crucial need for ongoing technological advancements in healthcare is the increasing volume of healthcare data [4]. Besides the increasing use of intelligent medical devices at home by patients, more patient-generated health data will be produced over time, i.e., measuring their vital signs and blood glucose [5] using thermometers and smart weight scales, INR meters and pulse oximeters, which are mostly simply purchased over-the-counter at pharmacies or via online platforms

for smart healthcare devices [6]. As a result of these continuous advancements in medical digitalisation, more diverse types of data are generated in ever greater quantities and put into service. Successful blockchain technology in the finance sector, quickly expands its playfield into other non-financial sectors due to its revolutionary decentralisation functionalities. Healthcare, with its data-rich environment and relatively established network of Internet of Things (IoTs) in general [3], offers numerous opportunities for the fast deployment of blockchain. Existing studies mainly focused on healthcare data management, secure and anonymous clinical trials [7], remote patient monitoring, etc, as these represent the most concerning difficulties for healthcare in the transitional digitalisation process. For instance, conventional paper health records seem to lack efficiency and may also be questionable or cause failure in clinical operations of the digital age [8]. Centralised IT systems presently employed in healthcare institutions also make it challenging to manage, exchange and retrieve medical data properly [9]. Those difficulties have made it extremely challenging to prepare comprehensive patient data and further enhance healthcare as well as medical research quality.

Although current literature about blockchain in healthcare is relatively established, there are very limited studies in dentistry. We used the keyword of "blockchain" AND "dentistry" OR "dental" to search for relevant research literature using the Google Scholar database. The manual screening was performed to exclude irrelevant materials, and it was revealed that only a few examples (which only focus on blockchain in dentistry rather than general healthcare) were found from reliable academic resources, including artificial intelligence (AI) toothbrushes [1], studies in oral and maxillofacial radiology, patients' digital health records, industry-specific cryptocurrency Dentacoin as well as dental care service applications. The data-rich dentistry industry also has a relatively established IoT network formed by various smart devices [3], which indicates dentistry is an under-researched but rewarding field for blockchain technology implementation. Moreover, dental professionals are not yet familiar with this technology, so it is also a crucial need to further increase the technological awareness of blockchain in dentistry via more research collaborations. Therefore, to fill in this emerging research gap and bring a positive change to the status of limited research and limited attention to blockchain in dentistry, this paper aims to serve such a purpose by only focusing on blockchain in dentistry and providing a timely conceptual study of presenting the possible applications of blockchain in dentistry. This contributes a more recent trajectory of blockchain in dentistry to the limited existing literature. Not only do we reflect on the limited existing studies, but more possible applications are also summarised based on bridging the needs of dentistry and our continuous research in big data, blockchain as well as other relevant technological advancements and their interactions with other sectors. These applications are also organised by different dental practice operations so that dental professionals can easily refer to their area of interest. It is also expected that this conceptual framework can keep improving and expanding further by attracting more attention to dentistry and inspiring more future research collaborations.

For the convenient reference of interested readers and dental professionals, the contributions of this study are summarised as follows:

- This paper contributes to the blockchain, dentistry as well as the general healthcare literature via providing a timely and more recent trajectory of blockchain in dentistry, an under-researched but data-rich and rewarding field;
- This paper fills in the research gap of blockchain in dentistry, brings a positive influence on the status of limited research and limited attention to blockchain in dentistry, and increases the awareness of blockchain technology among dental professionals;
- This paper outlines the vision for applying blockchain in dentistry by interpreting the role of blockchain in different dental practice operations so that dental professionals can easily refer to their area of interest;

- This paper identifies and discusses the challenges of implementing blockchain in dentistry and also provides insights on future research directions in the field of blockchain in dentistry.

The remainder of the paper is organised as follows: Section 2 clarifies the theoretical background, including a brief description of blockchain and an overview of blockchain in healthcare; Section 3 presents the conceptual framework of possible applications of blockchain technology in dentistry; existing challenges and concerns are discussed in Section 4; finally, Section 5 concludes insights emerging from the research and avenues for future research.

