Decentralized Care: Leveraging Blockchain to Re-Design Risk Sharing

Wei-Chun J. Hsu[1,2,3]

1. Department of Pharmacology & Toxicology, University of Texas Medical Branch, 301 University Blvd, Galveston, Texas, 77555-0617, United States
2. Biochemistry and Molecular Biology Graduate Program, Graduate School of Biomedical Sciences, University of Texas Medical Branch, 301 University Blvd, Galveston, Texas, 77555-0617, United States
3. M.D./Ph.D. Combined Degree Program, Graduate School of Biomedical Sciences, University of Texas Medical Branch, 301 University Blvd, Galveston, Texas, 77555-0617, United States

*To whom correspondence should be addressed: Wei-Chun H. Hsu, M.D./Ph.D. Combined Degree Program, 301 University Boulevard, Galveston, TX, 77555, USA, E-mail: jihsu@utmb.edu

Abstract

Healthcare costs in the U.S. continue to rise, and the integration of information technology in healthcare continues to be challenging. Recently, the blockchain, a distributed, decentralized property title registrar, introduced by the electronic currency Bitcoin, has emerged as a disruptive technology currently being studied in disparate fields ranging from financial transactions to document authentication. We believe that blockchain can be harnessed to create a new model of health insurance: decentralized autonomous health insurers (DAHIs). Using a decentralized blockchain based on smart contracts and pegged sidechains, we believe that DAHIs can be engineered to provide the services of traditional health insurers, while possessing clear benefits such as greater efficiency, mutual ownership, and the advantages of both centralized and decentralized healthcare systems. As such, we believe leveraging blockchain technologies to healthcare, including decentralizing health insurance, can produce innovative, adaptable methods of health care rationing and delivery.

A middle-aged female patient sat quietly in the doctor's office for her annual checkup. Taking the fingerstick glucose, the doctor appeared visibly shocked by the readout … 397 mg/dL. "Miss, do you ever check your sugar at home?" "No Dr. H … ever since my old meter broke, the insurance company wouldn't pay for my new meter or the test strips". Checking with the insurance company after nearly 2 hours of being placed on hold, the doctor did indeed discover that her insurance wouldn't pay for test strips for her particular brand of glucose meter. Similarly, the insurance company excluded blood pressure cuffs from the list of compensated medical devices, despite paying hundreds of dollars a month for her blood pressure medication. After her labs came back the next day showing a diagnosis of acute kidney injury, the doctor wondered out loud: "shouldn't there be a better way for insurance to pay for the basic care that my patients need?"

In 2015-2025, healthcare spending in the United States is projected to grow by 5.8% a year, representing a 1.3% increase in the growth rate compared to national GDP [2]. This trend towards a continual increase in expenditures, combined with questions about the efficacy of healthcare spending on performance metrics such as QALY, have prompted many discussions into alternative models of healthcare resource allocation. At the same time, high-profile breaches of healthcare data such as the leakage of over 80 million records containing medical identification and Social Security numbers at Anthem in 2015 [3], one of the largest insurers in the nation, have prompted grave concerns about current standards of data security, integrity, and privacy, which remain considerable hurdles in the adoption trends of electronic medical records (EMR) technologies. We believe that blockchain technologies, in addition to effectively compartmentalizing and segregating healthcare information, can be leveraged to produce

