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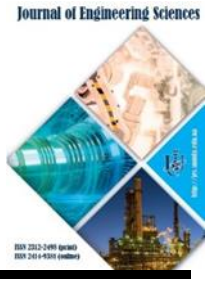

Investigation of the Blockchain Structure for Hydroxyapatite-Based Scaffolds

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Abstract. Regenerative biomechanics provides exciting technologies for developing functional substitutes, intending to restore and regenerate damaged tissues and organs. Scaffolds are in great demand. However, there are risks of biocompatibility when using scaffolds. Each bone substitute has its chemical composition, and other characteristics have advantages and disadvantages. Reproducibility, data sharing, privacy concerns, and patient participation in clinical trials are significant problems in modern clinical trials. In the era of the Internet, data is collected constantly. Today we need applications that ensure the privacy of users' data. Blockchain technology helps to compensate for severe data management problems (e.g., patient recruitment, ongoing monitoring) in clinical trials (CT). The article examines the principles of blockchain operation and approaches to bone substitutes' design. Based on this data, a blockchain model for biomaterial surgery has been created, facilitating interaction between the parties and reducing errors.

Keywords: life cycle assessment, clinical trials, biomaterial, implant, risk assessment, transaction.

1 Introduction

Biomaterials differ in chemical composition, the biological mechanism of action, and other characteristics. Each of them has its advantages and disadvantages [1]. A compromise is required between mechanical and biological characteristics when using synthetic materials.

Since scaffolds are not permanent implants, their leading role is to promote extracellular matrix formation [2, 3]. Because of this, there are risks of biocompatibility when using scaffolds [4].

Clinical Trials (CT) help test and validate the safety of newly discovered drugs in specific patient populations. However, such research usually faces many challenges (massive financial costs, regulatory and administrative barriers, and an insufficient labor force).

In addition, CT faces several data management challenges related to protocol compliance, patient registration, transparency, traceability, data integrity, and sample reporting [5]. Confidentiality of personal data and patient inclusion in clinical trials are essential for modern clinical trials [6].

In the Internet era, personal data is collected continuously. Today, we need privacy apps that always keep users in control of their data [7].

Blockchain can potentially solve such problems due to its intrinsic characteristics and properties [5]. The principle of the blockchain is that any service entrusted to trusted third parties can be built in a transparent, decentralized, secure "trustless" way at the top of the blockchain (in fact, there is trust, but it is hardcoded into the blockchain protocol due to the complex cryptographic algorithm) [6].

The purpose of this work is to investigate approaches to the design, manufacture, and intended use of scaffolds based on life cycle principles and approaches to risk assessment, as well as methods for building blockchains, and create blockchain technology for regenerative biomechanics that could facilitate data exchange between different parties and reduce errors.

2 Research Methodology

2.1 Principles of bone tissue production

Cells, scaffolds, and growth factors are the main components of tissue engineering.

Figure 1 is a diagram showing the concept of skeletal tissue regeneration using scaffold-based tissue engineering strategies, including its components (cells, biomaterials/scaffolds, and growth factors) and the influence of the environment for the pre-preparation of engineered implants [8].

According to the QbD concept, there are three approaches to scaffold design, where eight quality dimensions are used [9]. 3D printing technology is the preferred manufacturing process for regenerative engineering applications. This technology can successfully form a well-defined complex and can be developed from the data of three-dimensional scans of individual patients.

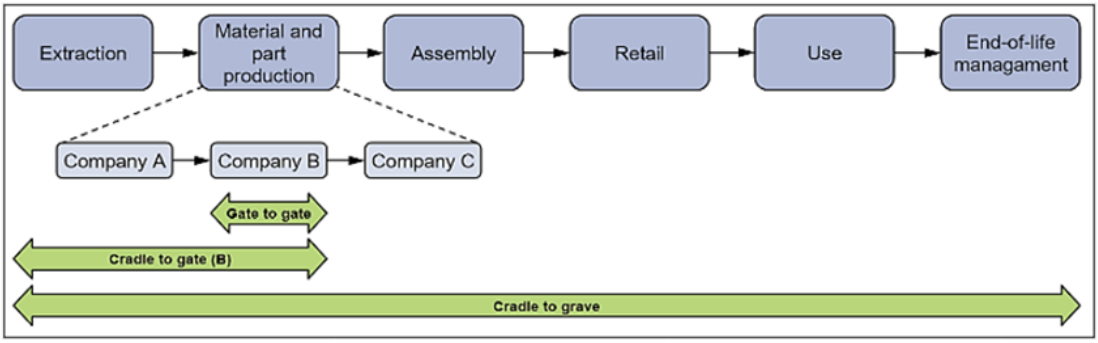

Figure 1 – The concept of skeletal tissue regeneration across the boundaries of the LCA scaffold system [10]

Preclinical trials are assessed by in vitro and in vivo tests before regulatory approval [11]. Risk assessment is carried out under the ISO 14971 standard (Figure 2) [12]. Risk management data is communicated to regulatory authorities at all stages, but especially in the first three stages, when hazards are identified, and measures are taken to manage them.

