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RESEARCH ARTICLE

A Bibliometric Analysis of Technology in Digital Health: Exploring Health Metaverse and Visualizing Emerging Healthcare Management Trends

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ABSTRACT The digital economy has engendered Health Metaverse, an innovative technology with vast potential to transform healthcare through immersive experiences. The Health Metaverse serves as a convergence point for a multitude of technologies, including artificial intelligence (AI), virtual reality in heath, augmented reality in health, internet-connected medical devices, quantum computing, and more. This convergence opens up possibilities, for advancing quality healthcare. Therefore, reviewing recent influential literature is critical to understand current methods and envision future improvements. This study utilizes a hybrid bibliometric-structured methodology combining descriptive and bibliometric network analysis. To gather information we conducted searches on the Web of Science database and reviewed references. Our inclusion criteria focused on articles and reviews published between January 2012 and June 2023. We used keyword groups for our searches. Then performed bibliometric analysis followed by content analysis. Papers were reviewed, analyzed and categorized into focuses on multimodal medical information standards, medical/social data fusion, telemedicine, online health management, and medical AI. This bibliometric analysis of 34 thousand publications over 10 years proposes medical and health informatics in the Metaverse. Five future research direction clusters were identified. It delineates intelligent solutions bridging healthcare barriers. In conclusion, this review examines the Metaverse, in healthcare explores cutting edge technologies, applications, projects and highlights areas where adaptation may be needed. It identifies adaptation issues and suggests solutions warranting further research.

INDEX TERMS Health metaverse, healthcare technology, health informatics, quality of care, digital health, data analysis, bibliometric analysis.

I. INTRODUCTION

In the field of healthcare the importance of smart healthcare 5.0 becomes clear as it aims to improve the well being of people worldwide by addressing their physical, social and mental health needs [1]. Healthcare systems are primarily focused on tasks that strengthen, rehabilitate, sustain and optimize healthcare services making contributions, to a nations growth and industrial progress. This dedication has driven the advancement of the healthcare industry through the integration of technology to enhance interactions among healthcare providers, patients and other stakeholders. Digital healthcare has played a role in transforming the health-care industry [2]. The implementation of health services

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through tools and internet platforms has greatly impacted how patients and physicians interact. This transformation can be observed through innovations like decision making systems in healthcare, virtual reality applications and digital health platforms [3]. Embracing these technologies offers opportunities to explore approaches for delivering treatments at costs while improving patient outcomes. Despite progress in the healthcare sector there are challenges that need to be addressed. These challenges include an increasing prevalence of diseases growing burdens on individuals and institutions alike a population that is aging rapidly insufficient numbers of healthcare professionals available for care delivery as well, as limited resources.In this environment there is a demand to offer healthcare services directly to peoples homes [4].

The healthcare industry worldwide including its employees, facilities and logistics has encountered difficulties as a result of the unparalleled COVID 19 outbreak. The ongoing global health crisis has sparked changes, in the healthcare industry leading to the adoption of technological advancements and proactive adaptations [5]. After the pandemic noticeable shifts have occurred in healthcare. Nowadays patients are actively involved in decision making and readily embrace virtual healthcare systems and digital innovations. The use of data and data analytics, accompanied by a rising trend in collaborative development, has become commonplace.

As a result governments, healthcare providers and other stakeholders have felt compelled to adjust and innovate to keep up [6]. However there are still challenges that need to be addressed as they will shape the future trajectory of the healthcare sector. Patients evolving needs and goals drive innovations in healthcare as their experiences play a role. They desire enabled, on demand interactions with clinicians that ensure patient centered services across locations and socioeconomic backgrounds. Recognizing the nature of each individuals health journey is essential, for tailoring services and creating personalized healthcare experiences [8].

Nowadays it has become crucial to utilize tools and services to ensure customer satisfaction keep track of and monitor health statuses and improve adherence, to medication. Consumers (Patients), in the healthcare industry are becoming more open to sharing their information. Therefore it is crucial for organizations to prioritize interoperability and build trust with consumers by showing reliability, transparency and empathy in their operations. The current expectation is a shift from focusing on healthcare to an textitasis on overall health and well being. This change calls for adjustments in how services designed and delivered. Embracing solutions has become essential to ensure consumer satisfaction enable efficient tracking of health status and promote better adherence to medications. Moreover organizations must place importance on data interoperability to foster trust among consumers by demonstrating reliability, transparency and empathy in their operations [9]. This marks a change towards prioritizing health and well being than just healthcare itself leading to transformative modifications, in service offerings and the channels through which they are provided.

In the healthcare field it is possible to enhance involvement during the process by using high quality immersive content and incorporating gamification elements. The healthcare system, in the Metaverse provides an enjoyable healthcare experience that is tailored to each patients needs. The Metaverse combines technologies like artificial intelligence (AI), augmented reality (AR), virtual reality (VR), telepresence, digital twinning and blockchain, which have had a significant impact on the healthcare industry [10]. By integrating these technologies, new and cost effective approaches, to treatment delivery can be explored, ultimately improving outcomes.

By creating a digital world that can be accessed online, the Metaverse replicates human actions and emotions, connecting the social and economic aspects of both the physical and virtual realms [11]. These tools greatly help healthcare professionals in effectively explaining complex concepts to patients, providing detailed step by step explanations of medical procedures and ensuring accurate adherence to prescribed medications. Additionally, by integrating digital twin solutions into the healthcare focused Metaverse, a new approach is introduced to keep patients well informed and engaged in their treatment journey. By combining vital signs, CT scans, health records and genetic test results, a virtual simulation of patients anatomy and physiology is generated within this virtual environment. This allows for continuous monitoring of their health status and provides valuable insights. Patients have access to their health data through a virtual dashboard where they can easily communicate with doctors, researchers, nutritionists and other individuals involved in their personalized care [12]. The recent pandemic has led to an increased demand for remote healthcare services, highlighting the potential of the Metaverse to provide a more comprehensive experience compared to traditional telemedicine systems based on video conferencing [13].