2. Theoretical Review

2.1. A Brief Description of Blockchain

Blockchain technology was first introduced by Satoshi Nakamoto [10,11], primarily famous as the basis of bitcoin [12]. Although the main application of blockchain is known to be in the field of finance [13], it has further expanded to other industries dealing with vast amounts of data [14]. A blockchain is used as a database that preserves information for a decentralised network [15], and it does not require any third-party validation; instead, all information stored in the nodes is immutable and unable to be modified or erased without the permission of all trusted miners [8]. All the transactions validated by users are traceable [16], and no third party will be directing these data and transactions [12]. This feature of blockchain is paramount for medical cases, as all patients' data are kept incorruptible, private and secure, and there is a transparent log of how and when healthcare providers access those data [17]. Blockchain is a distributed ledger technology (DLT) that has non-mutable, tamper-proof properties assuring integrity [18] and is used in a synchronized, shared environment [16]. Blockchain allows peer-to-peer transactions or data exchange between two particular parties [19]. Record validation in blockchain relies on cryptographic proof, and this cryptographic validation is conducted collectively by a network of users following a set of predefined rules. As a result, the database is ensured to contain only one authentic version of events, which cannot be altered without majority approval. A hash is used to lock each set of records in the database (called a 'block') to the previous blocks so that when one block is changed, all consecutive blocks are also modified [8]. The following are the spectacular characteristics of blockchain technology:

Decentralization: Blockchain technology does not require any third-party validation, enabling each node to have an equal value of votes in the network; benefiting from a decentralised network of computing nodes, blockchains are immune from failures or attacks.

Persistency and security: All data and transactions stored in the nodes are immutable and unable to be modified or erased without the permission of all trusted miners.

Anonymity: Replacing names with unique IDs makes it possible for all users of the system to have access to all data without risking their real identities being exposed. This will overcome ethical and legal issues.

Auditability: Each transaction within the blockchain has a reference point; the transactions are also imprinted into the blockchain's nodes. The reference points enable each enacted transaction to be traced. Any changes made in the information in one block are stored in a new block with precise details of the changes, date, time, etc, rather than rewriting the data in the main block [11,15].

2.2. Overview of Blockchain in Healthcare

The dynamic between healthcare professionals and patients is inevitably transforming through the advancements of technologies and dramatically improved access to information. Medical treatment has evolved from a one-way practice led by healthcare professionals to a cooperative activity between them and the patients [5], which stays in line with the emerging trend of a more patient-centred healthcare system [8]. Patients are beginning to generate tremendous amounts of information alongside routine clinical examinations and treatments. The information is primarily unattainable, unstandardised and difficult to use

and share [9,10,20], not to mention concerns over data security and accuracy. Therefore, the traditional means of gathering patients' health data is no longer efficient, and the successes of blockchain technology in finance further promoted its expansion to other non-financial fields, among which healthcare is one of the significant areas with use cases springing up. There is a well-established collection of existing systematic review articles focusing on blockchain applications in healthcare, so a brief list of recommendations is summarised below for interested readers and the same reviewing contents will not be reproduced here. To reveal the progress status of blockchain implementations in healthcare, a systematic mapping study process was followed by Agbo et al. (2019) [21] and seven strands of application areas (i.e., remote patient monitoring, electronic medical record, drug supply chain, etc,) were identified and supported by relevant use cases. A recent review paper by Hussien et al. (2021) [22] grouped those interactive use cases into telecare medical information systems and E-health systems, while comprehensive bibliometric analysis, keyword research and citation distribution analysis were conducted. There are also review articles specifically focused on one area of interaction, for instance, electronic healthcare record systems [23] or articles addressing the readiness assessment of blockchain applications in healthcare [24]. Use cases were grouped by healthcare issues as well as blockchain characteristics in [25,26], and a well-summarised map of healthcare problems and blockchain opportunities can be found in [27]. A list of start-up companies offering blockchain healthcare solutions can be found in [28]. Interested readers on blockchain-enabled functionalities or more technical features of the blockchain platform and its architecture for healthcare can refer to [29,30].

3. Blockchain in Dentistry

Existing difficulties for healthcare in the transitional digitalisation process are no exception for dentistry, i.e., it also has the crucial need for a more efficient and secure approach to gathering, maintaining, handling, storing and transferring patients' health data generated by various devices and platforms. As was mentioned in Section 2.1 above, a blockchain serves as a database that preserves information for a decentralised network, and it does not require any third-party validation; instead, all information stored in the nodes is immutable and unable to be modified or erased without the permission of all trusted miners [8]. These important blockchain properties distinguish its significance and suitability in dentistry rather than traditional or cloud data storage. With a blockchain, all data sharing and transactions are traceable and validated by the network, and no third party will be directing these data and transactions. For dentistry as well as the general healthcare sector with significant data ownership, privacy and security concerns, as all patients' data are now kept incorruptible, private and secure, and there is a transparent log of how and when healthcare providers access those data, implementing blockchain in dentistry could overcome many existing difficulties and promote more future advancements. For instance, it can be utilised to balance the privacy and accessibility of electronic health records (EHRs) [31]; a blockchain has the capability of making healthcare-related data even more secure and transparent than today [17]. However, it is of note that only a few studies have been conducted on its potential uses, and dental professionals are not yet familiar with this technology. The dentistry industry has a data-rich environment and a relatively established Internet of Things (IoT) network formed by various smart devices [3]. This makes dentistry an under-researched but rewarding playfield for blockchain technology implementation, which could lead to significant impacts on dentistry as well as other overlooked healthcare fields in general.

