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DIGITAL TRANSFORMATION IN HEALTHCARE: KEY TECHNOLOGIES AND APPLICATIONS

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ABSTRACT

Digitalization has become inevitable in healthcare as in other fields. It is predicted that healthcare services will become digital with the combination of genomics, artificial intelligence, the Internet of Things and robotic technologies. There is no doubt that this digital transformation will significantly change both the roles of healthcare professionals and the health status of patients over the next two decades. Although some of these technologies have started to be included in the health ecosystem, it has been anticipated that a certain period time is required for genomics, artificial intelligence and robotic technologies to be fully ready within the scope of digitalization in health. In addition, synergetic technologies should be developed to interpret and integrate data to be used in these approaches. It is expected that digital health technologies and related tools, whose sole goal is to improve human health, will be included in our lives more prominently and their positive effects on human health will be felt soon.

Keywords: Artificial intelligence, digital health, genomics, robotics, wearable devices.

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1. INTRODUCTION

In recent years, medical science and healthcare services have been subject to digital transformation in many different sectors. Digital healthcare services and related technologies have a great potential for early diagnosis and more effective, personalized treatment options for diseases. Incrementing needs in fields such as patient-centered treatment approaches, security of health data, the efficiency of diagnosis and treatment processes, administrative efficiency, preventive treatment services and effective intervention of emergencies have made digitalization in health more essential. For this purpose, it is crucial to develop novel digital medical tools equipped with new technologies (genomics, AI, robotics, etc.), but this approach requires multidisciplinary efforts with the cooperation of many specialties including healthcare personnel, scientists, engineers and ethicists [1]. This transformation process requires hard and intense effort. When compared with the digital revolution in various industrial sectors, we see that healthcare services get behind in this transformation. The main reason for this delay is the strict regulatory mechanisms that are regulating healthcare services [2]. Despite this slow progression, some countries have taken huge and pioneering steps toward digital healthcare transformation. Several countries have begun to implement various digital healthcare services in their health ecosystem, and this is bringing revolutionary developments to their healthcare services. For example, UK's 100.000 Genomes Project is accounted as one of the most important digital transformation efforts in healthcare. The sole goal of this project is to integrate genomic services into routine healthcare and lead off personalized medicine initiatives [3-5]. Similarly, the Danish National Genome Center aims to advance personalized medicine by sequencing the genome of patients for clinical and research purposes. The center is involved in the processing, analysis and secure storage of genome data. It also offers guidance on data interpretation [6]. Health data recording platforms where physicians can access their patients' old health data such as medications, diagnoses, radiological images, etc. are also becoming widespread. Examples include *e-nabız* in Türkiye [7], *Kanta* in Finland [8] and *Journalen* in Sweden [9].

Hereof, the integration of genomic services into the healthcare system is one of the most significant milestones for the digital transformation of the healthcare systems. This integration has the potential to revolutionize the whole body of healthcare services end to end. Along with genomics, other digital technologies like telemedicine, wearable devices, remote monitoring, artificial intelligence, and robotic systems have become more prevalent digital transformation of healthcare. In order to produce better results, digital health services should be in a continuous state of renewal and development. For this, these services should include up-to-date and harmonized multi-layered data which are combined with electronic health records (EHRs). EHRs can include past diagnosis and treatment data, administered drugs, clinical reports, genomic data, medical tests, and radiological imaging results. A synergetic combination of health data and the aforementioned technologies have great potential to support decision-makers in terms of diagnosis and personalized treatments. Ultimately, unnecessary analyses and imaging processes can be prevented, so cost-effective treatments and easy follow-ups can be accomplished [1].

This review aims to sum up the importance of several digital health technologies and their relevance to digital healthcare transformation, as well as projections for the future.

2. ADVANCED TECHNOLOGIES IN DIGITAL HEALTH

In today's medical services and public health literature, digital transformation has become extremely popular in health services, preventive health applications, and health, with the use of digital devices and artificial intelligence-based applications, mobile applications and websites [10]. Individuals in today's developed societies tend to monitor and keep their health parameters under control, with the increasing awareness of healthy living. This phenomenon increases the demand for an informatics infrastructure where personal medical data can be transmitted electronically and for healthcare professionals who can communicate regardless of time and place. Technologies that can collect and record personal health data in real-time can connect and exchange data with remote servers over the internet, thus enabling health services to be provided without time and place limitations [11, 12].