Additionally, Extended reality (XR) technologies like mixed reality (MR) have the potential to bring significant advancements to the healthcare and medical education fields. One exciting application is the use of AR glasses, which enable patients to have real time video consultations with doctors, allowing for remote specialized care and quick diagnoses. This not only improves patient provider interaction but also allows offsite clinicians to receive live emergency streaming for timely treatment [14]. By combining AI with mapping mirror worlds can accurately simulate real life medical scenarios for training purposes. The recent pandemic has highlighted the usefulness of the Metaverse in providing care. Augmented reality technology allows for explanations of procedures going beyond mere theoretical knowledge. Esteemed institutions are increasingly utilizing XR and AI to educate physicians through simulations of procedures and detailed models of cellular level anatomy [15].

As a result, these sophisticated technologies provide elevated visual representations, improved comprehension, and practical experience in pioneering methods. Consequently these advanced technologies offer enhanced representations improved understanding and practical hands on experience in methods. The Metaverse allows for 360 degree visualizations of conditions showing promise as a platform, for preparation, collaboration and immersive experiences although it is still in its experimental stages [16]. The global market for Metaverse healthcare has experienced growth with a value of \$5.06 billion in 2021. Projected to reach \$71.97 billion by 2030 demonstrating a Compound Annual Growth Rate (CAGR) of 34.8% during the period from 2022 to 2030 [17]. North America is expected to take the lead due to the presence of Metaverse focused companies and infrastructure as the integration of AR and VR in healthcare which facilitates substantial investments in AR products and applications. Extensive research has explored applications of the Metaverse in healthcare. Notably potential transformations, across collaboration, education, care delivery models monetization strategies and wellness have been discussed [18]. A study conducted by [19] investigated real life scenarios where AI and data science were utilized in hospital management to uncover the obstacles faced during implementation. Furthermore cutting edge technologies such, as telepresence, digital twinning and blockchain hold potential, in delivering advantages particularly in the realm of remote patient monitoring [20]. In summary, to put it simply innovative and interactive reality technology solutions have potential to revolutionize healthcare by improving training, delivery of care and overall outcomes. Nevertheless, additional research is essential to surmount current challenges and harness its full potential in practical scenarios.

Bibliometrics allows for the analysis of publications, researchers, journals and institutions to uncover patterns, in research impact and citations within a specific field [19], [21]. Thus, this study conducts a review using analysis of over 30 thousand spanning a decade to explore the impact of Metaverse in transforming healthcare. It also expands on surveys to examine how these technologies have been integrated into the healthcare sector. This study employs a bibliometric analytics framework to comprehensively analyze recent literature, delving into research trends concerning emerging technologies in healthcare operations and system. It scrutinizes both the challenges and potential solutions within this burgeoning field.

Additionally this study aims to answer three research questions (RQ) that address gaps in research;

- (RQ1) What is the primary focus of research on healthcare management within medical and healthcare contexts?
- (RQ2) How have keywords and clusters related to emerging technologies in healthcare operations and system evolved over time?
- (RQ3) What are the potential areas for practical applications and future direction based on our analysis?

As a result, following our initial analysis, we conducted a comprehensive systematic review aimed at elucidating the conceptual framework of the emerging Health Metaverse (HM) concept. This thorough review delves into its research framework, explores the challenges encountered within this domain, and assesses its potential applications. This exhaustive analysis of existing literature serves to consolidate current knowledge and identify areas of focus for future research, development, and implementation of innovative immersive technologies. These technologies encompass augmented and virtual reality, telepresence, the Internet of Things (IoT), digital twinning, AI techniques, blockchain, quality of service, and experience. The ultimate objective is to address healthcare issues through a combination of legal and technological approaches.

II. MATERIALS AND METHOD

A. RESEARCH METHODOLOGY

The flowchart shown in Figure 1 illustrates the analysis performed on a cutting edge technology in the digital realm, which holds great potential in healthcare. This technology aims to provide experiences for both patients and medical professionals as part of the ongoing digital transformation in healthcare. The analysis adheres to the following procedure:

Firstly, we identify relevant keywords and design search strategies that cover three distinct research areas (RA);

- (RA1) digital transformation in the medical and healthcare sector,
- (RA2) operations management in healthcare,
- (RA3) quality of services in health management.

Secondly, using these selected keywords we utilize the Web of Science database to retrieve publications for further examination.

Thirdly, employing visualization tools we conduct trend analysis and topic analysis on publications related to transformation in healthcare. This enables us to extract findings from the bibliometric study and identify areas with potential for future research.

Lastly, we present our interpretation of research concepts, future challenges and avenues for exploration, within the field of HM.

B. DATA COLLECTION

The number of articles discussing advancements in healthcare transformation has been increasing each year since 2012. To analyze the research thoroughly we carefully selected publications, from the regarded Web of Science (WoS) database covering the period from January 2012 to 2023. Our focus was exclusively, on articles and review articles. We categorized these publications into three groups known as RA1, RA2 and RA3 to gain an understanding of the subject matter through a review of existing literature and reports. For each category we identified a set of search keywords using operators like "AND" and "OR" to refine our research process as shown in Table 1. We retrieved a collection of papers from the WoS database including titles, keywords, author details, abstracts and references-all saved in plain text format.