Given the very limited amount of research in this specific field, this paper aims to present a conceptual study on the possible applications of blockchain in dentistry, the framework of blockchain in dentistry can be found in Figure 1, and more details for each strand can be found in the following subsections. The framework is organised by different areas of dentistry operations so that dental professionals can easily refer to and identify areas of interest. This is also in line with one of our key objectives regarding increasing the awareness of blockchain technology among dental professionals.

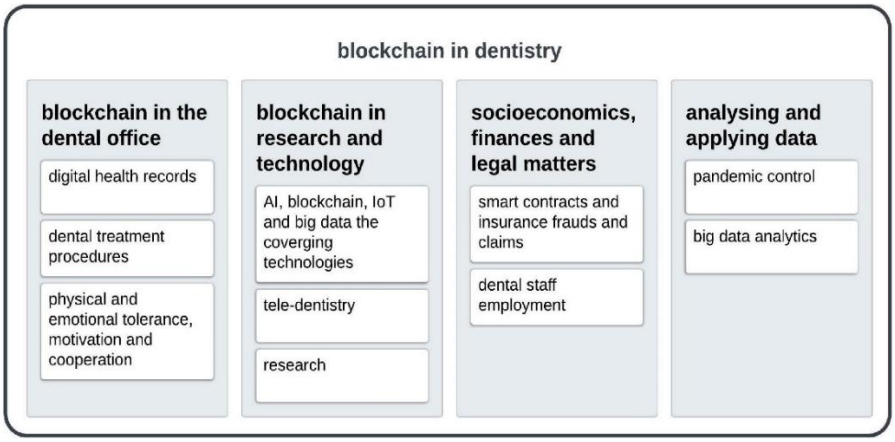

Figure 1. Blockchain in dentistry.

It is of note that this framework is not a product of reviewing the existing blockchain in dentistry literature due to the amount of research being very limited and not all possible areas of applications being identified. Following the guidelines of a conceptual study, which could bridge existing theories, link work across disciplines, provide multi-level insights and broaden the scope of our thinking, the following sessions and possible applications are summarised based on bridging the specific needs of dentistry to relevant blockchain properties, the current strands of the framework are grouped based on the existing literature of blockchain in healthcare [25–27], our coauthors' knowledge and day to day work experience as dental professionals, as well as our continuous research in big data, blockchain as well as other relevant technological advancements and their interactions with other sectors.

With regard to the completeness and maturity of this framework, to the best of our knowledge, this is the first framework of blockchain in dentistry, organised by different dentistry operations for the convenient reference of dental professionals, it is also acknowledged that this conceptual framework is only at the very beginning stage of development, and it can keep improving and expanding further, as the areas of applications are continuously growing along with fast-advancing technologies. A more technical note regarding the type of blockchain we are referring to while proposing the possible blockchain applications in dentistry in the following subsections, it is consortium blockchain considering its popularity for general healthcare data relevant applications.

3.1. Blockchain in the Dental Office

3.1.1. Patients' Digital Health Records

In the event that patients are to see multiple dentists, they may undergo many repetitious dental examination procedures [32]. They may need to fill out forms repeatedly describing their entire medical and dental information over and over again; hence patients may sometimes fail to remember every medication they have been taking. They may also find some of their underlying diseases inconsequential or refuse to mention them. They may also need unnecessary dental X-rays, which may cause them to be exposed to radiation several times.

Additionally, filling out dental records and observing and writing down every patient's exact condition, including oral, dental, etc, can be a long and challenging issue for dentists, leading to ineffective consultations and prolonged treatment sessions. There is also a possibility for patients who are referred from one dentist to another to be misdiagnosed [31]. Blockchain technology made it possible to minimize dental session time, decrease trouble for both parties and make it possible to deliver dental service with more cognizance and attention.