Predictions of how these digital technologies will come to dominate in public health as a means of providing information, delivering patient care and collecting large masses of data have proliferated [13].

In the context of technologies including genomics, digital medicine applications (telemedicine, mobile/wearable technologies, and Internet of Things), artificial intelligence, and robotics are expected to have an impact in changing the roles of health professionals in the next decade.

In this section, these technologies are examined separately. Most importantly, hybrid tools need to be developed within these technologies. So, the revolutionary benefits of digital transformation in healthcare can be acquired.

2.1. Genomics

The sequencing capacity of an individual's genome has increased significantly. For years, conventional and microarray-based genome scanning technologies have provided important insights to clinicians in diagnostics. However, conventional technologies have lower genome scanning resolutions than Whole Genome Sequencing (WGS). This disadvantage can hamper the diagnosis of genetic diseases in many instances. For example, small deletions, insertions, duplications can be missed with these conventional methods, while WGS can detect nucleotide level variations. In addition, there are many diseases whose by genetic background is still unknown. Therefore, whole genome sequencing is the best way to detect genetic variations that cause diseases. The United Kingdom began to implement whole-genome sequencing for routine use after completing the 100.000 genomes project. By sequencing 100.000 individuals' genomes, the UK gained significant insight in diagnosing, treating, and understanding the molecular basis of certain diseases including cancers and rare diseases.

UK's NHS (National Health Services) genomics medical service aims to implement whole genome sequencing as a routine national healthcare service, with the superior goal of sequencing and analyzing 5 million genomes in the next five years [5]. Within this vision, it is being anticipated that the genomic health services (especially whole-genome sequencing) will encompass all diseases and eventually will be implemented to health ecosystem [1]. Thus, prevention, management, early detection and treatment of diseases can be controlled more efficiently. As a result, WGS can be provided as a routine laboratory test and it may replace other conventional diagnostic techniques in near future.

Parallel with the routine use of WGS, genomic data utilization, data security and genomics awareness to people will be the critical matters to handle. From a technical aspect, there is a significant need to establish sufficient data storage spaces and build secure, sustainable High-Performance Computing data centers. Also, regulations for data security and privacy should be granted with solid policies and people must be informed that their personal data is safe with global regulations. Public health agencies and their collaborating institutions should minimize risk by improving staff skills and the way data is acquired, used, maintained, stored and shared. When individuals believe that their data is stored securely, they will be able to easily give consent for its use [14, 15]. Implementing and combining genomics data with electronic health records is another challenge to be accomplished. This combination is critical, because, it is crucial to analyze and interpret genomic data together with deep-phenotyping data for more precise results. So, clinicians can calculate genetic risk scores more efficiently, prescribe personal treatments or recommend lifestyle changes [16].

Before integrating genomic medical services into the health ecosystem, genomics education should be given to the health workforce. Citizens should also be informed of the benefits of genomics services and how their genomics data could positively affect their health, as well as the whole population. Furthermore, genome sequencing techniques expand the scope of genomic medicine by enabling us to understand tumors, microbiomes, and other genomes which has clinical significance such as pathogenic bacteria and viruses [1]. Soon, genomic services will not be limited to only genome sequencing which only enables us to read and understand human genome variations. Disease-associated mutations that are discovered by genome sequencing can also be corrected with genome editing tools to treat diseases. In recent years, such treatments are being investigated by editing the specific DNA sequence in the individual's genome using CRISPR / Cas9 technology [17]. For example, there are some exciting new developments in curing hemophilia with this novel gene-editing technology [18]. In addition, the NHS has authorized the use of gene editing methods for the treatment of Adenosine deaminase deficient severe combined immunodeficiency [19]. Gene editing therapies show great promise in cancer too, especially in hematological malignancies. The best example of such personalized gene-editing therapies is CAR-T (Chimeric Antigen Receptor T cell therapy) [20]. CAR-T has also been authorized for the treatment of Non-Hodgkin and B-cell lymphomas, and future genome-editing therapeutics research is concentrated on curing solid tumors [21].

