A MARKETPLACE FOR HEALTH: OPPORTUNITIES AND CHALLENGES FOR BIOMEDICAL BLOCKCHAINS

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ABSTRACT

Incentive alignment is a fundamental challenge to improving the financial and operational efficiency of the healthcare system in the United States. The current system incentivizes payers to reduce utilization and providers to perform procedures, while patients are caught between cost savings and utilization. Blockchain is an emerging technology that enables the construction of large-scale open digital networks with characteristics that can incentivize participants towards a common goal. There is an opportunity to use blockchain technology to reimagine how we cooperate to promote health and potentially improve efficiency of the healthcare system. In this perspective, we discuss the strengths and limitations of this new technology through the lens of healthcare. We explore how challenges in healthcare (e.g. costs, accessibility, and data ownership) can be addressed by blockchain technology and, equally important, how they cannot. Through the evaluation of existing projects, we find clear advantages and disadvantages of the technology and identify open areas of innovation for healthcare executives, academics, and entrepreneurs.

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1 Introduction

The current US healthcare system operates under conflicting incentives: payers are rewarded for reducing costs, which may limit coverage and access; providers are paid when they perform procedures and services; pharmaceutical companies create drugs which maximize market potential; and patients are incentivized to avoid the healthcare system altogether due to cost and frustrating inefficiencies.

Incentive misalignment contributes substantially to the trends of increasing healthcare cost and declining health outcomes in the United States. It is a systemic problem that has resulted in some of the industry's biggest challenges, including the lack of price transparency, the inability to access and share data, and inconsistency in healthcare quality[1, 2, 3, 4]. This is a challenge familiar to public health officials all over the world – how can individuals be incentivized to act in theirs, and the communities, best health interest. Governing agencies use laws, regulations and public outreach to promote healthy behaviors. Most successful have been campaigns to promote sanitary conditions and vaccinations[5, 6], resulting in a marked increase in human longevity and the eradication, or near eradication, of many life-threatening diseases[7, 8, 5, 6]. Regulation and laws are sticks to discourage unhealthy behavior, but thus far these agencies have not had the capability to provide carrots to incentivize technology to promote healthy behavior.

There are few individual rewards for takings actions to stay healthy and avoid disease – another way of thinking about it is that there is currently no reward for maintaining health, while there is a large market for treating disease. It is this dynamic that rewards products that maximize hospital reimbursements and hinders products that promote healthy behaviors, like good nutrition and exercise. As a result, technologies have evolved to meet the specific needs of individual stakeholders – a myopic approach that resulted in an electronic health record system created with billing, and not the physician-patient relationship, in mind[9]. These tools reinforce existing conflicts and further strain the relationships between stakeholders. What is needed is an approach that rewards cooperation, that promotes healthy behavior and rewards healthcare partners for their participation. What is needed is a 'market for health.'

Table 1: Medical and dental expenses eligible for preferred tax status in the United States (e.g. itemized deductions, health savings account). IRS Publication 502 [10].

Does not cover	...but does cover
Health club dues to improve general health or to relieve physical or mental discomfort	Chiropractor, acupuncture, physical therapy, and procedures and drugs to treat cardiovascular disease
Toothbrush and toothpaste	Tooth extractions, root canal and dental implants
Weight-loss program to improve general health or sense of well-being	Bariatric surgery, insulin, ACE Inhibitors
Diapers or diaper services	Hospital visit resulting from diaper dermatitis and UTIs caused by re-using diapers

Fundamentally, blockchain is a technology that organizes communities[11, 12]. In this way, it is more of an enabling approach, like the internet, than any specific technological solution, like the electronic health record. Where the internet enabled ad hoc networks of communication, the blockchain enables ad hoc networks of human behavior. For example, in the 10 years since bitcoin was first introduced, a community of strangers has worked together to produce the world's most powerful supercomputer – a computer without any "owner" [11]. Bitcoin incentivized people to buy or repurpose their computers and connect them to each other to create a global, ownerless payment network.

Blockchain technology has several features that incentivize disparate entities to cooperate (Table 2: a network that is open and egalitarian, an immutable and verifiable historical record, digital scarcity, rewards for participation, and no central authority[11]. Interest in blockchain is spanning many industries, including finance, supply chain, cybersecurity, and, now, healthcare. With over $680 million in private investment in biomedical blockchain companies [13], there is no lack of excitement about the potential impact this new technology can have on an industry that is traditionally resistant to disruption. In the following sections we evaluate and critique several use cases of biomedical blockchains. We synthesize what we have learned about where this technology may solve some of healthcare's most important problems and, just as importantly, where it is likely to fall short.