Furthermore, patients' EHRs collect information from their medical history, medication orders, vital signs, laboratory test results and radiography. Findings, physician and nurses'

notes, routine dental session observations and all other sources as IoT [33,34]. On the other hand, EMRs (electronic medical records) are essential pieces of highly sensitive personal information in healthcare that need to frequently be handed over among healthcare colleagues. Blockchain provides trust, accountability and transparency to EMRs and EHRs and makes them immutable and transparent history [35].

3.1.2. Dental Treatment Procedures

Blockchain technology and IoT made it possible to store essential dental data for further usage whilst privacy and security of information can be ensured, and the disease outlook can be stored safely [36]. Gradually by moving towards personalised patient care, the individual dental prognosis will be assessed more precisely by knowing their exact indicators (such as cleaning abilities, cavities or endodontic or cancerous lesions developing rate, teeth anatomy and maybe even their oral bacterial flora, the clinicians will have massive support in decision making, prevention and therapy [20]). Another perspective on blockchain features is that dentists must enter and describe the whole treatment procedure they have performed with all the details, including diagnosis, clinical findings, decision making, materials used and the treatment process in the blockchain system; hence each dentist is fully responsible for their performance.

Since patients have access to their treatment information, the probability of errors or negligence in the treatment process by the therapist could be significantly reduced. On the other hand, due to the existence of all treatment documentation and the impossibility of manipulating them without the agreement of both parties, this could prevent unnecessary and unfair lawsuits by the patient against the healthcare provider [20,37]. Drug prescriptions will also be modified since prescribers are provided with the whole history of the set of drugs that patients are currently taking, have taken in the past and the drugs to which they may be allergic. The decision-making process during patient examination is affected by this information; since medications can interfere with laboratory tests, the physician will also be illuminated to prescribe the proper additional medicines for the patient if necessary [38]. Currently, due to a lack of an intelligent approach to history taking, we are facing drug administration system medication errors, sometimes patients' inability to recall every drug they are taking or have self-administered may cause adverse drug effects.

We can also benefit from the combination of AI devices, such as 3D scanners with blockchain technology abilities in prosthodontics, i.e., producing exact fit dentures [36]. By keeping the scans and measurements of a patient's previous prosthesis, such as complete dentures, single crowns, bridges, etc. As an example, in case the patient has lost or broken their previous denture, it can help construct a new denture more efficiently, saving a greater deal of time, since usually fabricating any prosthesis requires multiple dental sessions. On the other hand, we can always keep records from the alveolar ridge and observe physiologic or pathologic changes in its shape due to using incompatible dental crowns or ill-fit dentures to modify the prosthesis and prevent more severe injuries to the alveolar bone.

3.1.3. Patients' Physical and Emotional Tolerance, Motivation and Cooperation

For most dental treatments to be perfectly effective a major factor is patients' participation in regular recall sessions, which should occur every 3 month and 2 year intervals based on patients' oral condition, annual checkups also have a great role in maintaining oral health generally, preventing oral disease and diagnosing pathologies as soon as possible. A common obstacle that many patients are dealing with is dental anxiety, causing patients to neglect their appointments while growing more ill with oral diseases [39]. Inputting patients with more specific information, including their cooperation during the treatment procedure and their ability to physically and psychologically tolerate the stress involved with the planned treatment, and inscribing the precise date of each recall session they have attended by the dentist, in addition to registering patient's motivation for maintaining a good oral hygiene by monitoring the quality of brushing and the number of brushings per

day using AI brushes decked with an AI system built into them; the brush connects to a phone application easily via Bluetooth [1]. Combining these AI tools with blockchain technology, a complete set of information about patients brushing time, frequency, adequacy or inefficiency can be easily secured and tracked. The patients' nutritional habits can also be monitored using potential mobile applications. This would not only facilitate online consults for anxious patients who strongly refuse their dental visits but also provides really helpful information for these patients' future dentists to choose the most practical way of managing patients mentally and physically, i.e., having a good understanding of how to deal with anxious patients, to assess the need for treatment modifications so that the patient will be able to cope with the stress of planned treatment, to determine which sedation technique is best, being prepared with the proper type of pharmacosedative techniques while being able to calm patients with conversational techniques [40]. Patients' pain control will become much easier as a result of a better connection between healthcare provider and patient as well. With a blockchain, we can keep this information in secure, anonymous clouds, enabling patients to protect their data and access their records on demand [41], patients' trusted dentist can access their information before upcoming sessions, and unlike conventional methods, the information is also easily transmittable from any dental office to another by the means of blockchain.