TABLE 1. Summary of search keywords.

Research area	Keywords
RA1	"Online health community*", "Digital health*", "Mobile health*", "telemedicine*", "virtual reality in health*", "augmented reality in health*", "Health monitoring", "face recognition", "sensors", "smart life", "virtual reality and health", "Metaverse*", "Artificial intelligence*", "Data mining*", "medical information standards*", "Machine learning*", "Optimization*", "Support vector machines*", "Particle swarm optimization*", "Simulation optimization*", "Decision making*", "Decision support system*", "Clinical decision support*", "Decision-making technique*", "Computed tomography*", "Collaboration*", "Simulation*", "Queueing theory*", "Bayesian inference*", "Exponential-family random graph models", "Interfirm networks*", "Social network analysis models*", "Governance agreement structure*", "Coordination control*", "Real-time data*","Service improvement*", "Service design*", "Knowledge modeling*", "Information flow*", "Process improvement*", "Operations Research*"
RA2	"Medical transfer*", "*Referral", "Delayed Diagnosis*", "Patient-physician matching*", "Tiered healthcare systems*", "Referral rate*", "Referral payment*", "Referral alliance*","Reverse Referral*","Intervention*", "Specialist*", "health communication*", "mutual referral*", "Referral process*", "Physician Referral Decision*", "consultation*", "general medical*", "Electronic referral system*", "patient-based*", "Specialty referral*", "Referral system*", "specialties*", "Referral protocol computerization*", "connected healthcare*", "online referral*", "referral letter*", "waiting to access*", "Wait times*", "wait list*", "Patient referral system*", "patient referral network*"
RA3	"Hospital quality*", "Hospital referral*", "Medical center partnership,*", "Healthcare*", "Patient referral problem*", "Hospital*", "Magnetic resonance imaging*", "Healthcare systems*", "interhospital*", "Healthcare coordination*", "integrated healthcare*", "Medical services*", "Ambulatory care*", "Specialties*", "Specialty care*", "medical clinical practice*", "Quality of healthcare*", "General practice*", "Primary care*", "Secondary care*", "Health system*", "quality of health care*", "health centres*", "healthcare innovation*", "patient centered care*", "healthcare improvement"

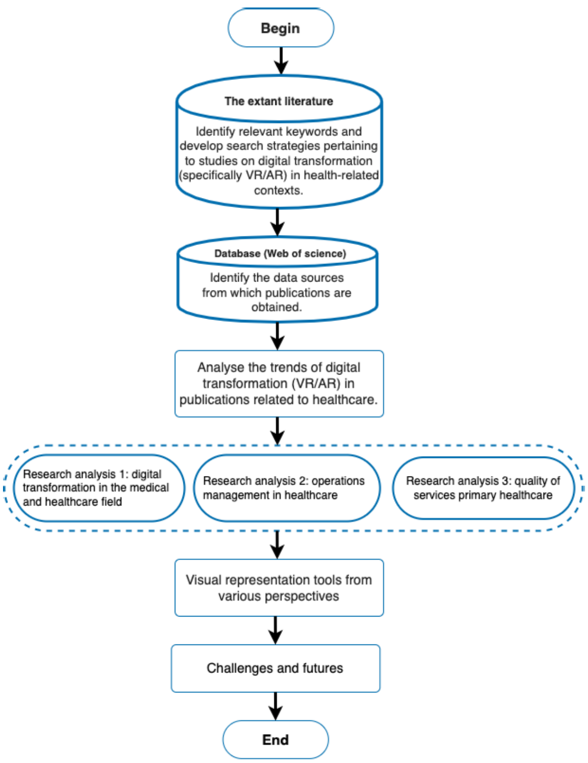

FIGURE 1. The methodology flowchart employed in this research.

C. DATA ANALYSIS METHOD

This research employs a range of methods to gain a thorough understanding of the complex digital health landscape. In response to the limitations encountered during our database search, we expanded our search parameters to encompass content related to digital medical and health technology. This broader approach involved the inclusion of news articles and reviews, in addition to academic publications and publicly accessible sources, in order to compile a comprehensive collection of bibliometric data. Initially, we conducted an analysis of keyword occurrences within the category of healthcare transformation as a basis for empirical research. We then used topic modeling to identify relevant keywords related to healthcare operations and the quality of primary care services grounded in evidence based practices. For our core data source we utilized the WoS database, which contained 30,015 relevant documents. We evaluated bibliometric analysis software tools like Microsoft Excel and VOSviewer ultimately selecting VOSviewer for its graphical distance based mapping approach. In this approach smaller distances indicate relationships between items such as keywords, authors organizations and countries [22], [23]. The size of each label represents the frequency of publication for that keyword while label color reflects cluster assignments determined by VOSviewers clustering technique. By synthesizing academic articles and reviews within the WoS database, this study employs quantitative methods to provide a comprehensive overview of advancements and strategic directions in the digital transformation of healthcare through emerging technologies in the HM.

III. RESULTS AND DISCUSSION

In this section, we present and provide an explanation for the findings of the descriptive and bibliometric network analysis.

A. DESCRIPTIVE ANALYSIS

In this subsection, we perform a citation trend analysis to evaluate the importance of contributions and quantify the degree to which respected publications are cited or referenced, following the approach outlined by Hajje and Mulla in [24]. This method enables us to identify the top 10 authors, sources of publication, organizations, countries, and influential articles characterized by the highest citation counts.

TABLE 2. Frequency of citations and publications across time.