2 Uses and Misuses of Biomedical Blockchains

Blockchain, and associated technologies like cryptocurrency and smart contracts, have several unique properties of interest to the healthcare ecosystem: (i) the ability for a network to cooperate trustlessly and unsupervised, (ii) the ability to reward/incentivize behavior that would otherwise not be in an individual's self-interest, and (iii) a mechanism

Table 2: Core Features of Blockchain Technology

Feature	Description
Open network	Anybody can participate, anybody can contribute, anybody can create. Thus far, innovation in health has been limited to large corporations and research hospitals.
No Central Authority	Democratic and egalitarian. This is in stark contrast to our current healthcare ecosystem in which all of the power is consolidated with very few players.
Immutability	Information on the blockchain cannot be changed. Provides the ability to track behaviors and data, including who accesses and when.
Digital Scarcity	Makes digital assets, like Bitcoin, possible. Necessary for creating value that can be used to incentivize and reward behaviors.
Incentives	Reward behaviors that benefit the network with digital assets (e.g. cryptocurrencies like Bitcoin).

for securing and verifying digital assets[14]. We reviewed existing biomedical blockchain projects with respect to the core features of the technology (Table 2). While there are projects making creative use of these features, we found that many current use cases of biomedical blockchains would be better suited by traditional solutions. For example, a core tenant of blockchain is the obviation of trust by establishing a transparent public record that anyone can verify. It is important to acknowledge that there is a lot of trust in the healthcare system. It is difficult to imagine a world in which healthcare operates in a completely trustless environment (e.g. without the trust between a patient and their provider).

According to the Biomedical Blockchain Database [15], the collective dollars raised by over 170 healthcare and biomedical blockchain projects is $683 million[13] at the time of this writing. The funded projects cover a wide spectrum of use cases. More than a third of which are working toward providing solutions for storing and managing patient data on the blockchain. Next most common are efforts to establish data marketplaces that incentivize participation in research and clinical trials. Other examples include payment and claims management, data science and analytics, and supply chain management. Here, we critically evaluate these proposed solutions for their appropriateness, in the context of the technological features of blockchains, and identify opportunities for future work.

2.1 Data Stewardship: ownership, access, and sharing (38%)

Data stewardship encompases ownership (who has the final say in how data are used), access (how data are distributed and transferred), and sharing (who uses your data and for what purpose)[16]. Improving data stewardship would have a positive impact on healthcare. For example, the access of lab results between institutions would reduce the need for multiple repeated tests, the sharing of clinical notes between providers would improve the continuity of care, and patient data could be made available for researchers to study while preserving privacy.

There is a growing trend that patients want to control how their data are used[17, 18]. Currently, companies and institutions decide how you access and share your data. Blockchain technologies promise the ability to give patients ownership by securing digital assets in a way that was not possible before [19]. But when the asset is a piece of data there are some subtleties on what that means exactly. What it allows a data owner to do is to grant and revoke ongoing access to data elements and to establish an immutable audit trail of data ownership. However, once someone has access to those data then they have it forever – just as they would off the blockchain. Blockchain does not, currently, guarantee that the data can be recovered once they have been given away. This is the primary limitation, in our view, that many of the blockchain data sharing projects suffer from.

Similarly, these projects often mention easing the access to data. However, there is nothing inherent to blockchains that allows patients to access their clinical data. Their data exists in a variety of areas (e.g. electronic health records, pharmacy databases, PACS systems[20, 21]) and, regardless of if they have a right to it, it is often extremely difficult for a patient to access all of their data. Data holders often cite technical challenges as a reason that this access is difficult. However, it is our view that the real reason is that these data holders are not motivated to make data available to patients. We believe that in the face of proper incentives seemingly "intractable" technical challenges would quickly become trivial.

True data stewardship may be possible through the blockchain functionality known as smart contracts. Smart contracts turn all the machines connected to a blockchain into general purpose computers and are the distinguishing feature of the Ethereum blockchain[22]. The use of these smart contracts is open – anyone who can code can write applications that

will run on the network. Using smart contracts, it may be possible to design applications to analyze patient data within the blockchain and distribute the results without revealing the data. Further, since the code itself is on the blockchain, it can be independently verified to perform as claimed and is immutable. We believe this is an especially exciting and unexplored opportunity for blockchain technology to greatly increase access to patient data while guaranteeing data privacy.

