Health Data in Dentistry: An Attempt to Master the Digital Challenge

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Keywords

Artificial intelligence · Dentistry · Medical informatics · Public health · Health services

Abstract

Background: Biomedical research has recently moved through three stages in digital healthcare: (1) data collection; (2) data sharing; and (3) data analytics. With the explosion of stored health data (HD), dental medicine is edging into its fourth stage of digitization using artificial intelligence (AI). This narrative literature review outlines the challenge of managing HD and anticipating the potential of AI in oral healthcare and dental research by summarizing the current literature. **Summary:** The basis of successful management of HD is the establishment of a generally accepted data standard that will guide its implementation within electronic health records (EHR) and health information technology ecosystems (HIT Eco). Thereby continuously adapted (self-) learning health systems (LHS) can be created. The HIT Eco of the future will combine (i) the front-end utilization of HD in clinical decision-making by providers using supportive diagnostic tools for patient-centered treatment planning, and (ii) back-end algorithms analyzing the standardized collected data to inform population-based policy decisions about resource allocations and research directions. Cryptographic

methods in blockchain enable a safe, more efficient, and effective dental care within a global perspective. **Key Message:** The interoperability of HD with accessible digital health technologies is the key to deliver value-based dental care and exploit the tremendous potential of AI.

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Introduction

Advances in information technology (IT) have fostered a global explosion of data generation. Accumulated big data is now estimated to be 4.4 zettabytes in the digital universe [1]; and trends predict an exponential increase in the future due to the widespread utilization of mobile devices, ubiquitous sensors, and cameras [2] (Fig. 1). Health data (HD) can be gathered from professional routine care and other expanded sources including the social determinants of health, such as Internet of Things (IoT), posts by patients on internet forums, surveys and questionnaires from patient support groups and patient diaries. Big data collaborations involve interactions between a diverse range of stakeholders with different analytical, technical, and political capabilities. Medical data technology has many areas of application in healthcare: prognostic analysis and predictive modeling, identification of un-

Fig. 1. Exponential growth of digitally generated data in Europe. [Modified according to United Nations, Economic Commission for Europe, 2015 (<http://data.un.org>)].

known correlations of diseases, clinical decision support for novel treatment concepts, public health surveys, and population-based clinical research, as well as the evaluation of healthcare systems [3].

HD has emerged as a promising source of health records. However, HD is essentially rendered useless if data collection systems are not integrated into the wider Health Information Technology Ecosystem (HIT Eco). On the one hand, the systematic collection and increased availability of HD will only be possible when its applications are known, sources are pursuable, and users are better able to undertake self-discovery of the data; on the other hand, it is the lack of trust between data custodians and data users, and the numerous hurdles with data sharing that have stifled the potential utility and value that could be derived from existing HD [4]. The improvement of consumer's trust in the security of data and facts emerges as a community-wide social and political objective. This implies that all data custodians must partake in a strong and clear cultural move towards enhanced usability in general and transparency in particular [5].

Dentistry has lagged behind medicine in embracing health IT but the extensive adoption of electronic health records (EHRs) is the first step in a more structured digitalized direction. The use of connected health technologies and HD has, however, remained largely unexplored and its potential for improving patient care has yet to be harnessed. Therefore, the goal of this narrative literature review is to present a blueprint that attempts to master the challenge of HD collection, sharing and analytics, including a forecast of upcoming developments of artificial intelligence (AI) in oral healthcare and dental research (Fig. 2).

Fig. 2. Idealized flow for the management of health data: collection, sharing, and analytics following uniform standards and integrated general patient consent.

Data Collection

Collecting HD is only valuable if this is done systematically according to harmonized and inter-linkable data standards to produce high-quality data. However, most of the databases are not compatible with each other today; and therefore, automated data collections and interpretations are still difficult. The use of EHRs, unlike paper-based systems, fosters compliance with documentation standards by forcing clinicians to enter data in a structured format, allows the monitoring of HD (this capability has remained largely unexplored), and promotes the sharing of information between various members of the healthcare team [6]. Nevertheless, the best data algorithms are only as good as the reliability and validity of the original input. A major problem facing data collection in healthcare is poor data quality characterized by missing and incomplete data, which occurs when there is no standardized format for capturing data or when specific population cohorts do not

Fig. 3. Health data availability can be viewed from four major perspectives in dentistry: (1) patients; (2) healthcare providers; (3) research and academia; and (4) policy makers.

have their data recorded accurately [7]. Uniform data standards in terminology, diagnostics and treatments, and software applications are crucial for value-based healthcare, which emphasizes better service and improved health outcome at a lower cost [8]. A standardized terminology in dentistry and the use of structured forms and templates to reduce the likelihood of missing or incomplete data will greatly facilitate the uniformity of data collected and its subsequent aggregation for analysis, learning, and quality improvement purposes [9].