Year	TP	TC	CA	CC	ACA	ACY
2023	1,950	430	30,015	22,965	1,9145	0.22
2022	4,511	3,117	28,065	22,535	1,878	0.69
2021	4,481	3,989	23,554	19,418	1,618	0.89
2020	3,755	4,656	19,073	15,429	1,2865	1.24
2019	2,998	2,308	15,318	10,773	898	0.77
2018	2,481	1,893	12,320	8,465	705	0.76
2017	2,146	1,509	9,839	6,572	548	0.70
2016	2,017	1,187	7,693	5,063	422	0.59
2015	1,733	1,138	5,676	3,876	323	0.66
2014	1,505	1,260	3,943	2,738	228	0.84
2013	1,298	729	2,438	1,478	123	0.56
2012	1,140	749	1,140	749	62	0.66

Initial descriptive analysis examined the exported bibliography file spanning 2012 to mid-2023. This analysis helped me gather statistics about publications, including the total number of publications (TP), total citations (TC), cumulative articles (CA), cumulative citations (CC), average citations per article (ACA), and average citations per year (ACY) as shown in Table 2. After searching through databases, we found 30,015 articles published between January 2012 and June 2023 that focused on the transformation of healthcare. These articles were then quantitatively analyzed to understand care patterns over the past decade. The results revealed an increase in both the publication and citation of articles related to this topic (as indicated in Table 2). To summarize this initial bibliometric analysis has provided a foundation of publication and citation data. It will serve as a basis for examinations of research progress in utilizing immersive and interactive technologies, for healthcare industries over the past ten years using rigorous quantitative methods. This will help identify research trends, priorities and strategic directions moving forward.

1) ANALYSIS OF THE OVERALL GROWTH

The analysis of publication and citation metrics provides valuable insights into the trends and impact of research in a specific subject area. By examining digital health publications and citations from 2012 to 2023, we observe an overall upward trend, although there is a decline in 2023 due to the dataset only including data from the first half of the year as depicted in Figure 2. Prior to 2012, there were very few articles, indicating that digital health was not yet a prominent research area during that time. However, from 2012 to 2014, there was significant growth in research exploring the digital transformation of the medical and healthcare industry. This growth then slightly declined after reaching its peak in 2014. Since 2016, we have seen a rapid proliferation of publications focused on conceptual definitions, frameworks and virtual reality applications for health purposes. The number of these publications has exceeded 400 annually. Additionally, citation analysis shows a consistent increase in research activity with over 1,000 additional citations per year between 2019 2020. By fitting our publication and citation data to Lotka's Law [25], we obtained exponential growth equations; $y = 966.39 \times e^{0.1444x}$ and $y = 581.33 \times e^{0.1794x}$ with corresponding R^2 values of 0.9801 and 0.7417, respectively. These exponential trendlines indicate that the field of digital health has evolved from an early stage to a phase of rapid development [26]. To summarize, a preliminary analysis of bibliometrics indicates that digital health is a rapidly growing field of research. This lays the foundation for more detailed examination of specific topics, trends and future strategic directions regarding these groundbreaking technologies.

The contemporary concept of primary care has spurred the integration of diverse medical and healthcare services into the healthcare ecosystem. Additionally, digital health is expediting innovation in the realm of medicine and healthcare. Health technologies involving VR and AR are enhancing the patient experience and medical outcomes. Even routine medical procedures, such as intravenous injections and blood draws, can benefit from technology, like projecting human vein maps onto the skin [27]. Many healthcare companies are investing substantial sums in advancing AR and VR technologies, aiming to enhance drug delivery and potentially replicate physical presence, addressing one of the primary limitations of current telemedicine models. The research landscape since 2020 has witnessed a growing interest in technologies such as digital health, online health communities, telemedicine, VR and AR, although this research is still in its nascent stages.

In the past medicine has always revolved around interactions. It usually starts with a patient initiating a conversation with a doctor to discuss their health condition. Afterwards the doctor evaluates the patients symptoms using sources of physiological information, such as emotional and physical responses, clinical data and more. Ultimately the doctor develops an optimal treatment plan for the patient. However, in todays world where big data, Metaverse and AI technology're prevalent individuals have somewhat become digital citizens. Even before the COVID 19 hit people were already exploring digital medical and health technologies to address their personal health concerns. The global pandemic has further accelerated this trend by promoting the growth of services wearable devices and telemedicine. The advancement of medical information technology, in healthcare is no longer limited to medical institutions or government agencies. At the time significant technological advancements have expanded existing medical information systems into a comprehensive healthcare ecosystem.

The advancement of healthcare industry innovation relies on a combination of computer science, telecommunications technology, medical and health services and computational biology. Furthermore behavioral science, psychology and education have roles to play in the research areas of VR/AR in the field of health. These fields are driving innovation in domains such as pain management, surgical procedures, medical training, virtual fitness programs, telemedicine practices and virtual patient communities. However there are still challenges to overcome including limitations like interchangeability and mobility issues as well as human