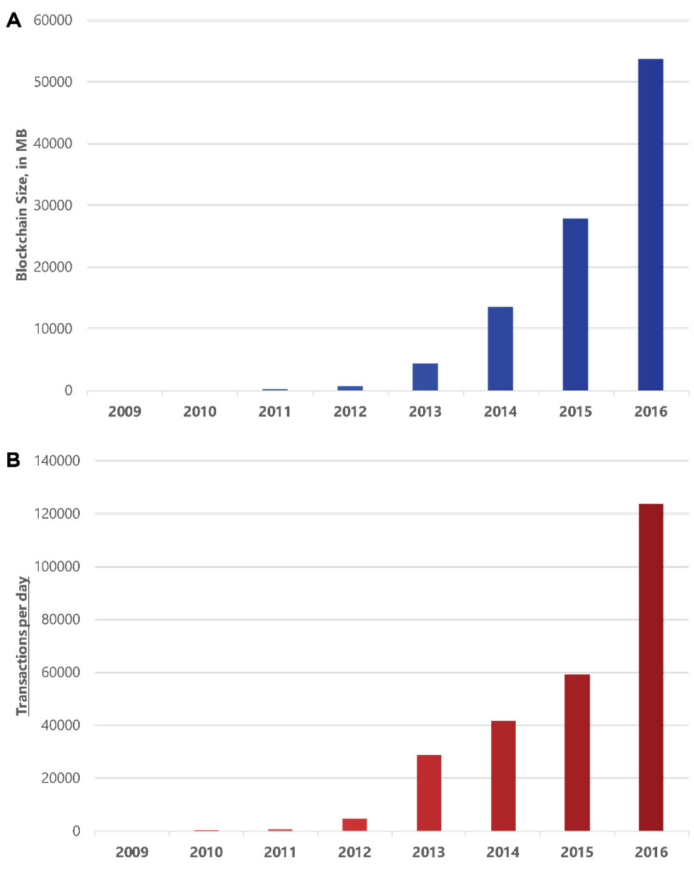

Figure 1: Exponential growth of the Bitcoin blockchain. A) Total size of the blockchain, in MB, on Jan 1st of each year from 2009-2016. B) Number of transactions, per day, on the blockchain on Jan 1st of each year from 2009-2016. Data derived from [1].

decentralized autonomous organizations (DAOs) that may revolutionize allocation and distribution of healthcare resources.

The inception of the blockchain concept began with the seminal paper “Bitcoin: A Peer-to-Peer Electronic Cash System” published by the pseudonymous Satoshi Nakomoto [7], in which he extended upon previous attempts at creating an anonymous, distributed electronic cash system with two fundamental concepts: a) a distributed property title ledger, called the *blockchain*, and b) the concept of a *proof of work* function which cryptographically chains together entries in the ledger, rewarding users who compete successfully to generate a solution. The result of this is a solution to the Byzantine General’s problem [8] for a decentralized currency; because each participant in the network knows the current chain and adding a solution to the chain takes a certain, predictable average amount of time, all participants can trust the “consensus” chain, which is the chain of answers that is the longest, without trusting any other participant. From mathematical theory to working application, Bitcoin has emerged as one of the largest decentralized payment networks currently in existence, with over 50 GB of ledger data stored and over 120,000 transactions processed per day (**Figure 1**). Analogously, these properties make the blockchain inherently suitable for storing data records that need to be a) fault-tolerant, b) immutable, c) independently verifiable and d) timestamped, which characterizes a large variety of healthcare-associated information such as progress notes, informed consents, operative reports, and diagnostic results.

Proof of Existence

What is proof of existence? The basic concept of blockchain revolves around the idea of a public ledger – a ledger of all transactions between accounts on the network owned and monitored by everyone but ultimately controlled by none. As such, transactions can only be added, never removed, from the network. Utilizing this concept, an asymmetric hash function (an algorithm that maps variable length data in a **unidirectional** manner to a fixed length string) can be used to encode an arbitrary document into a hexadecimal string, converted into sets of **valid** but **unspendable** bitcoin/blockchain addresses by basic math, and token amounts of currency sent to those addresses to create a ledger entry in the blockchain. After the transaction is included in the next block, the hash value (and therefore the existence of the document which generated the hash function) is permanently certified to exist at least as early as the time the transaction was confirmed [4-6]. Given the cryptographic properties of modern hash functions, embedding the hash and adapting some other document to match the hash is also impossible, due to a property called **pre-image resistance**, which essentially implies that it is computationally infeasible to find an input that hashes to any output specified in advance.

The three aims of the National Quality Strategy [9] include providing better care through making healthcare more patient-centered, reliable, accessible, and safe; creating healthy people and healthy communities by supporting proven interventions to address behavioral, social, and environmental determinants of health; and providing affordable care by reducing the cost of quality health care for individuals, families, employers, and

government. Blockchain technologies provide an opportunity to intervene in all three aims. Through “proof of existence” approaches (**see sidebar**), blockchain technologies can authenticate the existence of important health records including patient records, diagnostic reports, and informed consents – by proving that a document was in existence at a specified point in time in a decentralized and trustless manner, legal questions such as whether a medical consent was obtained prior to the start of an invasive procedure can be more effectively answered. Similarily, a decentralized method of document authentication provided by such approaches can substantially reduce technology and compliance costs by using the decentralized properties of blockchains as a failsafe redundancy mechanism in conjunction with traditional backups. However, the true impact of blockchain on these three aims may be explored by considering the possibility of applying the concept of decentralized autonomous corporations (DAOs) to the most prevalent gatekeeper of medical care in the US – private insurance companies.