3.2. Blockchain in Research and Technology

3.2.1. AI, Blockchain, IoT and Big Data the Converging Technologies

The incorporations of technological trends into healthcare, namely, information technology, nano-medicine, biotech, IoT, AI, augmented intelligence, social media, blockchain, personalised medicine, EHRs, wearable devices, etc, are improving healthcare outcomes as a result of combining diagnosis and treatment [42]. Today, businesses rely heavily on data. Big data is being utilised in almost every sector, including healthcare [43].

Douglas Laney came up with the most widely accepted definition of big data. He suggests that big data extends in three measures, volume, variety and velocity, which indicates the data collection and preparation for future processes [42]. Analysis of large data sets containing a variety of data types could help reveal hidden patterns, unknown correlations, etc. Similarly, healthcare providers' functional ability, customer service and advertising possibilities will increase due to the usage of the analytic findings from health data [19,43].

Through machine learning algorithms, computers are enabled to learn and improve independently with no need for direct programming; hence machines are becoming capable of making wise decisions to reason and solve problems. These high-tech computing algorithms are capable of interpreting and comprehending innumerable complex health data collected from records and wearable medical devices, monitoring and recording patients' state of health continuously. The gathered data can be deployed in various fields, including preventing or diagnosing diseases, designing innovative treatment procedures, health records processing and so forth [42,44]. Another technological tool, IoT, plays an important role and has a wide range of benefits in medicine, such as tracking data, enhancing medication management and rapid interventions [45]. These three advancing technologies IoT, blockchain and AI, work closely together and create a rapidly expanding enabling environment for data-rich sectors such as healthcare. Security and clarity are provided by the blockchain. Moreover, decentralizing healthcare interactions, integrity, credibility and controlling access are presented by blockchain technology. Moreover, new value-based care and payment strategy may also emerge. AI and IoT shape the smart and intelligent part of the application. The decision making and analyzing capabilities are linked with AI, while IoT ensures the connection, adaption and efficacy of the system. Furthermore, AI and blockchain can accelerate modifications and promote revolutionary changes in various industries.

Blockchain technology combined with IoT, AI and machine learning opens up new possibilities for digital health economies [19]. Combining these technologies, our communications will face a shift from people to devices progressively. The goal is to deliver reliable

data at the right place and form in real-time. Tracking tons of IoT-connected devices and synchronizing them, blockchain allows transactions to be processed, eradicates failures, and builds a flexible framework to run physical stuff on. The secure nature will guarantee the trust and privacy of data, expenses will be minimized due to the exclusion of third parties and one-to-one interactions and the time required reduces from days to seconds [46].

3.2.2. Tele-Dentistry

The arrival of IoMT (Internet of Medical Things)-based technologies revolutionised the old healthcare system into a new, smart and personalised one. One of IoMTs several applications is tele-dentistry; it is a nascent concept that integrates telecommunications in dentistry through networking and exchanging digital information by the use of phones, photos and videos, analysis of clinical information and image from remote distances and distant consultations to provide oral healthcare and education services [47]. Thanks to tele-dentistry, patients will find a satisfactory way to maintain self-care, in addition to fewer office visits and saving time. Tele-dentistry will make a positive impact on the elderly population, which is growing in number since the mean age has increased recently, especially for those who suffer from the limited ability to move, special care patients and people in remote areas who do not have access to medical centres.

Tele-dentists can also provide efficient dental care for emergencies, such as trauma, which requires prompt intervention even outside of working hours [3]. Considering the challenges for patients to give their whole information to the online counsellor dentist in a short period of time while on a phone call or online consultation for remote diagnoses and operations, the sensitive nature of patient data makes security, scalability and privacy of data among the most important requirements for establishing successful clinical communications involving remote patients [48]. By securely providing all patients' previous dental and medical information in an instant, blockchain technology makes it possible and much easier for the dentist to give accurate advice online, considering all aspects of the patient's health situation.

3.2.3. Research

Nowadays' the digitally expanding world has enabled a large amount of health data and patient-generated data to be accumulated. Health data may be used for clinical trials or other research programs or shared among healthcare providers during the referral process. Therefore, managing health data effectively requires more than just ensuring integrity when it is collected and stored but also streamlines interoperability by addressing quick access and filtering options through user-friendly applications [3].

Information gathered by patients, dentists, statisticians, organisations and committees should circulate smoothly among all parties to maximise research outcomes, blockchain technology accelerates and secure these study processes [14,49]. Applying blockchain technology could make a huge upturn in the research field by transferring health data authority from clinics and corporations to patients and people who are directly engaged with this information [49].