2.2. Telemedicine

Telemedicine is an application that makes it possible to provide remote clinical services in the same format as face-to-face consultation by using various telecommunication technologies. Since the demand for healthcare services has increased in recent years, telemedicine provides great benefits to both patients and healthcare professionals [22]. Telemedicine first emerged when patients received information from doctors over the phone, who did not require any emergency intervention, face-to-face consultation, or specific clinical measurements. Afterward, the utilization of telemedicine services expanded with the widespread use of advanced mobile applications, wearable sensors, portable home care robotic systems, and artificial intelligence algorithms. While telemedicine has a long history, its technological evolution is making significant contributions to the digital transformation of healthcare today. Eventually, telemedicine services are divided into sub-fields such as teleradiology, telerehabilitation, telecardiology, home telecare, and telediagnosis. Telemedicine services, whether integrated directly into the health system or provided through online services, are becoming increasingly popular. Possible advantages of telemedicine approaches can be included easy access to remote diagnosis and treatment of elders and bedridden patients. Also, with the help of telemedicine, healthcare workers can access much more easily to their patients who are particularly residing in crowded cities [23]. Positive feedback and good results have already been reported about video consultations by patients during their long-term care [24].

With the introduction of telemedicine applications, the approaches of healthcare beneficiaries to information quality and satisfaction, access, effectiveness and trust issues have been the subject of research [25]. One of the most important advantages of Tele-Medicine is that it facilitates access to health services for patients with financial and transportation limitations. At the same time, telemedicine helps to reduce the time patients spend on healthcare services. It can provide serious benefits in the management of chronic non-communicable diseases such as lung diseases, diabetes, hypertension, cognitive diseases etc. [26, 27].

In a study conducted by the World Health Organization (WHO) in 2009, it was shown that teleradiology is used the most of the tele-medical methods [28]. It has been determined that the development of mobile devices and applications with advancing technology has made a remarkable contribution to telehealth. Important advances have been made in the follow-up and treatment of patients through these applications [29].

Swiatek et al. reported that 35.6% of surgeons made more than half of their daily visits online in their study of 902 spine surgeons from seven different geographical regions during the pandemic period. Especially in academic hospitals in North America and Europe, this applications have been reported more widely [30].

In general, physician-patient satisfaction has also been investigated in telemedicine studies. Villa et al., in a study conducted at a center providing oral care, patients 91.8% of them ensure adequate communication with the specialist they are consulting, 92.8% of them understand the patient's problem, two thirds of the patients believe that this practice it has been reported that it makes it easier to access medical care and treatment, and as a result, 84.7% of them are satisfied with Tele-Medicine practice [31]. Participating experts stated that Tele-Medicine application increased the quality of patient care by 82.3% and was effective in 50% of the visits. In the same study, the desired biopsy rate after examination was reported as 30%, and it was suggested that this method is effective not only for patient evaluation, but also for providing advanced diagnosis and treatments [31].

As a result, telemedicine services enable reducing the burden of chronic disease, improving patient outcomes, increasing the effectiveness of treatment and care practices, and effectively using the increasing need for healthcare. For telemedicine services to become widespread, they should be considered as a field of expertise, disseminated at the level of national policies, including in clinical practices, administrative support should be provided and financial resources should be determined [32].

2.3. Mobile/Wearable Technologies and Internet of Things

Expectations regarding health services are the early detection of diseases, monitoring the health status of individuals with chronic diseases, making a healthy lifestyle a habit and improving the general quality of life of individuals. With the number of self-care activities that can be done at home and the increase in the awareness of individuals about technology, the demands of doctors to remotely monitor the health status of their patients have increased the need for wearable technology. Wearable technology is defined as any electronic device placed on the body or clothing by various methods [33, 34].

The Internet of Things is an innovative technology that enables physical objects used in daily life to exchange data among themselves over the Internet. The basic idea behind the Internet of Medical Things (IoMT) applications is to detect and process patient data without any restrictions, and to provide remote communication with smart devices. Today, there have been a lot of changes in wearable technologies. Desired changes have been experienced in the devices used in this area and their efficiency has been increased. Innovative wearable devices have become able to do many tasks that computers and smart mobile phones can do. It is possible to provide instant data transfer by connecting wearable devices with applications prepared for smart phones [34, 35].