The Concept of Decentralized Autonomous Health Insurers (DAHIs)

The decentralized autonomous organization (DAO) is a new form of legal structure, made possible by blockchain technologies, that serves as a new governance and ownership structure distinct from a traditional corporation in fundamental ways. As first outlined by Ori Brafman in the book *Starfish And The Spider* [10], DAOs fundamentally arise from the concept of an organization whose bylaws are established not by teams of leaders, but by consensus, immutable rules established and set at the time of inception. In essence, Bitcoin was the first DAO to be established; however projects established since its inception, such as Ethereum [11] and Counterparty [12], have vastly expanded the repertoire of DAO technologies to include voting, smart contracts (**see sidebar**), dividend allocations, and other novel features that may enable the creation of decentralized autonomous health insurers (DAHIs).

Since the inception of health insurance, the fair allocation of resources has been the predominant factor behind myriad rules and regulations in the industry. The era of the 1970s, and particularly with the start of the Reagan administration, has brought about a seismic shift in decision-making circles that has espoused the benefits of market forces, rather than government “command and control” regulatory programs, to improve healthcare delivery, fight health care cost inflation, and improve quality of care [14]. These changes, reflected in the proliferation of health maintenance organizations (HMOs) and group policy insurance, has not been without criticism – such as the existence of unequal health care plans – but in the National Medical Care and Expenditures Study (NMCES) conducted by the National Center for Health Services Research in 1977, participants of managed care plans express significantly higher levels of satisfaction with costs and benefits, and are as healthy as, participants in PPO or other plans [14].

Smart contracts

How do smart contracts work and how do they apply to DAHIs? **Smart contracts**, as first proposed by legal theorist and computer scientist Nick Szabo, are a digital construct that serves the purpose of a contract, a set of promises agreed beforehand, in contract law. The idea of smart contracts is that many of the terms of traditional contracts (e.g. collateral, terms, bonds) can be embedded into hardware and software in such a way to make a breach of contact "expensive" for the breacher, allowing technological solutions to contract enforcement that reduce costs and increase efficiency [13]. Given the ability of blockchain transactional systems to secure financial assets by cryptographic proof of work, smart contracts allow for self-enforcing health insurance contracts to be designed, where the address controlling the smart contract and assets (e.g. payments for health insurance) is secured by "writing" the terms of the contract onto the blockchain without the need for a central authority to provide enforcement.

The Affordable Care Act, established in 2013, was another step in the introduction of market-based reforms to the healthcare industry. By many metrics, the Act has in fact reduced the percentage of uninsured people, increased patient pools, and improved some health outcomes in the young by enabling them to remain on their parent's insurance plans [15]; however, the costs for many participants have in fact increased due to rapidly rising deductibles and increased shares of medical expenses not covered by deductibles [16], and health outcomes for the population at large are, at best, unclear. In addition, the inconsistent expansion of Medicaid in different states, as well as interoperability issues caused by an amalgam of state and national exchanges has created a chaotic situation for many healthcare insurance consumers.

We believe the concept of DAHIs to be an evolutionary step in the market-based reforms that has characterized the recent progress of healthcare that fully leverages modern-day technology. The concept of DAHI is nascent, but not unknown; a proposal to implement a DAHI with Ether smart contracts has been previously brainstormed and presented at a BitTorrent conference [17]. However, to our knowledge, we are not aware of any major insurers or HCOs currently investigating feasibility studies in this field.

Advantages and limitations of DAHIs compared with traditional insurance companies

How can DAHIs improve on traditional health insurance while retaining the fundamental goal of health insurance – namely, intertemporal risk diversification and risk sharing? Cost minimization is one of the key advantages of DAHIs – due to the properties of DAOs, contract-based health insurance systems specify the terms and conditions of the plan – such as length of contract, premium, coverage amounts, and exclusions – as intrinsic system parameters, avoiding legalese and reducing litigation concerns. As opposed to traditional insurance companies, many of which are for-profit, risk-sharing in DAHIs is a fundamental property of the system, enabling benefits of selling insurance contracts, as well as the costs incurred by reimbursements, to be borne equally by all members of the

mutually-owned DAHI, reducing the need to secure financing from Wall Street or for-profit venture capital. (This applies similarly to reinsurance, which can be thought of as DAHIs of DAHIs). The community-centered perspective of risk-sharing in DAHIs also reinforces the goal of the DAHI as a *mutual* provider of care, which significantly facilitates the delivery of quality, affordable care and may also provide significant incentives towards increasing use of preventive care services.