At stages of the life cycle, environmental risk is regulated by the ISO 14040: 2006 standard (Figure 3) [10].

2.2 Blockchain technology in biomedicine

Blockchain technology has opened up tremendous opportunities in healthcare, discovering the actual value of interoperability. Blockchain technology features such as data provenance, transparency, decentralized transaction verification, and immutability can help offset severe data management challenges (such as patient recruitment, ongoing monitoring, data management, and data analysis and accurate reporting) in clinical trials (CT) [13].

When patients undergo a medical examination, their information is registered at the registration desk, and a smart contract is established. Next comes the diagnosis. The examination results are collected using Internet-based devices and recorded in an electronic medical record system connected to a smart contract in the blockchain, where the data is encrypted. Once added to the blockchain, it is impossible to change the data, but authorized parties can only access it. Each patient is provided with an electronic medical record account when registering for an appointment. It is unique and contains the patient's identification number and personal information.

The person gives personal information (name, age, contact details, medical history). After that, the account is added to the blockchain, waiting for further updates after the medical results. The smart contract is activated on the blockchain stored in the EHR account. It has coded rules that control new registrations, and it focuses on the execution of transactions added to the chain, such as forcing transactions to obtain consent from both healthcare providers and patients before allowing a third party to view. The following types of policies are recommended for inclusion in a smart contract. The privacy policy of personal data is related to how healthcare institutions collect and use patients' personal information. They also inform patients about what specific information is collected and whether it is kept confidential and protected from misuse or abuse by sharing it with partners. The Health Records Policy governs the types of data collected and recorded, standards for medical records and management, and the responsibilities of healthcare professionals in data processing. These principles should be consistent with common law and best practices. The Third Party Involvement Policy addresses the rights and obligations of pharmaceutical companies, insurance companies, and governments in collecting and using patient information and treatment outcomes. After registering an EHR account, patients provide their digital signature to activate the smart contract. Contract violations can be identified, and a warning issued to the patient and individuals. The smart contract governs the creation of new identities. Registration of a person is carried out only in certified institutions. It also contains a PPR contract issued by the interaction of data received from both parties. This contract defines data ownership and access to permissions

associated with medical records maintained by healthcare professionals.

PPR defines data metrics attached to a hash of a subset of patient data that make it impossible to change the data at the source. It also allows customers to have full access to and control their data and share it with others. Finally, it contains a list of links to the PPR contract, which lists all prior and current information exchanges between two nodes in the system, such as all people served by a healthcare professional or all healthcare providers who provided services to a patient, or a third party with whom the patient shares records. The blockchain and smart contract maintain all medical journals for an indefinite period, so one participant can always access the journals by updating the latest blockchain from the network. Figure 4 shows this process [14].

The rest of the blockchain models are presented in Table 1.

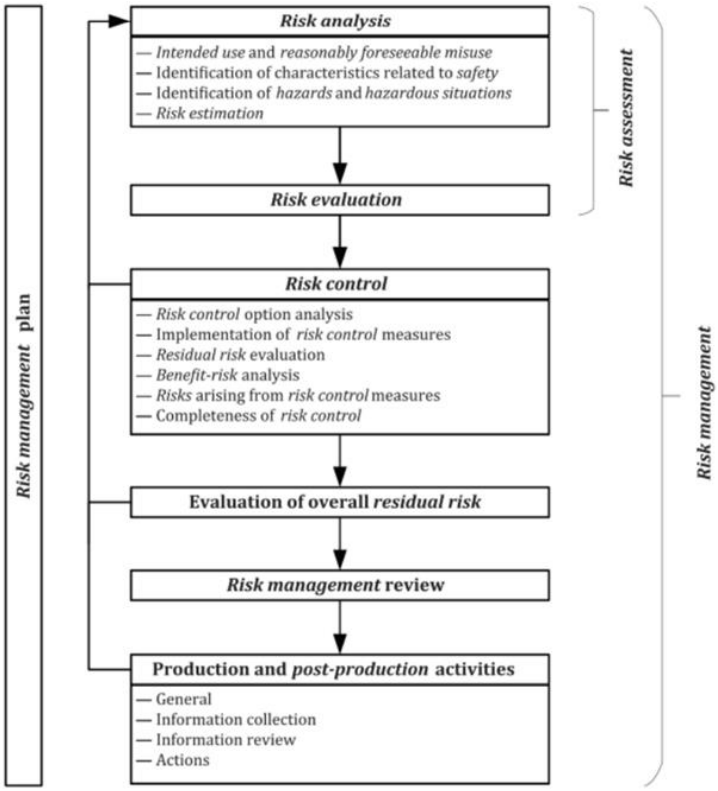

Figure 2 – Quality risk management process [12]