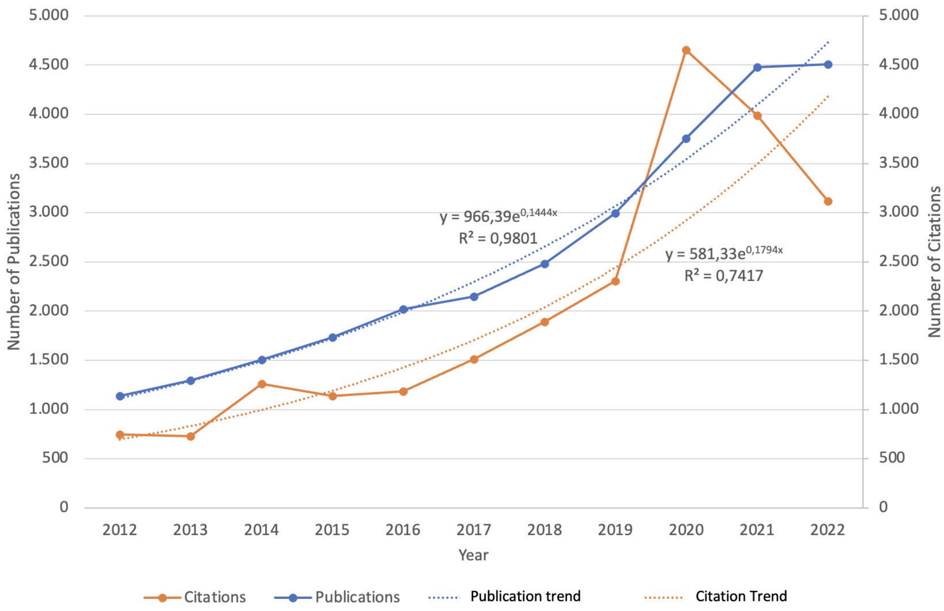

FIGURE 2. Analysis of publication and citation trends over time.

factors such as skills development, resistance to change and building trust. Regulatory and legal considerations also pose hurdles. Hence digital healthcare embodies a virtual community focused on health matters existing alongside the world but functioning autonomously. It serves as a space that combines medical knowledge with various forms of medical information. The primary goal is to encourage the adoption of digital transformation within the medical and healthcare sector. In contrast to the broader concept of primary care within healthcare settings, our specific focus in digital healthcare revolves around processes related to knowledge acquisition, including digitization initiatives, as well as operations management within healthcare that pertains to interactions among users. Additionally, we textitasize the perspectives related to the quality of services, which entail harnessing advanced technologies. In the healthcare landscape today seamless interoperability between systems is crucial. Service providers and stakeholders increasingly require the ability to exchange data effortlessly across systems institutions even international borders. Unlike existing health tools available today; future virtual health services aim to create a more immersive environment rooted in healthcare by utilizing AR/VR technologies along, with related virtualization technologies.

According to the data presented in Figure 3, Health Care Sciences Services emerge as the predominant domain, comprising 20.3% of the articles within this category. It is followed by Surgery, accounting for 11.5% of the articles, and Public Environmental Occupational Health at 10.8%. The Cardiovascular System Cardiology, Neurosciences Neurology, and Medical Informatics domains make up 7.3%, 7.2%, and 6.0% of the articles, respectively. Research Experimental Medicine contributes 4.7% of the articles. In contrast, areas like Rehabilitation, Emergency Medicine, and Psychology have made minimal or negligible contributions to telemedicine and science. These areas present opportunities for interdisciplinary research that can involve aspects such as laws, technology, and human elements.

Previous studies on improving virtual healthcare services have often had a narrow focus. They mainly examined individual performance metrics like waiting times or time until diagnosis [28], [29], [30]. Some research looked into the collaboration among healthcare providers [31], specific interventions such as electronic consultations [32] or referral letters [33] and specific referral categories like cross referrals and palliative care [34], [35]. Additionally, certain studies explored the impact of risk factors such as low income, age and medical conditions on referral outcomes [36], [37]. A systematic review also examined performance measures related to specialty referrals [38]. While these studies were valuable, many of them had limited scopes or only considered literature published before 2015. As a result, they failed to consider more recent approaches like simulation and optimization models [39], [40]. The objective of this study is to provide a comprehensive exploration of digital healthcare topics. To achieve this goal, we will conduct a bibliometric analysis of the literature from previous years. By studying publication and citation patterns, our study aims to identify trends in research and pinpoint areas that require further knowledge. Ultimately, our findings will guide future research directions and offer an extensive perspective on advancements across different fields and methodologies. Virtual healthcare services aim to create a more engaging healthcare environment by utilizing the virtualization technologies.

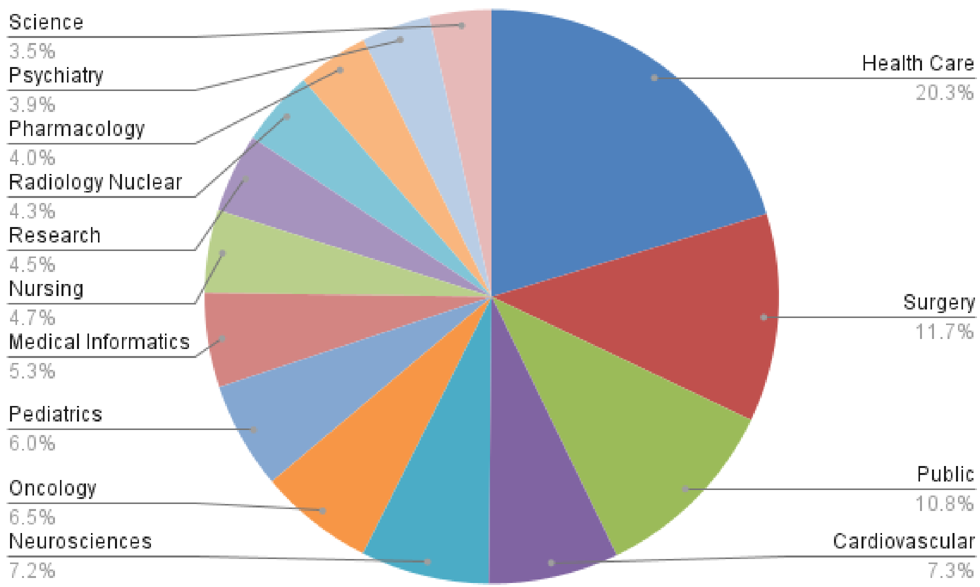

FIGURE 3. Total papers by subject area.