An era of self-sovereign data management is not without tradeoffs. Corporate data stewards currently provide protection against loss, theft, and accidents as a consequence of building brand trust and various legal liabilities. These protections are not available in the nascent blockchain space. There is no recourse for private keys that are lost, no undo button for transactions with the decimal point in the wrong place, and no fraud protection if your account is compromised. There is no customer support on the blockchain.

2.2 Patient and Data Recruitment (23%)

There is great excitement around being able to incentivize patients to share their data with scientists to conduct research studies. Several projects have arisen to organize communities around sharing of personal health information[23]. For example, recent projects have promised to use a blockchain to store and secure user genetic data[24]. These networks would distribute the data to scientists and researchers that need access to conduct their studies and would reward users for sharing those data. They would also allow the user to track how and where there data are used. We believe this is an exciting and valid use of blockchain technology, insofar as these networks encourage people to participate in research studies and share their data. A common claim, however, is that because of the immutability of blockchains, the provenance and authenticity of the collected data can be ensured. This is not true. The fact that the blockchain is immutable does not imply that the data are authentic. The only thing that can be verified is that the data are the same as when they (or more likely their unique data fingerprints) entered the blockchain. Data can be manipulated in many ways before it enters the blockchain, including omission, fabrication, and falsification. Further, nothing inherent about the blockchain prohibits a bad actor from contributing fabricated data, which we dub "blockspam," and collecting rewards. In fact, as the value of data contribution increase, we will almost certainly be inundated by blockspam.

2.3 Supply Chain Management (9%)

Supply chain management is one of the most cited use cases for blockchain technology, and, while there are some advantages, we believe that it is an area where the potential impact has been overstated. What blockchains offer is for multiple parties in a supply chain to track products without putting any single party in control. This has the beneficial property of being difficult to lose and enables tracking without requiring trust. However, the other guarantees (namely the immutable historical record) only apply to digital assets and do not guarantee the same for physical objects. A digital asset, for example, cannot be changed without that change being tracked on the blockchain where a physical object can. Another way of saying it is that for physical objects the blockchain can only track a shadow, where for digital assets it tracks the object itself.

Now, if the supply chain is moving digital assets then blockchain may be the only mechanism that exists for management. For example, imagine a marketplace for patient data that allows researchers around the globe to access vast amounts of clinical, genomic, and behavioral data. It is reasonable to expect that those who contribute those data be compensated for its use. For example, the patient who contributes the sample, the doctor who writes an laboratory order, the laboratory technician who performs the test, and the data scientist generates derivative data all have a small stake, or microequity, in the subsequent use of those data. Blockchains provide the technology necessary to track these contributions and to compensate each of the stakeholders appropriately – although it's not clear if such a framework would even be legal today[25]. Remember though, that anytime data are being onboarded to the blockchain there is the opportunity for fabrication and falsification. Future systems might have strategies for how to address and mitigate the effect of this blockspam.

2.4 Clinical Trials Management (5%)

The purpose of most clinical trials is to seek regulatory approval for medical interventions (i.e. drugs and devices). This process is required by a strong central authority, like the FDA, to establish trust between those that who create an intervention and the providers who will use it. Doctors want to know a medicine is likely to work before prescribing it to their patients. Blockchains, on the other hand, are specifically designed for situations where there is no central authority. Further, they do not provide any mechanism for establishing trust. On the contrary, they obviate the need for trust.

There are three common justifications for using blockchain in support of clinical trials [26, 27]: (i) ensuring data integrity, (ii) improving data transparency and real-time sharing, and (iii) improving enrollment efficiency. It is our opinion that only the latter may be well-matched to the features of the blockchain.

Several groups have argued that the reproducibility crisis in clinical trials could be solved by securing data integrity with audit trails on a blockchain. Most reproducibility issues, however, are a result of post-hoc subgroup analyses, serendipitous removal or inclusion of certain patients, or changes in the case or controls definitions[]. To the extent that using a blockchain would force investigators to register their study designs publicly, it may have a positive effect on reproducibility. However, without loss of functionality (WOLOF), a centralized system, such as ClinialTrials.gov, could solve this same challenge and would be exceptionally simpler to implement.