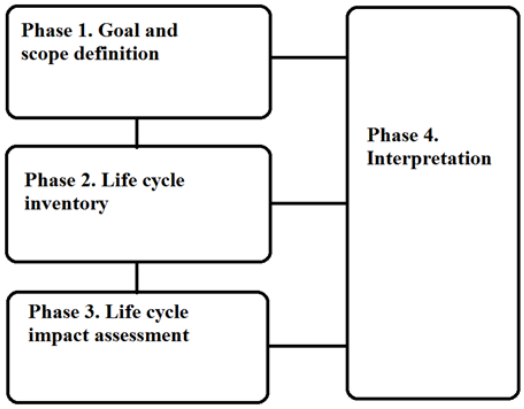

Figure 3 – Environmental risk assessment

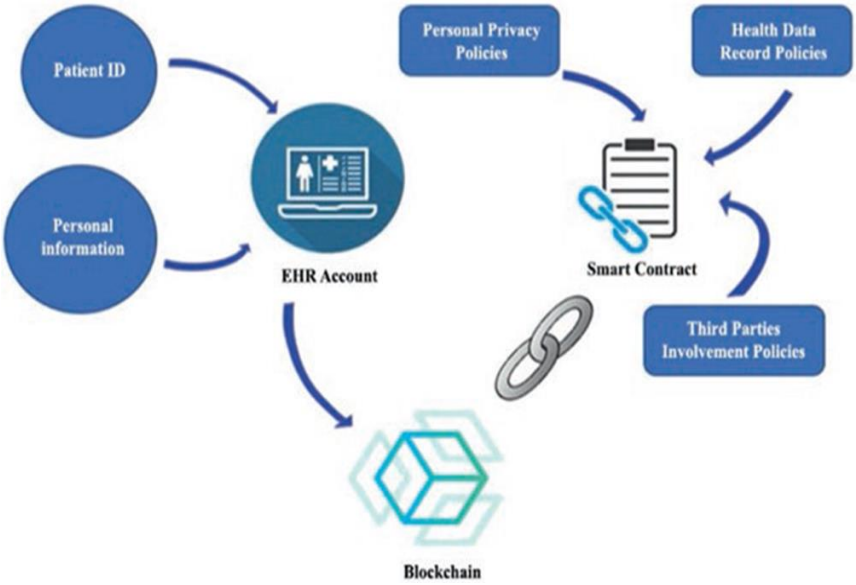

Figure 4 – Patient registration and personal profile setting [14]

Table 1 – Some blockchain models

Blockchain technology	Data	Benefits	Disadvantages	Source
Private blockchain	EHR	A smart blockchain-based application for managing and sharing healthcare data	No scalability or availability considerations, data exchange is limited	[15]
Proof of work	Location	Layered location sharing scheme	There is no discussion of under what critical condition the patient's whereabouts data will be obtained	[16]
Ethereum platform	Health data	Economic smart contracts	Interaction between different parties is not considered	[17]

3 Results

3.1 Blockchain process structure

Our proposed process for transferring health information on the blockchain consists of the following steps.

3.1.1 Registration

The patient is registered at the clinic. His data is recorded, a smart contract is established with the insurance company. The patient is the leading party receiving treatment based on personal information. Doctors enter information about treatment use of drugs. A smart contract is entered into when patients fulfill certain insurance contract conditions to pay the surgical fees. Smart contracts are self-executing contracts on the blockchain network. Contracts are converted into computer code, saved, and executed by the blockchain network.

3.1.2 Survey

A medical examination of the patient is carried out. The results are forwarded to the manufacturer. Some images may be needed here, such as an MRI scan to determine the condition of the patients [18].

3.1.3 Manufacturing

The manufacturer designs the implant and assesses the risks according to ISO 14971 and ISO 14040:2006 standards.

Life Cycle Assessment is a tool for assessing a product's environmental and potential aspects. It is carried out by compiling a list of inputs and outputs, assessing the environmental impact, the impact of inputs and outputs, and interpreting the results for the study [10]. The results are reported to the regulatory authorities.

3.1.4 Preclinical studies

The material is preclinically tested in the laboratory, the results are reported to the regulatory authorities. Medical devices are tested for cytotoxicity, genotoxicity, sensitization, and irritation [11].

3.1.5 Implantation

The material is implanted into the patient (Figure 5).