Population-based linkage of patient-level information constitutes the foundation of an effective HIT Eco. Creating avenues whereby HD can be easily collected on the front-end by clinicians or medical auxiliaries in a structured manner and extracted or aggregated on the back-end within a larger HIT Eco will increase our understanding of risk factors, trend patterns, and treatment outcomes. The integration of PGHD into this HIT Eco will further augment such data registries as patients gather data on a routine basis and can easily paint a more holistic picture of their health status as well as provide some insight into other social determinants of health that ultimately affect their treatment outcomes [10] (Fig. 3).

However, the integration of HD into HIT Ecos brings to light ethical concerns regarding privacy infringements and the use of aggregated HD for purposes other than the

delivery of healthcare [11]. Since there are multiple and oftentimes conflicting perspectives among stakeholders involved in big data collaborations, it is essential that a generally accepted code of conduct is defined and established that guides the ethical and meaningful use of HD within a global implementation. This could involve the implementation of a universally accepted general patient consent (GPC) at the point of data collection which allows patients' linked biomedical data to be stored un-anonymized in data registries and used for future research purposes, especially in cases where consent might not be feasible after the fact. Particularly in research using de-identified patient data, appropriate security protocols such as the establishment of access permissions to patient identifiers, algorithms for statistical analyses, and interpretation of generated data need to be developed and implemented [12].

Data Sharing

The ubiquitous collection of HD inevitably leads to a huge accumulation of patient-level information. Efficient management of HD should not only involve maintaining integrity in its collection and subsequent storage, but must also encompass assuring safety when data is shared and

simplifying interoperability by utilizing user-friendly applications for quick access and filtering options [13]. As conventional methods for collecting patient data, such as (prospective) clinical trials, have become more complex due to high costs, time expenditures, and difficult patient recruitment, the existence of a linkage between HD collection platforms and the EHR is a promising tool in health-care science [14]. Register-based controlled (clinical) trials [RC(C)T] are well-characterized, particularly for medical research, generate comprehensive evidence with a high level of external validity, and allow observations with minimal loss to follow-up of large sample sizes [15].

Data anonymization is a type of information sanitization whose primary intent is privacy protection. It is the process of either encoding or removing personally identifiable information from datasets. Anonymization methods include encryption, hashing, generalization, pseudonymization, and perturbation. De-anonymization is the reverse engineering process used to detect the source data. The most common technique of de-anonymization is cross-referencing data from multiple sources [16]. The potential for re-identifying individual patients from anonymized data poses unique challenges to biomedical research, as the protection of patients' privacy is paramount (<https://www.whatisgdpr.eu/>). The complex legal landscape around health privacy, e.g., sharing data across national borders, creates both obstacles for individuals trying to access their personal information and also hurdles for biomedical researchers attempting to establish RC(C)Ts. In this context, the delicate handling of dental biobanks with sensitive patient material, such as saliva, blood and teeth, must be clarified, as these samples could be used for genetic analysis [17].

Collection of health-related information generated today is not strictly regulated outside clinical trial settings and the use of data for non-healthcare delivery in terms of research purposes is poorly integrated between the HD platforms and EHRs. Data interoperability should enable the secure exchange of electronic health information with, and use of electronic health information from, other HIT Eco without special effort on the part of the user. Moreover, it means complete collection, exchange, and usage of all electronically accessible health information for authorized use under applicable legal law regulations without any kind of constitutional blocking [18]. Increased sharing of data could facilitate greater leveraging of technology by analyzing larger cohorts to improve patients' and dental healthcare providers' interactions with policy makers and government and to increase administrative efficiency. However, researchers trying to share

data across health systems, let alone across borders, face huge regulatory burdens that render large-scope data sharing efforts next to impossible. If biomedical researchers want to take advantage of today's technical interoperability solutions, regulatory bodies need to solve privacy, ethics, security, and intellectual property issues [19].