The use of smartphones equipped with advanced sensors and applications has increased in recent years. In this way, smartphones can basically track daily health-related parameters and activities of their owners. Consequently, these devices has become important component of digital health technologies. With help of collected data from these devices, they have great potential for early diagnosis and follow-ups. These applications can include wearable sensors and video cameras that can be used for remote monitoring of patients [36-39].

Especially chronic disease follow-up and early warning applications are some of the current and effective usage of this technology. In addition, applications such as remote monitoring, telerehabilitation, smart sensors and medical device integration can be given as examples [40]. Individuals with chronic diseases (diabetes, cholesterol, heart diseases, etc.) and patients who need to be followed at certain periods of time can be closely monitored with the help of wearable sensors. Data obtained from sensors can be transferred and analyzed within a digitalized health system. Thus, various diseases can be intervened early and deaths can be prevented.

Wearable technology reduces the need for direct patient-expert interaction to make the measurements and provides innovative ways to obtain and present the necessary data [40-42]. When it comes to health, it doesn't matter whether the data collected is related to blood sugar level or heart rhythm, total steps taken and calories burned, it is vital for people to monitor all kinds of health information. [43, 44]

By using an IoMT device that has sensors that measure parameters such as body temperature, movement activity, blood pressure, glucose and oxygen in the blood, routine control and determination of the activity level of the patient can be done remotely. Patient data can be sent to doctors for examination, in case of a problem, the patient is called to the hospital or an ambulance is sent in case of an emergency [45, 46]. Thus, unnecessary hospital admissions and the spread of infectious diseases are prevented, more effective service can be provided to other patients and health expenditures are reduced.

In the research conducted with the help of IoMT-enabled wearable devices working over Bluetooth, the weight and blood pressure data of the patients were continuously followed up and cancer screenings were performed. With the help of treatment according to these data, it has been shown that cancer patients show much less severe symptoms. In another study, the IoMT device (iTBra) detected temperature changes in the breast tissue and cancer was diagnosed at an early stage [43-47].

The use of IoMT not only improves patient safety and quality of care but also reduces care costs. According to a study conducted in Singapore, the use of telephone therapy for diabetic radiculopathy alone saved $29.4 million. With the widespread use of IoMT in the field of health, many diseases can be detected at an early stage and deaths related to these can be reduced and financial savings can be achieved [42, 43].

2.4. Artificial Intelligence (AI)

It is estimated that AI technologies will have a great impact on the digital transformation of healthcare services. In this context, health authorities should support the workforce and scientists who can design these technologies and integrate them into daily medical use. To achieve this goal, it is necessary to train people with the essential technical skills and encourage whole ecosystem. In health services, data density is high and multi-layered. So, there is a need to organize complex classifications to constitute comprehensible interpretations. AI and deep learning techniques are the most suitable approaches to achieve this goal. Several deep learning technologies are already designed and implemented for automatic image interpretation from MRI (Magnetic resonance imaging), CT (Computed Tomography) data which are actively used for diagnostics [1]. Necessarily, advanced analyzing algorithms, high computing power, and large data storage space are required to get the best interpretation and benefits from the multi-layered health data. With the provision of optimal conditions for these technologies to work at high performance, AI-based technologies can improve their clinical diagnostics accuracy.

Big data is another must for all AI-based systems. More precise results and interpretations can be obtained after the processes of storing, grouping, labeling, processing, and evaluating massive and multi-layered medical data by relevant AI-based algorithms. At this point, personal privacy and data security must be ensured. Storing the personal and medical data in a digital environment bring great responsibility to health authorites. Various protocols have been developed for ensuring data security. Most of them are of the concept that data is kept in a single center or distributed across several centers. Data storage and transmission activities are carried out through these centers. In recent years, blockchain-based, decentralized, distributed structures have become popular. Blockchain technology [48] allows data to be stored and distributed independently from a central authority. Blockchain technology is one of the best options that may be applied for securing health data. The scheme of this technology has the highest capability to eliminate potential security breaches.

Decision support systems are another AI-based promising application in healthcare. For instance, such systems can be utilized for the precise diagnosis of diseases by only analyzing blood samples. They can also detect embolisms, tumors, bleedings from radiology images (CT, MRI, mammography, x-ray, etc.) by training them with adequate image datasets. With the help of decision support systems, adequate physical therapy can also be accomplished by analyzing and interpreting various biomechanical parameters of limbs such as strength, range of motion, etc. [49].