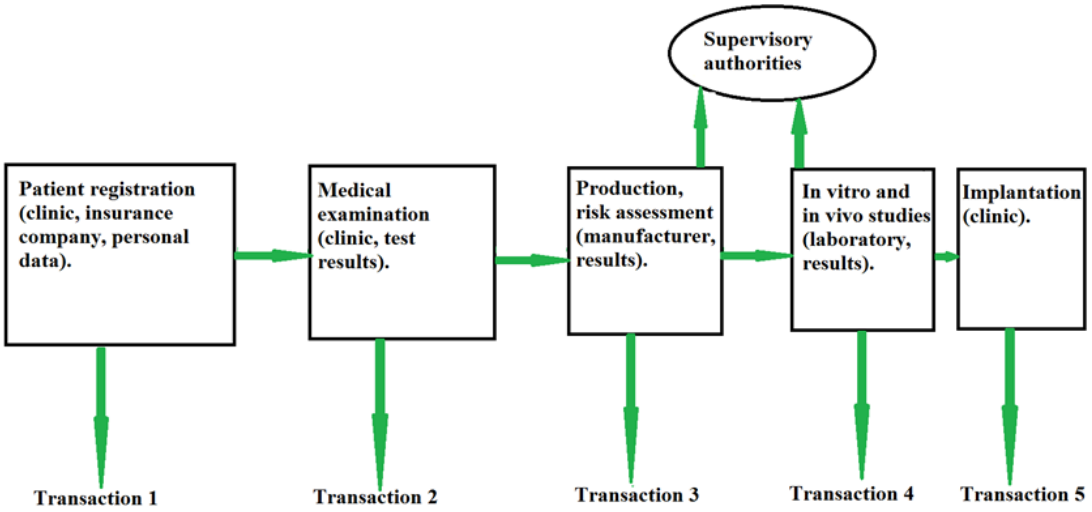

Figure 5 – Proposed blockchain process

3.2 Data structure

The data structure is determined by members and assets [18]. Participants – doctor, patient, insurance company, biomaterial manufacturer, regulatory authorities, laboratories. Assets have patient records (survey data), product information (material, dimensions), transactions, risk assessment results, and preclinical testing (Figure 6).

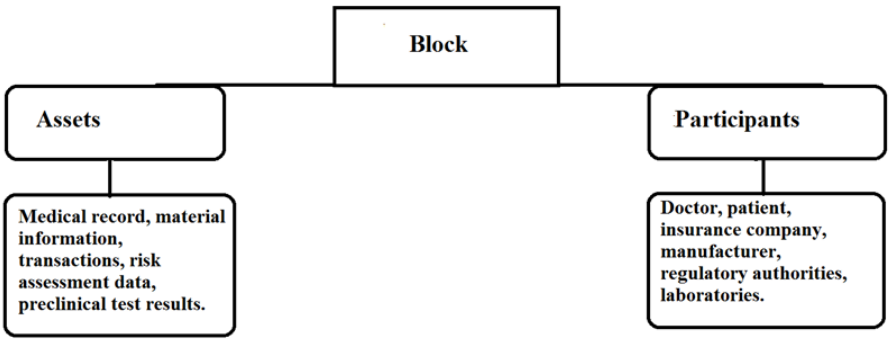

Figure 6 – Proposed data structure

The patient is the main participant who receives the treatment, with personal data such as health information and medical data.

The doctor conducts diagnostics operates on the patient. He assesses the patient's condition and decides which surgery is necessary and which implant he needs. Patient information and implant characteristics will be sent to the manufacturer.

The implant manufacturer receives information from the surgeon. Depending on the diagnosis made by the surgeons, the implant can be custom-made according to the patient's characteristics or using a standard implant.

The patient can purchase health insurance from an insurance company. This establishes a smart contract that enforces the contract between the patient, the hospital, the implant manufacturer, and the insurance company.

Regulatory authorities receive information on risk assessments from the manufacturer.

The material is sent to the laboratory for preclinical studies on cytotoxicity sensitization. Information about them is also transmitted to the regulatory authorities.

4 Conclusions

Clinical testing helps confirm the safety of open-label drugs in specific patient populations. But such research usually faces many challenges, such as massive financial costs, regulatory and administrative barriers, and several data management challenges related to protocol compliance, patient registration, and transparency.

The blockchain network is used in the biomedical field to store and exchange patient data across hospitals, diagnostic laboratories, pharmacies, and doctors.

Blockchain programs can pinpoint severe errors in the medical field.

Thus, it can improve the healthcare system's productivity, safety, and transparency of health data exchange.

This paper proposes a blockchain network for scaffolds based on hydroxyapatite, considering the life cycle of scaffolds, approaches to risk assessment, and clinical testing. This blockchain structure will improve its integration into implant surgery in the future.

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