In brief, the assessment suggests that digital health is a swiftly growing research area marked by contributions from around the world. Initial results reveal significant investments by healthcare firms in advancing AR and VR technologies. The objective is to improve drug delivery and potentially recreate physical presence, addressing a crucial limitation in telemedicine. From 2020 onwards, there has been a rising interest in research concerning technologies such as digital health, telemedicine, online health communities, and VR/AR, although these are still in their early stages. This sets the groundwork for more in-depth investigations into specific topics, trends, and strategic directions concerning these innovative technologies. Papers in fields such as rehabilitation, emergency medicine, and psychology have made minimal or negligible contributions to telemedicine. This presents interdisciplinary opportunities that involve technology, law, and human aspects. Identified publication trends indicate a probable increase in the number of papers focusing on AR, VR, and MR surgical techniques. In addition, recognizing prolific authors and institutions contributing to digital health acknowledges key contributors in the field. A more in-depth analysis of publication and citation trends across disciplines and over time can offer a profound understanding of the impact of technologies and their evolution in shaping the future of healthcare.

2) PUBLICATION SOURCES

In this subsection, we analyze the distribution of journals within the field of health services research and subsequently assess their citations. To gauge the influence and overall quality of these journals, we utilize the 5-year impact factor (IF) data provided by WoS. This metric is calculated by dividing the total number of citations (TC) received by papers published in a journal over the previous five years by the total number of papers (TP) published in the journal during that same five-year period. Table 3 presents a summary of the top 10 journals based on various criteria, including TP, TC, highly cited journals (h-index), and their respective 5-year IF.

Analysis of contributing journals revealed BMJ Open as the top source with 1,090 articles included in this study, followed by PLOS One with 507 articles and BMC Health Services Research with 437 articles in Figure 4. Ranking journals by total citations shows the Cochrane Database of Systematic Reviews received the most citations at 16,076, despite only contributing 197 articles. BMJ Open (12,492 citations) and PLOS One (7,825 citations) also ranked highly. The impact factors for these most-cited journals were also relatively high, with JAMA Network Open at 13, Cochrane Database of Systematic Reviews at 10.9, and Journal of Medical Internet Research at 7.6, all exceeding 6. In summary, bibliometric analysis identified the major contributing journals and highlighted those with significant impact in the field based on publication volume, citation counts, and impact factors. This informs the influence of key sources publishing research related to improving referral processes and connectivity in healthcare delivery.

3) MOST IMPACTFUL ARTICLES

Historically, healthcare followed a hospital-centric model with professionals treating patients in clinical settings [51]. However, a paradigm shift towards patient-centered care now textitasizes individuals taking an active health management role. For instance, wearable devices enable continuous, non-invasive monitoring of vital signs and biometrics to improve outcomes and quality of life [52], [53]. By providing real-

TABLE 3. Top productive and cited journals contribution and its impact.

Journal Name	h-Index	5 Year IF	TP	TC	Most cited article	Citation number article
BMJ Open	46	3.3	1,090	12,492	Impact of COVID-19 pandemic on utilisation of health-care services: a systematic review [41]	356
PLOS One	42	3.8	507	7,825	An Integrative Model of Patient-Centeredness - A Systematic Review and Concept Analysis [42]	376
BMC Health Services Research	32	3.5	437	4,724	Identifying keys to success in reducing readmissions using the ideal transitions in care framework [43]	99
Trials	22	2.5	389	2,955	A remote monitoring and telephone nurse coaching intervention to reduce readmissions among patients with heart failure: study protocol for the Better Effectiveness After Transition-Heart Failure (BEAT-HF) randomized controlled trial [44]	51
Journal of Medical Internet Research	34	7.6	231	4,819	A Changing Landscape of Physician Quality Reporting: Analysis of Patients' Online Ratings of Their Physicians Over a 5-Year Period [45]	259
JMIR Research Protocols	15	1.8	211	1,078	Impact of the Mobile Health PROMISE Platform on the Quality of Care and Quality of Life in Patients With Inflammatory Bowel Disease: Study Protocol of a Pragmatic Randomized Controlled Trial [46]	43
Cochrane Database of Systematic Reviews	63	10.9	197	16,072	Decision aids for people facing health treatment or screening decisions [47]	1,881
Telemedicine and E-Health	27	4.3	195	3,071	Cost-Utility and Cost-Effectiveness Studies of Telemedicine, Electronic, and Mobile Health Systems in the Literature: A Systematic Review [48]	253
JAMA Network Open	29	13	158	2,964	Patient Characteristics Associated With Telemedicine Access for Primary and Specialty Ambulatory Care During the COVID-19 Pandemic [49]	309
International Journal Of Environmental Research and Public Health	14	4.79	147	812	Impact of Nurse-Patient Relationship on Quality of Care and Patient Autonomy in Decision-Making [50]	63