Strikingly, early preventive treatment practices can be applied by AI-aided analyzing genomic data. For example, combined analysis of nutritional habits, weight change, diet programs with genomics data can help determine obesity and heart disease risks. After determining disease risks, virtual guidance services can propose individual diet programs and lifestyle changes for better health. AI-based mimic recognition and natural language processing systems are also expected to take an active role in psychotherapy [50, 51]. Artificial intelligence also makes important contributions to administrative processes in healthcare. Appointment and scheduling processes can also be automated with artificial intelligence-based algorithms. So, scheduled payment transactions can be achieved by integrating the hospital information system and banking/insurance systems. By incorporating hospital management programs into the main system, stock planning of drugs, vaccines, medical consumables, surgical tools and, laboratory materials can be made automatically. Such practices have the promising offerings for increasing the capability of administrative processes.

2.5. Robotics

Robots are frequently used in healthcare due to their ability to operate with high accuracy and precision. Robots can apply sensitive contact forces when accomplishing their tasks with various control methods. More importantly, robots can be remotely controlled in highly contaminated environments (ie. areas exposed to viruses, bacteria, and radiation, etc.). Surgical robots, care robots, rehabilitation robots, exoskeletons, and hospital robots can easily accomplish their operations in such environments with great precision. In addition, as robots become smaller in size, they are envisioned to be able to perform more detailed and precise tasks. Accordingly, robots will be able to operate critical tasks even in a blood vessel. Presently, robots used in health services are supported with primal artificial intelligence, but it is predicted that this will change over time, and artificial intelligence will have more say in robots' operation. This predicts that the robots will implement their own decisions while performing tasks, where ethical and legal problems may arise at that point [1].

The first medical robot concepts in healthcare were developed for the purpose of CT navigation and have a simple structure equipped with a probe. These robots are mainly used for collecting biopsy samples from organs. Following robot designs was capable of performing other specific surgical procedures autonomously. However, such autonomous robots were not welcomed by most surgeons. Consequently, most of the medical robots were modified to be used manually under the complete operation of surgeons. Today, medical robots are generally used in numerous surgical procedures for creating incisions with the help of computers and software [52].

Robot-assisted surgery is mainly associated with laparoscopy. Robot-assisted laparoscopy has many advantages like having small incisions, reduced blood loss, and quick recovery time. Along with patients, surgeons also benefit from robot-assisted surgeries with the help of their advanced ergonomic capabilities. The main disadvantages of such robotic methods are the high cost and the need for the hard training of surgeons and surgical teams [52].

The utilization of rehabilitation robots and exoskeletons in rehabilitation and physical therapy has increased significantly in the last 20 years. Robots for upper and lower limb rehabilitation differ from each other in terms of control, propulsion, mobility, and exercise capacities [53]. The use of robotic technologies in the field of prosthetics has recently gained momentum. Developed lower and upper limb prostheses are becoming capable of adapting to the user's movement profile, learning and responding appropriately to environmental conditions. This is made possible by innovative designs, new control systems and artificial intelligence methods. Robotic exoskeletons are also widely used in rehabilitation, helping paralyzed people to walk and move [54].

Depending on the world population growth rate, we see that the number of elderly and disabled individuals has increased accordingly. Various care robots have been developed for these individuals to maintain their vital activities. As an example, robotic systems can enable mobilization and support feeding activities of bedridden patients.

Another significant advantage of robotic systems in healthcare is that they can maintain their operations in contaminated environments because their functions are not affected by microorganisms, viruses, or radiation. Mobile robots which are specialized in disinfection purposes are also widely used in the COVID-19 pandemic [26, 55]. Robots can also be used in the applications of serving food and medicine to patients. These robots can be controlled remotely, as well as work autonomously with the help of optimum route planning algorithms and image processing techniques. The combined use of artificial intelligence and robotics can help healthcare professionals to provide safer and high-quality services to their patients.