Embracing blockchain technology provides the possibility to securely exchange data. It enables patients to directly upload their data to the system without having to share sensitive data and explicitly authorizes the purchased data to be used. For instance, patients can receive benefits and payouts, access privileges and sell their data to consumers (i.e., researchers) for the standard value using data value model-based transparent pricing [14,49,50]. Patients also have the choice to provide researchers with temporary access to only certain parts of their data [42]. By screening patients for prospective clinical studies and filtering patients according to trial-specific inclusion criteria, high-quality clinical trials can be conducted more quickly with a larger sample size. Researchers can also benefit significantly by choosing the most efficacious set of data to work on, in addition to having access to previous data for possible future uses [3]. Meanwhile, some researchers are actively seeking new treatments and techniques by reviewing archival medical records [51].

Without demographic databases, studying rare diseases for future diagnostic approaches and treatment planning is nearly impossible. By providing more secure data sharing, blockchain technology appears to be ideal for optimising the collection and preservation of population-based rare disease records [52]. Patients can pseudonymously offer their unusual or understudied disorder data to be investigated. Thus, the research could better involve those who lack trust in research organisations and are less willing to corporate or remain unnoticed in research due to a lack of accessibility or facilities [7]. Furthermore, since blockchain technology-empowered transactions are subject to cryptographic validation, data integrity and veracity are accredited, and malicious manipulations are prevented. All transactions are traceable being timestamped, a public record of all data is also maintained by each user and finally, it is possible to verify the validity, existence and integrity of data with the double key system, while not compromising clinical information privacy [14].

3.3. Socioeconomics, Finances and Legal Matters

3.3.1. Smart Contracts and Insurance Frauds and Claims

Globally billions of healthcare transactions are conducted each year, raising concerns about the safety and security of healthcare platforms designed to protect patients' records privacy. Meanwhile, even though health insurances protect citizens' belongings, the number of frauds committed within the healthcare system continues to rise [53]. By allowing transparency in transactions, building a trusted blockchain can help insurance companies in terms of increasing the efficiency of claims processing by combining inputs from various sources without any information being altered.

Using a blockchain as a reliable medical insurance data storage provides users with high authenticity, being capable of ensuring the originality and provability of data [9]. One of the most common healthcare frauds is the leak of patients' personal information and exploiting patients by forcing them into false cases or fake scenarios. These have cost billions for insurance companies by filing out illegal claims for scam therapies, lab tests, surgeries and forged medicine from pharmacies, not to mention the significant loss of government revenue, patients themselves, healthcare providers and pharmacies at the same time. Employing traditional systems, the evaluation of the total loss or recoverable amounts is still difficult, even after the fraud has been detected. As the number of illegally processed health insurance claims is growing exponentially, blockchain-empowered fraud inspections could be more straightforward, resulting in a clearer context. Blockchain enables patients to take ownership and access their health data without being concerned about fraud by cryptographically securing patients' information [53].

Another term related to legal medicine is a blockchain-based feature called a smart contract, a self-executing, smart agreement between contract correspondents that are transcribed directly into lines of computer-coded algorithms. Smart contracts are defined as a series of computerised protocols that simplify, affirm or enhance negotiation processes and operate across a distributed, decentralised blockchain network providing secure, efficient transfer of health data with an emphasis on privacy matters. Eliminating third parties while enhancing traceability and security by the use of blockchain smart contracts, an efficient value-based payment system is formed, reducing mistrust between health providers and patients. Smart contracts can also enhance fraud detection while reducing administrative expenses [9,14,53]. Furthermore, as medical records will be protected, governed by privacy regulations and cannot be kept indefinitely, litigations caused by leaking information do not justify hospitals providing information to third parties, and the government will inspect healthcare documents for illegal practices [51].

3.3.2. Dental Staff Employment

Any industry willing to obtain continuous growth requires an upgrading set of skills that brings in proficiency and creativity, especially in the digital era [54]. By means of cryptographic protocols, dental providers' expertise and skillfulness information could be noted and shared via blockchain.