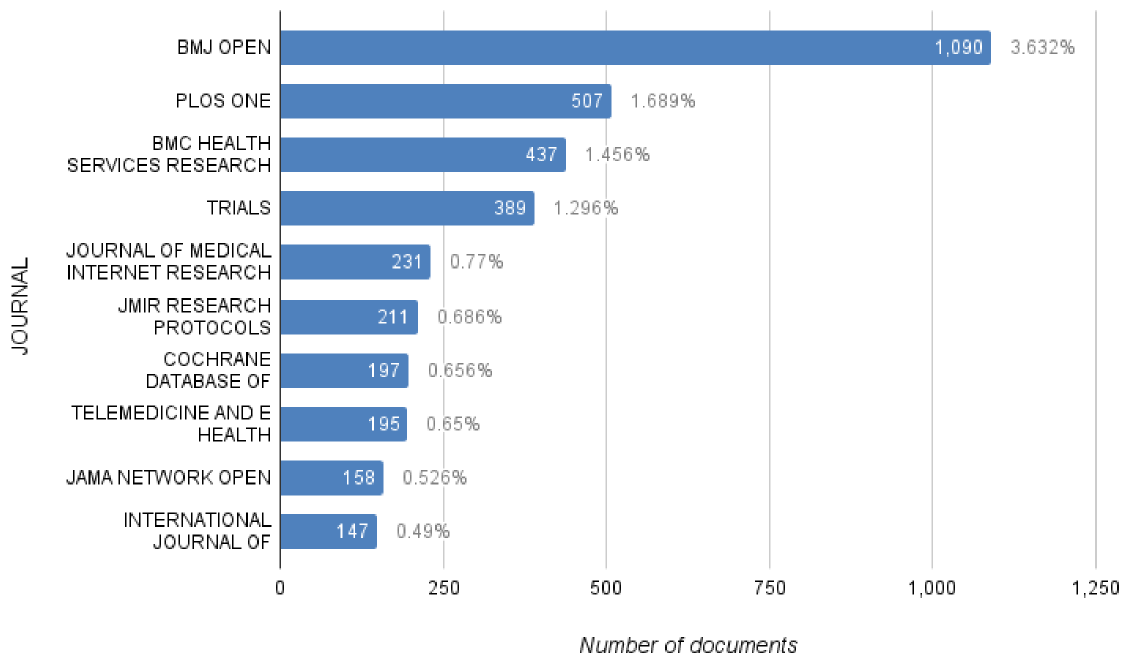

FIGURE 4. Top journal contributions.

time data, wearables facilitate early detection of conditions like heart disease, diabetes, and sleep disorders, allowing users to monitor health status daily and make informed lifestyle decisions. Furthermore, analysis of top articles by journal, citations, references, and research directions shows a focus on areas including healthcare services, decision support, referrals, economics, risk factors, virtual reality therapy, assessments, meta-analyses, and tele-rehabilitation are summarized in Table 4.

According to Table 4 offers an in-depth analysis of the top articles, with a notable focus on the first five articles aimed at providing valuable insights into decision support techniques and computer-aided detection. These insights are intended to enhance healthcare systems and address diseases, including COVID-19. Furthermore, among these top articles, five highly-cited studies delve into various aspects of diseases care, encompassing topics such as diagnosis, risk assessments, referrals, real-time health data sharing through wait-lists and services, and the resulting impacts on behaviors, health outcomes, and healthcare systems. Additionally, there are four review articles suggesting that this research holds substantial value by exploring the emerging integration of technologies such as AI, blockchain, the HM, IoT, robotics, and cloud computing in healthcare. Despite being relatively new within academia and among professionals, these areas represent economically feasible real-world solutions for virtual healthcare. In summary, this study aims to strategically build upon existing interdisciplinary literature by analyzing the focus and influence of these key prior works, thereby advancing our understanding of the technologies that are shaping the future of healthcare delivery. The shift to patient-driven care and technologies empowering self-monitoring has driven research on improving care coordination, connectivity, and personalized interventions to engage individuals in their health. A comprehensive perspective is critical to strategically advance patient-centered innovations in healthcare.

The work in [47] studied assesses the efficacy of decision aids as interventions providing information on treatment or screening options, benefits, and risks to improve decision alignment with personal values, synthesizing evidence from randomized controlled trials comparing decision aids to usual care or alternatives across outcomes related to decision-making processes, behaviors, health, and healthcare systems. It was the most-cited article, with 1,914 citations. Paper in [54] contributes to evidence-based guidelines, which advocate for the implementation and assessment of interventions such as site-specific programs. These interventions aim to reduce unnecessary antibiotic use by relying on scientific evidence, ultimately promoting appropriate stewardship. The work textitasizes the pressing need for research into optimal models, taking into account organizational and prescriber factors. This research can enhance care coordination, inform clinical and operational decisions, improve referral accuracy, mitigate economic risks, and reduce patient safety risks associated with inappropriate antibiotic prescribing. The work has received 1,760 citations. More recently, article [64] explains recent research on post-stroke active rehabilitation indicates extended reality and robotic technologies demonstrate equivalent or superior outcomes to conventional therapy for improving motor function and activity in both subacute and chronic patients, with meta-analyses showing virtual reality and robotics significantly outperform conventional methods in the chronic phase, underscoring the promise of immersive and intelligent HM innovations for advancing patient recovery through personalized interventions adapted to impairment severity. The research conducted in reference [65] explores the feasibility of incorporating Cognitive Remediation (CR) as an additional therapeutic approach for treating bipolar disorder (BD) by utilizing fully immersive VR in the healthcare context. Furthermore, it seeks to offer preliminary insights into the therapeutic effectiveness of this study protocol, which involves integrating CR within a fully immersive VR environment alongside the standard BD care regimen. The notable increase in the number of cited references, totaling 103, can be attributed to the burgeoning field of research within the HM. A pivotal concern within the healthcare industry revolves around its impact on healthcare referrals.

Within the framework of advancing digital transformation in healthcare, paper in [66] explored delves into potential research directions to provide insights for future studies and strategies regarding the effective integration of AR into telemedicine. This study is significant for establishing a human-centered theoretical framework for the metaverse as a therapeutic space, linking it with existing psychotherapy theories, and paving the way for innovative psychotherapy strategies. It addresses the current lack of a unified definition for the metaverse, highlighting the importance of building a solid theoretical foundation for future research in this area.