3. Conclusions

With the combination of technologies such as the Internet of Things, artificial intelligence, robotics and genomics, early diagnosis of diseases and the development of personalized treatments will be possible by ensuring digital transformation in the field of health. These treatments and preventive diagnostic approaches are basically based on the combined analysis of personal information (clinical, lifestyle, environmental exposures, etc.) and genomic data. Accordingly, many countries are gradually incorporating genomics and related technologies into their health ecosystems for more precise, cost-effective diagnostics and treatments. With this integration, it has become important to develop systems that provide remote information flow, including artificial intelligence, and apply them to the health field. The most problematic process to deal with in such systems is the acquisition, secure storage, interpretation and utilization of data [56, 57]. In this process, data must be protected from malicious people and organizations. In addition, this data should be categorized in a meaningful way to provide targeted benefit. The development of these technologies, their adaptation to the field of healthcare, ensuring data security and the meaningful use of data can be seen as a roadmap of the digitalization process in healthcare. With the various opportunities offered by the digitalization of healthcare, health authorities can more effectively manage the economic and physical burden of chronic and rare diseases. As a result of these benefits, healthcare costs can be reduced through increased efficiency. Ultimately, all stakeholders involved in healthcare (patients, healthcare professionals, administrative staff, suppliers, etc.) will gain maximum benefit from the digital transformation of healthcare.

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There is no conflicts of interest in this study.

REFERENCES

1. Topol, E., “Preparing the healthcare workforce to deliver the digital future”, The Topol Review. 1-48, 2019.

2. Coravos, A., Goldsack, J.C., Karlin, D.R., Nebeker, C., Perakslis, E., Zimmerman, N., Erb, M. K. "Digital medicine: a primer on measurement", Digital biomarkers. 3(2):31-71, 2019.

3. Genomics England, "The 100,000 Genomes Project", Genomics England. https://www.genomicsengland.co.uk/initiatives/100000-genomes-project. (Access year: 2023).

4. Siva, N., “UK gears up to decode 100 000 genomes from NHS patients”, The Lancet, 385(9963): 103-104, 2015.

5. Department of Health and Social Care, "Matt Hancock announces ambition to map 5 million genomes", 2018. https://www.gov.uk/government/news/matt-hancock-announces-ambition-to-map-5-million-genomes. (Access year: 2023).

6. Laugesen, K., Mengel-From, J., Christensen, K., Olsen, J., Hougaard, D.M., Boding, L., et al., “A Review of Major Danish Biobanks: Advantages and Possibilities of Health Research in Denmark”, Clin Epidemiol., 21;15:213-239, 2023.

7. Köksal, M.O., Akgül, B., “The role of digital health technologies in disaster response”, The Lancet, 401(10388), 1566-1567, 2023.

8. Hyppönen, H., Lumme, S., Reponen, J., Vänskä, J., Kaipio, J., Heponiemi, T., Lääveri, T., “Health information exchange in Finland: Usage of different access types and predictors of paper use”, International Journal of Medical Informatics, 122, 1-6, 2019.

9. Hägglund, M., Scandurra, I., “Usability of the Swedish Accessible Electronic Health Record: Qualitative Survey Study”, JMIR Hum Factors, 9(2), 2022.

10. Ackerman, L., "Mobile Health and Fitness Applications and Information Privacy", San Diego, CA: Privacy Rights Clearing House. 2013.

11. Yao, W., Chu, C.H., Li, Z., "The adoption and implementation of RFID technologies in healthcare: a literature review", Journal of Medical Systems. 36(6): 3507-3525, 2012.

12. Köse, G. Kurutkan, M.N., "Sağlık hizmetlerinde nesnelerin interneti uygulamalarının bibliyometrik analizi", Avrupa Bilim ve Teknoloji Dergisi, 27: 412-432, 2021.

13. Tian, S., Yang, W., Grange, J.M., Wang, P., Huang, W., Ye, Z., “Smart healthcare: making medical care more intelligent,” Global Health Journal. 3(3): 62–65, 2019.

14. Myers, J., Frieden, T.R., Bherwani, K.M., Henning, K.J., “Ethics in public health research: privacy and public health at risk: public health confidentiality in the digital age”, Am J Public Health, 98(5):793-801, 2008.

15. Karabekmez, M.E., “Data Ethics in Digital Health and Genomics”, New Bioeth, 27(4):320-333, 2021.

16. Nature Medicine, "GWAS to the people: Editorial", Nature Medicine. 24, 2018.

17. Uddin, F., Rudin, C.M., Sen, T., “CRISPR gene therapy: applications, limitations, and implications for the future”. Frontiers in Oncology. 10, 2020.