The hiring process will be simplified as the credentials of dental staff are logged by trusted dental institutions and healthcare organisations [18]. The present process of gaining authority to be a dental workforce, whether as a dentist, dental assistant or engaging in any other possible career path, requires a detailed application with full information of previous jobs and experiences the applicant had in any institution, office or clinic they have ever worked for. It may be a toilsome task taking much time for additional working hours for an employee to trace the applicant's credentials [55]. By developing a blockchain with a concise and validated version of public records of specific healthcare professionals' training, knowledge, outcomes and behaviours, the information asymmetry will be eliminated. A third-party credential guarantor would not be necessary as the information mentioned above is transparent and accessible to patients, employers and stakeholders.

Not only that healthcare organisation will be able to acquire credentials more quickly, but the public, as well as employers, will also have the ability to engage directly in a faster and more efficient manner. It will also offer medical institutions' insurance and healthcare providers the opportunity to take advantage of current and previous employees' credentials [18,55].

3.4. Analysing and Applying Data

3.4.1. Pandemic Control

The dental industry could be negatively affected by the outbreak of airborne viruses spreading through the respiratory tract or body secretions. COVID-19, for example, is transmitted through sneezing, coughing and breathing non-infected people can be afflicted with the inhalation of droplets and aerosols created by infected people. Due to the extensive aerosols created during dental treatment, particularly during the use of high-speed drills, ultrasonic scalers and air/water syringes, dental personnel are at a greater risk [56]. It is becoming increasingly important to analyse the health outcomes of large groups of people to eliminate widespread diseases and promote good health. Public healthcare manoeuvres could be greatly enhanced by the use of blockchain technology.

The blockchain facilitates profound intuition into health trends by utilising distributed ledger technology to foster an alliance between various stakeholders involved [9]. It could promote advancements in transactions between different platforms of the healthcare organisation, such as pharmaceutical requirements, hospital databases and supply chain logistics. Research and treatment can also be accelerated by blockchain technologies, as the centralised control over patient data are reduced.

The integration of blockchain and AI benefits pandemic management in many ways; for example, in order to monitor, detect and predict the spread of this virus, an AI-powered platform can be developed. In addition to estimating the number of COVID-19-positive cases and death cases in any region, AI will also assist in determining which countries, regions, and people are most virus-exposed so that the appropriate preventive measures can be taken in advance. Moreover, as a result of AI, a new and cost-effective diagnosis system is developed, for instance, using machine learning and deep learning algorithms for facial recognition [41]. Rao and Vazquez [57] provide a tool based on an AI algorithm to quickly detect infected cases measure and assess risk based on symptoms and indicators related to the new coronavirus via a simple mobile-based or web-based survey. This algorithm can send alerts to clinics or remote medical units and request health examinations or case confirmation according to the answers received [18]. Globally, health professionals are urged to screen quickly, forecast and trace contacts, and develop drugs and vaccines to prevent the spread of the pandemic. Patient-centred approaches based on blockchain and AI would enable personalised healthcare services for patients and healthy individuals [41].

3.4.2. Big Data Analytics

Combining discrete pieces of data into big data models renders the most reliable results, especially in subpopulation variations, which are not evident in small samples. Our diagnostic resources are enhanced under the use of AI; as a result, we will be able to extract more information than we are normally able to from the data acquired for a certain

clinical condition [43]. Identifying patients' likelihood of tooth loss based on precautionary elements such as oral hygiene, caries prevalence and treatment options, combined with the capability of computer-aided radiography that can detect cavities, pulp lesions, etc, as well as considering various socio-medical factors based on big data analytics, allows personalised teeth prognostications [20]. With the use of big data in dentistry, expenditures on dental appointments can fall, risk factors for conditions will become less prevalent, and pharmaceutical effectiveness can be evaluated [42]. A blockchain-based health record database aims to offer healthcare providers a specific, consistent resource used in patient care. Thanks to its capacity to ensure correctness, blockchain technology can feed data into AI systems in addition to extracting results produced by them [43].

4. Challenges

Deploying blockchain in healthcare has shown a promising future as evidenced by its numerous advantages whilst it is not without challenges [49], and dentistry, as an important field of healthcare, also faces these challenges.

Firstly, there is no proper blockchain foundation for healthcare currently, not to mention scaling blockchain applications in practice. A key problem is that no apparent stakeholder seems eager enough to establish one. It is likely to implant a health data documenting system based entirely on blockchain but not performable any time soon. Utilising a blockchain-based patient health record coupled with an existing health data system is a more realistic scheme [58]; the system must be rebuilt, new staff should be educated and employed, and directors may be convinced that blockchain technology is worth the financial investment, to bolster system improvement, health-based startups are mainly in charge in the near term [43].