Blockchain is getting a lot of attention recently. It is a distributed ledger technology implemented in a decentralized manner used to record transactions [20]. The records are kept across many computers such that data cannot be changed retroactively without the alteration of all subsequent blocks and collusion with the entire network [21]. Blockchain will have a profound transformative impact on the global economy and society including health-care business for data sharing [22]. It offers a new way to manage trust between untrusted parties by supporting an immutable record of transactions: (1) distributed database; (2) peer-to-peer transmission; (3) transparency with pseudonymity; (4) irreversibility of records; and (5) computational logic [23].

Data Analytics

The secure sharing of HD provides opportunities for research when this data is integrated into EHR systems that are part of a larger HIT Eco. Establishing huge population-based cohorts will help to identify unknown correlations of symptoms and diseases, novel prognostic factors, risk analysis, innovative treatment concepts, and facilitate the evaluation of entire healthcare systems. The linkage of patient-level information to population-based citizen cohorts and biobanks provides the required reference of standardized diagnostics and screening cutoffs that could detect new biomarkers through personalized health research. Here, a continuous feedback loop is necessary whereby science has to report the obtained findings in a format that is easily accessible to clinical front-end providers and policy makers [24].

Falling costs (per record) of digital data storage and the spread of low-cost and powerful statistic tools and techniques to extract patterns, correlations and interactions, are also making data analytics more usable and valuable in dental medicine. Nonetheless, the personnel costs of maintaining HD, as well as the need for IT experts and scientists, are climbing rapidly and have to be considered as well. Therefore, HD science has to foster an open digital ecosystem that will accelerate efficient and cost-effective biomedical research to enhance oral health for the benefits of the community [25].

Interoperability is a prerequisite for data sharing, and consecutively, for the analysis of all data including HD. Here, learning health systems (LHS) are a proposed solution for rapidly applying the best available scientific evidence in real-time clinical practice. In a LHS, evidence and practice come together in a virtuous cycle, stimulating and influencing each other positively. It is a dynamic progress of science and informatics to align and generate new knowledge as an ongoing, natural byproduct of the healthcare service; and seamlessly refine and deliver best practices for continuous improvement in diagnostics, therapy, and consecutively, treatment outcomes [26].

Researchers and clinicians have to realize that advancing dental research alone will not fix the local healthcare system. Most dental innovations take 5–10 years to move into real-world healthcare settings [27]. A shared commitment to leverage scientific knowledge and evaluate changes in real-time allows rapid, point-of-care improvements to move innovations forward. Strong leadership support and a growing partnership between research and clinical operations are necessary to evolve as a successful LHS. This partnership has fostered a culture and an infrastructure to facilitate rapid learning with continuing communication, engagement, and flexibility – met from all partners [28].

Focused issues are shared decision-making to ensure that treatments are more consistent with patients' ideals and preferences, and value-based benefit design, using incentives and disincentives to steer patients toward the most effective, evidence-based services (and away from unproven concepts). Core characteristics of LHS are access to patients for research, immediate availability of best practice knowledge to support (clinical) decisions, and continuous improvement through ongoing studies.

Too often, researchers, clinicians, and policy makers operate in separate worlds, with different time horizons. Although the pace of research is accelerating, it is still far slower than the urgent time frame inherent in clinical care decision-making. Researchers who seek to improve care outcomes should consider spreading novel findings beyond journal articles by embracing implementation science principles to accelerate the translation of their findings into health outcomes [29]. Academia and the research community need to think carefully about dissemination tools that really work well for reaching clinical leaders. Broader internal and external dissemination routes include newsletters, trade publications, websites, reports in the media, and meetings with stakeholders including patients, clinicians, and administrators. HD analytics should not just result in the publication of journal

articles and shelf-ware reports, but support care decisions at the local level to embrace the broader conception of a learning commons [30].