18. Miesbach, W., Meijer, K., Coppens, M., Kampmann, P., Klamroth, R., Schutgens, R., Lebeek, F.W., “Gene therapy with adeno-associated virus vector 5–human factor IX in adults with hemophilia B”, blood, 131(9):1022-1031, 2018.

19. Aiuti, A., Roncarolo, M.G., Naldini, L., “Gene therapy for ADA-SCID, the first marketing approval of an ex vivo gene therapy in Europe: paving the road for the next generation of advanced therapy medicinal products”, EMBO molecular medicine. 9(6): 737-740, 2017.

20. Porter, D.L., Levine, B.L., Kalos, M., Bagg, A., June, C.H., "Chimeric antigen receptor–modified T cells in chronic lymphoid leukemia", N engl j Med, 365: 725-733, 2011.

21. https://www.nice.org.uk/guidance/TA567, (Access year: 2023).

22. Marshall, M., Shah, R., Stokes-Lampard, H., "Online consulting in general practice: making the move from disruptive innovation to mainstream service", Bmj, 360, 2018.

23. Farr, M., Banks, J., Edwards, H. B., Northstone, K., Bernard, E., Salisbury, C., Horwood, J., "Implementing online consultations in primary care: a mixed-method evaluation extending normalisation process theory through service co-production", BMJ open. 8(3): e019966, 2018.

24. NHS England, General Practice Forward View, NHS England www.england.nhs.uk/gp/gpfv/. (Access year: 2023).

25. Korkmaz, S., Hoşman, İ., "Sağlık sektöründe tele-tıp uygulamaları: tele-tıp uygulama boyutlarını içeren bir araştırma". Uluslararası Sağlık Yönetimi ve Stratejileri Araştırma Dergisi. 4:251-263, 2018.

26. Pourman, A., Ghassemi, M., Sumon, K., Amini, S.B., Hood, C., Sikka, N., "Lack of telemedicine training in academic medicine: are we preparing the next generation?" Telemed e-Health. 27(1):62-7, 2021.

27. Lesher, A.P., Shah, S.R. "Telemedicine in the perioperative experience", Semin Pediatr Surg.27(2):102-6, 2018.

28. World Health Organization. "Medical devices: managing the mismatch: an outcome of the priority medical devices project". Geneva. 2010.

29. Wilson, L.S., Maeder, A.J. "Recent directions in telemedicine: review of trends in research and practice", Healthcare Informatics Res. 21(4):213, 2015.

30. Swiatek, P.R., Weiner, J.A., Johnson, D.J., Louie, P.K., McCarthy, M.H., Harada, G.K., "COVID-19 and the rise of virtual medicine in spine surgery: a worldwide study", Eur Spine J. 30(8):2133-42, 2021.

31. Villa, A., Sankar, V., Shazib, M.A., Ramos, D., Veluppillai, P., Wu, A., Shiboski, C., "Patient and providers' satisfaction with tele (oral) medicine during the COVID-19 pandemic", Oral Dis. 10.1111, 2020.

32. Pazar, B., Taştan, S., İyigun, E., "Roles of nurses in tele-health services", Bakirkoy Tip Dergisi (Medical J Bakirkoy). 5(1):201, 2015.

33. Sana, F., Isselbacher, E.M., Singh, J.P., Heist, E.K., Pathik, B., Armoundas, A.A., "Wearable devices for ambulatory cardiac monitoring: JACC state-of-the-art review", J Am Col Cardiol.75(13):1582-92, 2020.

34. Demirci, Ş.,"Sağlık hizmetlerinde sanal gerçeklik teknolojileri", İnönü Üniversitesi Sağlık Hizmetleri Meslek Yüksekokulu Dergisi. 6(1): 35-46, 2018.

35. Lewy, H., "Wearable technologies – future challenges for implementation in healthcare services", Healthcare Technology Letters. 2(1): 2-5, 2015.

36. Garg, S.K., Liljenquist, D., Bode, B., Christiansen, M.P., Bailey, T.S., Brazg, R.L., Denham, D.S., Chang, A.R., Akturk, H.K., Dehennis, A., Tweden, K.S., Kaufman, F.R., "Evaluation of Accuracy and Safety of the Next-Generation Up to 180-Day Long-Term Implantable Eversense Continuous Glucose Monitoring System: The PROMISE Study", Diabetes Technol Ther, 24(2):84-92, 2022.