Additionally, blockchain's reliability depends intensely on its users; for instance, submitting low-quality or invalid data to the chain by users will make a huge bias since the false information stays on the chain. From another point of view by building a patient-centred system in which patients are completely in control of their data, yet not knowing what to do with it or still delegating the management of their data to a third party, it is likely that a management system based on trust is not attainable anymore [59]. We cannot expect blockchain technology to be the ultimate solution for all healthcare sector obstacles, but it holds great promise for significant cost savings by eliminating unnecessary partakers throughout the medical procedure [43].

Blockchain also has its limitation in scalability as the decentralised network grows along with the amount of data being processed, validations by members of the network may inevitably encounter latency of processing, which is also closely associated with its growing concern of energy sustainability for maintaining this decentralised network. However, it is of note that the current centralised infrastructure (relying on third-party authorisations and validations) was not built in one day, not to mention the overall costs of forming and maintaining the current centralised systems. Altogether, these costs should be considered when a fair comparison is considered between blockchain-based infrastructure and the current dominant centralized infrastructure.

The successful comprehensive implementation of a blockchain-based network could replace the entire current, centralised infrastructure, and the fusion of big data and blockchain has obvious advantages. Researchers have been continuously making progress in overcoming the scalability and energy efficiency challenges of blockchain. However, the biggest obstacle to promoting further advancements on a large scale, and eventually a comprehensive implementation of blockchain, is still the existing centralised infrastructure, which plays a dominant role and may not be interested in being replaced.

A major research challenge to focus on is how blockchain works with AI and IoMTs intricate and heterogeneous communication and analytic scheme. Since there will be different data access control protocols for communication networks used by the IoMT delivery program held by different service providers, blockchain's mechanisms will need to be modified to promote a single global access policy for the entire network. A coherence

mechanism is further required to discern the order in which blocks are added because the network is composed of distant nodes and computers [45].

5. Conclusions and Future Research

As a successful and powerful foundational technology with revolutionary functionalities, whilst facing critical challenges, blockchain is only starting to make its way into the dental industry and is still at an early stage [43,49]. Among the limited research in this specific field of application, studies have been conducted in oral and maxillofacial radiology [20], patients' digital health records [3], Dentacoin, an industry-specific currency [59], as well as dental care service application [60]. Although the current trajectory indicates blockchain is not yet commonly used and well-acknowledged by dental professionals, it is predicted that in the next 5–10 years, we will see the penetration of blockchain in healthcare systems, and significant impacts will be soon revealed in data sharing between independent clinicians and researchers, smart medication prescriptions and financial matters [43]. Personalised medicine will be possible, via a safe, decentralised and high-speed platform for managing health data, as well as increasing efficiency through its interaction with technologies such as AI, big data and machine learning, etc. Blockchain can increase the speed and quality of these technologies' capabilities; meanwhile, these technologies can be a tool for injecting data into the blockchain too. This conceptual framework proposed by this paper can keep improving and expanding further as the areas of applications are continuously growing along with fast-advancing technologies.

The role of blockchain in dentistry has received very little attention [9], and even its immeasurable potential is obvious, just as its implementations in general healthcare, dentistry seems to be more hesitant than others to embrace digitalisation. Independent dental clinics and dental professionals, most likely independent business owners, would need sufficient financial viability, robust trustworthy platforms with successful examples, collaborative channels, reliable and efficient technical support, as well as the industry-wide commitment to standards and security aspects [26,61] to overcome their hesitation and start to make real progress in ultimately transforming the efficiency of the dental system through blockchain services.

Sectors that embraced blockchain in its early stage can serve as great examples for those that fall behind, as there will be more clear evidence of both positive impacts and limitations. The limitations of blockchain technology concerning scalability, security, privacy, energy sustainability, as well as regulation and legislation lag, will be one of the emerging future research directions. It is also expected to see emerging research into incorporating the Metaverse, NFTs, etc, to promote oral health and advancements in dentistry [62]. Further increasing technological awareness and reducing relevant knowledge gaps via continuous research collaborations are also crucial tasks. Future research would also benefit from a better understanding of the specific need of dentistry and its stakeholders for tailored blockchain deployment. Moving forward, with more established implementations of blockchain in dentistry, it will then allow more empirical studies to be conducted in this specific field. Moreover, the framework of blockchain in dentistry shall be further refined and expanded. It is also expected to bring significant insights via establishing the dentistry-specific readiness assessment for blockchain as well as other revolutionary technologies. Moreover, our research team will continue studying other technological advancements and their interactions with different sectors of potential.

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