A second argument is that a blockchain would improve real-time data transparency and sharing[27]. As currently implemented, nothing about the blockchain is real-time. In a distributed network, there is an inherent trade-off between security and scalability as reflected in transaction rates. At the time of writing, the two most widely used and secure blockchains, Ethereum and Bitcoin, processed a transaction every 20 seconds and 9 minutes, respectively. By comparison, a modern centralized database system can run 1000x that number of transactions per second. Further, in a clinical trial, it's more about data reporting (between the trial sponsor and the FDA) then it is about sharing among different parties. In fact, we go to great lengths to conceal ongoing study results so as not to unduly influence trial outcomes.

Finally, improving enrollment efficiency is another cited application of a blockchain in clinical trials. This could be accomplished by using these networks to incentivize participation or by enabling the construction of owner-less patient registries. However, there are many other barriers to trial enrollment, such as an onerous trial design that requires too many visits or has too long of a follow-up period, or clinician enrollment fatigue [28], that would be difficult to address with blockchain technology.

3 An Example Opportunity for Biomedical Blockchains

The future is in active patient participation. We believe that the fundamental problem in healthcare is that stakeholders are not properly incentivized to work together to improve health. Blockchain is a technology for incentivizing networks around common goals and may be the best technology currently available for making the systemic changes required to improve longevity, lower costs, and equilibrate access to services. Patients are motivated, especially in the cases of rare and understudied diseases, to contribute to research that could lead to treatments. For example, recognizing a need, the Cystic Fibrosis Foundation partnered with Vertex to conduct research that ultimately led to the development of kalydeco – first drug approved to treat the underlying cause of the disease. As a result, the foundation amassed a huge fortune, to the tune of over $3 billion [29].

Using blockchains we can reimagine the drug discovery framework. One significant opportunity for blockchain technologies may be in early stage drug development. Thee right patient data has been demonstrated to be extremely valuable[30, 31]. Currently, the collection of this data would have to be coordinated by a foundation or medical organization. However, in the future a network built on a blockchain could allow for ad-hoc creation of research networks. In these networks each patient's data could be tracked and the patients can be rewarded for their contribution to the development of the new drug. Blockchains provide the technological framework to allow patients to self organize without the need of any coordinating center or foundation. Sensitive issues around data usage, governance, and royalties can be explicitly and clearly encoded into these frameworks.

In this possible future, instead of billions of dollars going to a single research foundation, the money would be shared across all of the contributing entities including pharma, foundations, and patients. This is in contrast to how drug development has been conducted where pharma uses patients to conduct their studies and then resells those drugs back to the patients. The CF Foundation example is an improvement over this paradigm, but a network where everyone who contributes benefits represent a significant step forward.

Reinventing privacy is necessary. For such a vision to be realized some significant challenges must first be overcome. Chief among them ensuring patient privacy while at the same time sharing their clinical data. Currently, we place trust in organizations like hospitals, laboratories, insurance providers and increasingly corporations, to responsibly manage our private health information. These organizations are in turn held accountable by laws, regulations and policies that guide when and how our data can be stored, shared and used. As these social contracts come under pressure, we are beginning to see cracks emerge in the bedrock of our privacy controls[32]: law enforcement accessing private genetic databases [33] [34], private corporations profiting from personal health data [35], and the routine data breaches of our most sensitive information [36].

An alternative and complementary approach may be to use cryptography to recode these social contracts into formal contracts on a blockchain [37]. Such an approach would guarantee (i) the parameters of the contract remain unchanged (immutability), (ii) nobody has special privileges or access ("no central authority"), and (iii) everyone has a record of who did what ("open network"). However a critical challenge will be how we manage private information in a technological framework oriented around radical transparency. We will need to learn how to establish privacy in an inherently trustless environment.

4 Conclusion

The challenges facing healthcare in our country will require incredible social engagement to solve. Very few technologies have the ability to effectively influence behavior at this scale. For evidence, one need only look at the thousands of failed mobile health apps languishing and forgotten on app stores. The current technologies that do have the ability to influence masses are uncontrolled, unpredictable, and sensitive to manipulation – e.g. facebook and the 2016 election. It's early days, but blockchains, with their ability to mobilize and change behavior at a global scale, might just be the social technology that we need to transform our current market for disease into a marketplace for health.

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