Of course, the concept of decentralized health insurance is completely foreign to most consumers and providers of health services, and significant external investment may be required to create the actual systems, undergo extensive user experience testing to optimize usability, and patch security vulnerabilities. The blockchain in general does not integrate smoothly with conventional healthcare and payment systems, which are contending with their own technological hurdles such as the mass adoption of electronic medical record technologies. Using the Affordable Care Act as a model, we expect incumbent adoption of such a different risk-sharing model to be initially significantly limited by limited insurer experience, size of existing operations, and existing biases against uncertainty [18]; thus, we expect initial scaling of proof-of-concept DAHIs to be limited to underserved groups and indigent care, existing community managed care organizations, and small-scale corporate group insurance more flexible to change.

DAHIs and "hyperlocal" insurance

In addition to advantages in efficiency and implementation, the blockchain concept offers opportunities to massively decentralize insurance risk pools, creating the concept of "hyperlocal" insurance. The proliferation of remote sensing technologies such as smart home technology and the Internet of Things (IoT), combined with analytic and actuarial expertise provided by Big Data, are already transforming actuarial models in disaster and weather insurance [19]. There is significant interest in transforming unstructured data from a patient's life, such as diagnostic reports, psychiatric evaluations, and even social network conversations, into actuarially-relevant information.

Investigators around the world have weighed the advantages and disadvantages of decentralized health care systems in a myriad of studies. Decentralization has been promoted as a strategy to empower local governments to contribute "local knowledge" – better matching need for care with availability of care, empowering local governments to make better public health decisions, etc – along the dimensions of delegation, de-concentration, devolution, and privatization [21, 22]. However, in some studies, including a comprehensive survey of a major anti-poverty program in Mexico, centralized care has actually been observed to produce better outcomes in terms of efficiency of care and in addressing regional disparities than decentralized modes of care [23]. We believe that blockchain technologies offer the ability to address the issue of decentralization in a different manner; specifically, the concept of pegged sidechains (**see sidebar**) allows decentralized DAHIs to match local needs while retaining the advantages of centralization

such as interoperability and asset transfers across chains without counterparty risk [20]. Utilizing pegged sidechains allows for the concept of "DAHIs of DAHIs", or insurance/reinsurance structures that enable DAHIs to specialize in certain aspects of health care provision or h/regional demographics, while providing a measure of stability to the entire system. In addition, the considerable infrastructure investment that already exists in Bitcoin technology, through companies such as Blockchain.info, Coinbase, and BitPay, can serve to implement validated, user-friendly, security-hardened payment systems that already exist transparently in Bitcoin to operate the actual DAHIs through pegging all DAHIs ultimately with Bitcoin.

Pegged sidechains

What are pegged sidechains and how do they work? Being the first blockchain in existence, Bitcoin's design was intentionally simplified, specifying the existence of only one native asset – Bitcoin – and lacking features that have emerged in later projects such as Ethereum. The desire to incorporate new technology and functionality into the Bitcoin blockchain, while keeping the idea of Bitcoin as it currently exists, is supported by the concept of pegged sidechains – alternate blockchains (called "**altchains**" or "**sidechains**") that are interoperable, or "pegged", with the Bitcoin blockchain, the analogy being that foreign currencies in developing countries can either be floating, or pegged with a stronger reserve currency. This concept makes the distinction between **"Bitcoin" the blockchain**, which we seek to supplant with sidechains that incorporate additional functionality such as smart contracts, signature verification, or higher transaction scalability, and **"bitcoin" the asset**, which we seek to retain and reuse as a measure of stability and value, decreasing currency volatility [20].

Prototyping a DAHI

A schematic of a simple, single DAHI is shown below (**Figure 2**). Briefly, a DAHI consists of a collection of members, who each pay an actuarially determined amount of premium into the DAHI pool to receive health insurance coverage. The provider network that contracts with the DAHI then bills for services through disbursements from the DAHI pool.

Members also elect delegates by consensus, which are selected members charged with administrative responsibilities, provider selection, as well as claims processing, and delegates are paid a salary from the pool for their services. Incentive and dividend payments to members and providers, based on achieved health outcomes, are also distributed based on any net profits the DAHI obtains from selling health insurance contracts. Additionally, DAHIs can participate in re-insurance agreements with other DAHIs by pegging the DAHI blockchain and buying/selling DAHI assets from/to other DAHIs.