Artificial Intelligence

AI is predicted as the further development of the digital revolution. AI tools in healthcare are rapidly maturing and are expected to have a profound impact in the near future [31], including, as some argue, the replacement of whole professions [32]. AI in healthcare uses algorithms and software applications to approximate human cognition in the analysis of complex data, including HD. A primary goal of dental AI applications should be the analysis of the relationship between prevention and treatment techniques in the field of public health as well as analytics of patient outcomes. AI solutions have been developed and applied to diagnostic recommendations, therapy protocols, biomedical pharmacy, personalized medicine, patient monitoring, and even foresight of epidemiological disease expansion from a global perspective [33]. In this context, AI will facilitate the translation of basic and clinical research to permit human clinicians to find the best modalities for their patients. The missing link between *in vitro* findings and the straight way into (routine) clinical therapy needs to be bridged for the benefits of a larger patient population as well as being made accessible to underdeveloped countries [34]. Moreover, AI will also approximate the gaps between dentistry and medicine to clarify the inter-relationship of general disease patterns and their mutual influence on oral health.

AI will aid human clinicians in diagnostics and treatment planning, particularly in radiology and all fields of 3D imaging. After entering patient information, on-the-spot recommendations from the HIT Eco with a list of differential diagnoses, treatment options, and probabilities of success will be immediately delivered to the clinicians [35]. The superimposition of 3D medical imaging files of the skull, the facial soft tissue, and the dentition to create a virtual dental patient appears to be a promising tool that will be useful in various clinical scenarios and indications: (1) preoperative clinical assessment and simulation of treatment planning; (2) postoperative follow-up documentation; (3) to facilitate more effective interdisciplinary communications and patient communications; and (4) as a training tool in dental education. Therefore, patient simulation technology will have wide-ranging applicability in prosthodontics and oral rehabilitation, im-

Table 1. Advantages of digital HD in dental research

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- Improved ability to find patient-level information through deliberate use of standardized data;
 - Development of a regulatory framework permitting timely access by trusted users;
 - Collaboration with HIT partners to succeed interoperability using standardized platforms for EHR;
 - Promotion of re-use of data already obtained and stored for the benefit of the community;
 - Systematic filtering of patients for prospective research applying trial-specific inclusion criteria;
 - High-quality clinical research with large sample sizes and accelerated recruitment;
 - Epidemiological surveys for public health-related statistics;
 - Early identification of emerging health issues and future research needs;
 - Simplified translation from dentistry to medicine and laboratory to clinical science;
 - Assessment of safety of treatment protocols and pharmaceutical therapy on an ongoing basis; and
 - Evaluate the effectiveness and efficiency of healthcare services and policy
-

plant dentistry, orthodontics, dentofacial orthopedics, as well as maxillofacial and plastic surgery [36].

AI will not only support dentists in their clinical work, but also make clinicians gradually dispensable for specific treatment steps [37]. Robots have increasingly been used to assist dentists with procedures such as root canal surgery and orthodontic operations as well as in training students. Recently, a Chinese robotic-dentist was first to fit implants in patient's mouth without any human involvement. Moreover, the progress will continue inexorably touching all fields of dental medicine [38].

Conclusion

Biomedical business moved through three stages in digital health: (1) data collection; (2) data sharing; and (3) data analytics. Interoperability of obtained HD is a key for value-based dental care. With the explosion of HD being gathered and stored, dental medicine is edging into the fourth stage of digitalization using AI.

As dentistry strives for better health IT and HD utilization, key aspects need to be considered for the establishment of a standardized data collection system that allows the real-time linkage of patient information from disparate data sources at the individual and population-levels and prompt data analysis to determine trends, risk factors, as well as treatment outcomes, which can guide clin-

ical decisions, research directions, and policy recommendations. System-independent interfaces for data collection and subsequent interpretation need to be invented and newly programmed. The implementation of standardized protocols ensures high-quality HD and enables comprehensive analyses, critical interpretation, and clinically useful transferable conclusions using EHR, HIT Eco, and automated LHS supported by AI.

The HIT Eco of the future combines the use of all HD to make decisions, ranging from individual care decisions with the help of a chairside clinical decision support system to population-based policy decisions about resource allocations and the production of significant research output as in high-impact publications. The goal must be to strive to translate evidence into practice and policy quickly. At the same time, to try to align research with the questions that clinicians and administrators need to answer as soon as possible (Table 1).

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Statement of Ethics

The authors have no ethical conflicts to disclose.

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Author Contributions

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