37. De Miguel, K., Brunete, A., Hernando, M., Gambao, E., "Home camera-based fall detection system for the elderly", Sensors. 17(12): 2864, 2017.

38. Majumder, S., Mondal, T., Deen, M.J., "Wearable Sensors for Remote Health Monitoring", Sensors (Basel). 17(1):130, 2017.

39. Aktan, M. E., Akdoğan, E., "Design and development of a mobile application for a robotic rehabilitation process: Diagnoconn", In 2017 IEEE 11th International Conference on Application of Information and Communication Technologies (AICT), 1-5: IEEE., 2017.

40. İleri, Y.Y., "Sağlık hizmetlerinde nesnelerin interneti (NİT): avantajlar ve zorluklar," The Journal of Academic Social Science. 6(67):159-171, 2018.

41. Xiang, G.Y., Zeng, Z., Shen, Y.J., "Present situation and development trend of China's intelligent medical construction," Chinese General Prac. 19(24): 2998–3000, 2016.

42. Perera, C.C., Liu, H., Jayawardena, S., "The emerging Internet of Things marketplace from an industrial perspective: a survey", IEEE Transactions on Emerging Topics in Computing. 3(4):585–598, 2015.

43. Tütüncü, D., Esen, M.F., "The use of Internet of Things in the management of epidemics: The case of COVID-19," Sağlık Akademisyenleri Dergisi. 8(2):169-177, 2021.

44. Xu, D.L., He, W., Li, S., "Internet of Things in industries: A survey", IEEE Transactions on industrial informatics. 10(4): 2233-2243, 2014.

45. Segato, F., Masella, C., "Telemedicine Services: How to Make Them Last Overtime", in Health Policy and Technology. 6: 268-278, 2017.

46. Yang, T.M., Gentile, C., Shen, F., Cheng, C.M., "Combining point-of-care diagnostic sand internet of medical things (IoMT) to combat the COVID-19 pandemic", Diagnostics. 10(4): 224, 2020.

47. Fox, G., Connolly, R., "Mobile health technology adoption across generations: narrowing the digital divide", Information Systems Journal. 28:995–1019, 2018.

48. Nakamoto, S., "Bitcoin: A peer-to-peer electronic cash system", Decentralized Business Review. 21260, 2008.

49. Aktan, M.E., Akdoğan, E., "Development of an intelligent controller for robot-aided assessment and treatment guidance in physical medicine and rehabilitation", Turkish Journal of Electrical Engineering & Computer Sciences. 29(1): 403-420, 2021.

50. Lee, E.E., Torous, J., De Choudhury, M., Depp, C.A., Graham, S.A., Kim, H.C., & Jeste, D. V. "Artificial Intelligence for Mental Healthcare: Clinical Applications, Barriers, Facilitators, and Artificial Wisdom", Biological Psychiatry: Cognitive Neuroscience and Neuroimaging. 2021.

51. Aktan, M.E., Turhan Z., Dolu İ. "Attitudes and Perspectives towards the Preferences of Artificial Intelligence in Psychotherapy", Computers in Human Behavior, 164:1-18, 2022.

52. Gyles, C., "Robots in medicine", The Canadian Veterinary Journal. 60(8):819, 2019.

53. Akdoğan, E., Aktan, M.E., Koru, A.T., Arslan, M.S., Atlıhan, M., Kuran, B. "Hybrid impedance control of a robot manipulator for wrist and forearm rehabilitation: Performance analysis and clinical results", Mechatronics, 49: 77-91, 2018.

54. https://interestingengineering.com/15-medical-robots-that-are-changing-the-world, (Access year: 2023).

55. https://aabme.asme.org/posts/robot-assisted-surgery, (Accessed: 05.06.2023).

56. Dash, S., Shakyawar, S.K., Sharma, M., Kaushik, S., “Big data in healthcare: management, analysis and future prospects”, J Big Data, 6(54), 2019.

57. Zhu, L., Zheng, W.J., “Informatics, Data Science, and Artificial Intelligence”, JAMA, 320(11):1103–1104, 2018.