Note that this schematic of a simple DAHI shares many similarities with existing group policy insurance and managed care systems – this similarity is intentional. For DAHIs to be successful, they must be evolutionary – that is, they must take aspects of conventional healthcare systems, but transfer these aspects into a blockchain-based framework.

Utilizing the strengths of the blockchain – decentralization, ownership structures, mutability resistance – while leveraging existing healthcare systems is essential to make DAHIs useful to members, providers, and the general public.

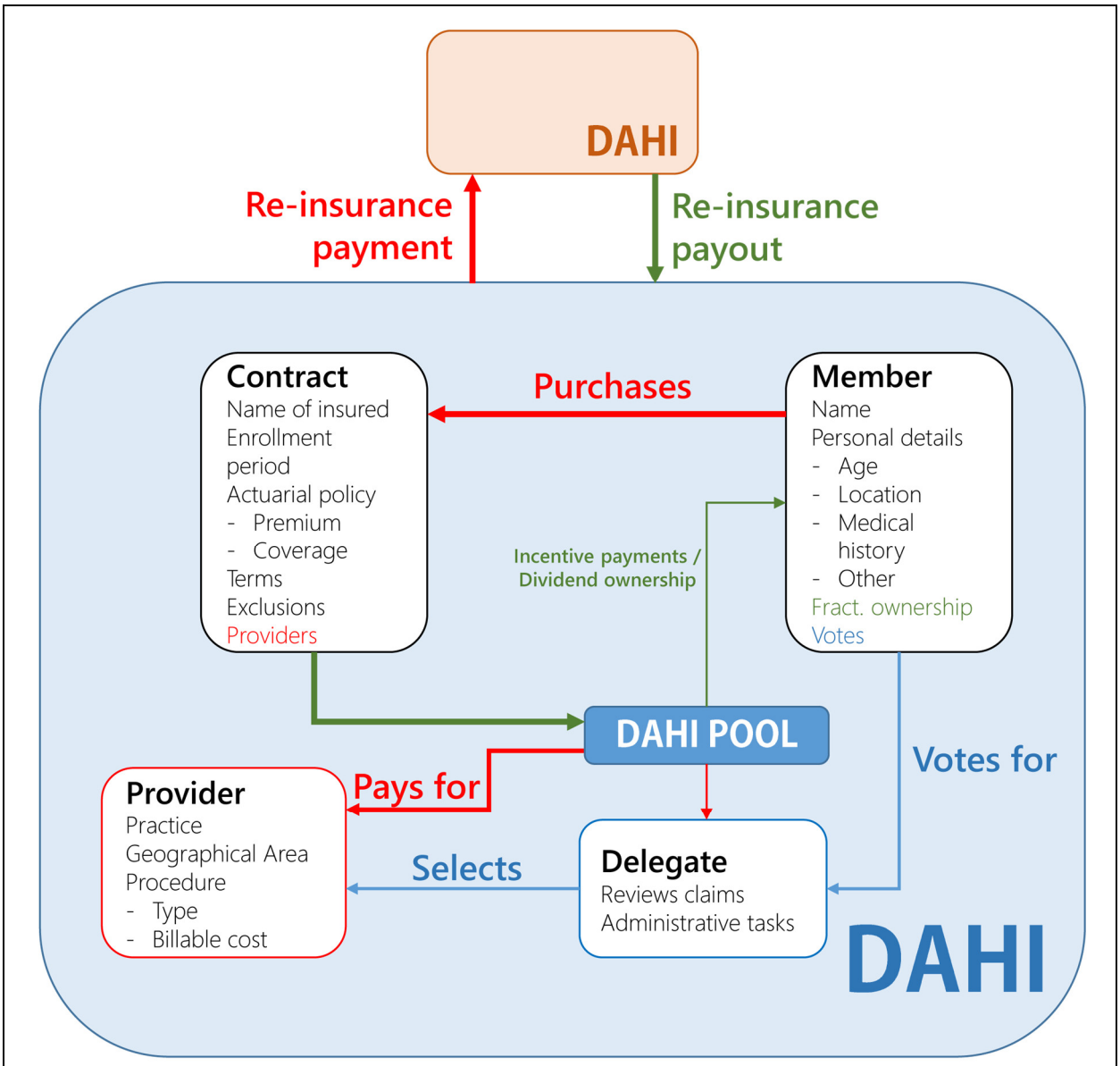

Figure 2: Structure of a simple DAHI. Members in the DAHI purchase insurance contracts, which are smart contracts that define an insurance policy with premiums, coverage terms, provider choice, and exclusions. The DAHI pool is a decentralized structure that receives contract payments, pays for providers and delegates (elected members that review claims, choose providers, and perform administrative duties), and distributes incentive and dividend payments (net profit from contract sales). DAHIs can also participate in re-insurance policies with other DAHIs through pegging of DAHI blockchains by buying/selling DAHI assets from/to other DAHIs.

Conclusion

Can blockchain technology address the three aims of the National Quality Strategy and improve healthcare outcomes? While it is unlikely that blockchain will significantly change healthcare outcomes in the short-term, we propose that implementation of well-designed, thoughtful applications of blockchain technology in critical area of health care delivery can reduce costs, increase availability, and facilitate the transition towards a more technology-oriented healthcare system. In particular, we believe decentralized autonomous health insurers (DAHIs) to be a prototype of technology-enabled health insurance of the future that can reduce costs and improve healthcare delivery by allowing DAHI members to be stakeholders and managers of their own healthcare. As the healthcare system continues to explore new and innovative applications of blockchain technology, we eagerly await new developments in this fast-growing, emerging field of healthcare information technology.

References

1. **Bitcoin currency statistics** [https://blockchain.info/stats]
2. **National Health Expenditure Projections 2015-2025.** In *Centers for Medicare & Medicaid Services*; 2015.
3. Creswell RAaJ: **Data Breach at Anthem May Forecast a Trend.** 2015.
4. Araoz M: In *Proof of Existence*.
5. Kirk J: **Could the Bitcoin network be used as an ultrasecure notary service?** In *Computerworld*; 2013.
6. Wile R: **SATOSHI'S REVOLUTION: How The Creator Of Bitcoin May Have Stumbled Onto Something Much, Much Bigger.** In *Business Insider*; 2014.
7. **Bitcoin: A Peer-to-Peer Electronic Cash System** [https://bitcoin.org/bitcoin.pdf]
8. Lamport L, Shostak R, Pease M: **The Byzantine Generals Problem.** *ACM Transactions on Programming Languages and Systems* 1982, **4:**382-401.
9. Services USDoHaH: **2013 Annual Progress Report to Congress: National Strategy for Quality Improvement in Health Care.** 2013.
10. Brafman O, Beckstrom RA: *The starfish and the spider : the unstoppable power of leaderless organizations.* New York: Portfolio; 2006.
11. **Ethereum Project** [https://www.ethereum.org/]
12. **Counterparty** [http://counterparty.io/]
13. Szabo N: **Formalizing and Securing Relationships on Public Networks.** *First Monday* 1997, **2**.
14. Gabel J, Jajich-Toth C, de Lissovoy G, Rice T, Cohen H: **The changing world of group health insurance.** *Health Aff (Millwood)* 1988, **7:**48-65.
15. Sanger-Katz M: **Is the Affordable Care Act Working?** In *The New York Times*; 2014.
16. **EDITORIAL: The painful costs of Obamacare.** In *The Washington Times*; 2016.
17. Metwally O: **Building smart contract-based health insurance.** 2014.
18. Abraham JM, Feldman R, Simon K: **Did they come to the dance? Insurer participation in exchanges.** *Am J Manag Care* 2014, **20:**1022-1030.

19. Chapman-Henderson L, Rierson AK: **Understanding the Intersection of Resilience, Big Data, and the Internet of Things in the Changing Insurance Marketplace.** Federal Alliance for Safe Homes; 2015.
20. Back A, Corallo M, Dashjr L, Friedenbach M, Maxwell G, Miller A, Poelstra A, Timón J, Wuille P: **Enabling blockchain innovations with pegged sidechains.** *URL: http://www opensciencereview com/papers/123/enablingblockchain-innovations-with-pegged-sidechains* 2014.
21. **Decentralization in health care.** In *European Observatory on Health Systems and Policies Series*; 2007.
22. Singh N: **Decentralization And Public Delivery Of Health Care Services In India.** *Health Affairs* 2008.
23. Vargas Bustamante A: **The tradeoff between centralized and decentralized health services: evidence from rural areas in Mexico.** *Soc Sci Med* 2010, **71:**925-934.