The analysis of highly impactful articles reveals a concentration on various areas, encompassing healthcare services, referrals, decision support, assessments, economics, virtual reality therapy, and tele-rehabilitation. Five studies that are extensively cited explore aspects of disease care, that is, diagnosis, referrals, data sharing, risk assessments, and resulting impacts. From the four influential reviews, the roles of emerging technologies in healthcare are highlighted, ranging from robotics to AI, cloud computing, blockchain, and human-meta. Through a careful examination of computer-based health decision support systems, the process of designing evidence-based and patient-centered care has become evident. This can be highly beneficial in improving connectivity, coordination, and interventions that are personalized to individuals.

4) AUTHOR PERFORMANCES

Analysis of highly cited authors identified influential researchers with high citation rates per publication, reflecting renowned healthcare and service scholars advancing knowledge through impactful publications. These prolific authors make notable contributions to state-of-the-art research and practice. Bibliometric assessments of individual researcher productivity and influence provide further insights into the scientific progress advancing healthcare knowledge.

In light of extensive collaboration, we have identified the top highly cited authors based on three key metrics: total publications (TP), total number of citations (TC), and citations per publication (C/P). The results, presented in Table 5, reveal that Liu, Yao (abbreviated as Liu, Y.) from Harvard University stands out as a prominent and well-recognized contributor, boasting a remarkably high C/P

TABLE 4. The productive and cited article contribution.

Title of the article	Journal name	Number of citations	Cited references	Category quartile	Key directions
Decision aids for people facing health treatment or screening decisions [47]	Cochrane Database of Systematic Reviews	1,914	405	Q1	patient-decision; decision support techniques; evidence-based information
Implementing an Antibiotic Stewardship Program: Guidelines by the Infectious Diseases Society of America and the Society for Healthcare Epidemiology of America [54]	Clinical Infectious Diseases	1,760	225	Q1	antibiotic stewardship programs; decision-support-system; health system
Convolutional Neural Networks for Medical Image Analysis: Full Training or Fine Tuning? [55]	IEEE Transactions on Medical Imaging	1,680	76	Q1	computer-aided detection; convolutional neural networks; medical image analysis
Identifying Medical Diagnoses and Treatable Diseases by Image-Based Deep Learning [56]	CELL	1,409	19	Q1	clinical-decision support; diagnosis and referral
Health Care-Associated Infections A Meta-analysis of Costs and Financial Impact on the US Health Care System [57]	JAMA Internal Medicine	1,145	54	Q1	health care system; excess length; economic-impact; risk-factors
Clinically applicable deep learning for diagnosis and referral in retinal disease [58]	Nature Medicine	1,101	43	Q1	fully automated detection; meta-analysis; artificial intelligence; referral
American Society of Clinical Oncology Provisional Clinical Opinion: The Integration of Palliative Care Into Standard Oncology Care [59]	Journal of Clinical Oncology	936	30	Q1	controlled-trial; advanced cancer; health care services; referral
Automated Identification of Diabetic Retinopathy Using Deep Learning [60]	Ophthalmology	654	34	Q1	computer-aided diagnosis; retinal images; referral;artificial intelligence based
Interventions for improving upper limb function after stroke [61]	Cochrane Database of Systematic Reviews	472	249	Q1	virtual reality ; interventions; collaboration; clinical decision making
Virtual reality exposure therapy in anxiety disorders: a quantitative meta-analysis [62]	Depression and Anxiety	349	44	Q1	cognitive behavior therapy; waiting-list; interventions; long-term effect
Can virtual reality exposure therapy gains be generalized to real-life? A meta-analysis of studies applying behavioral assessments [63]	Behaviour Research and Therapy	245	33	Q1	virtual reality therapy; behavioral assessment; meta-analysis; wait-list
New technologies promoting active upper limb rehabilitation after stroke: an overview and network meta-analysis [64]	European Journal of Physical and Rehabilitation Medicine	3	65	Q1	robotics; virtual reality; telerehabilitation; primary care
A Recovery-Oriented Program for People with Bipolar Disorder through Virtual Reality-Based Cognitive Remediation: Results of a Feasibility Randomized Clinical Trial [65]	Journal of Clinical Medicine	-	103	Q2	virtual reality; cognitive remediation; mental health; recovery
Perceptions About Augmented Reality in Remote Medical Care: Interview Study of Emergency Telemedicine Providers [66]	JMIR Formative Research	-	72	Q3	virtual reality; augmented reality; telemedicine; remote medical services

value of 39.48. Following closely are Keely, E. from the University of Ottawa and Wang, J. from the University of South Alabama, with C/P values of 19.79 and 19.60, respectively. Additionally, notable authors in terms of C/P productivity include Liddy, C. from the University of Ottawa and Patel, A. from the University of New South Wales Sydney.

Overall, understanding key drivers of research impact can inform strategies to build on existing evidence and promote meaningful discoveries. Bibliometric analysis utilizes author-level metrics like the h-index, g-index, and m-index to quantify scholarly impact and influence. The h-index measures productivity as the number of papers (h) with at least h citations. The g-index indicates g papers with at least g^2 citations. Proposed in 2005, the h-index gained popularity for assessing productivity and impact, although variants address limitations (e.g. g-index, m-index) [67]. For instance, scholar Lee has an h-index of 16 based on 29 highly cited papers out of 61 articles that garnered over 800 citations during 12 active publishing years, giving an m-index of 1.33. In summary, bibliometric assessments of researchers' productivity and citation counts provide insights into scientific influence and progress in healthcare research.

To assess authors' productivity in terms of total publications, we have generated Figure 5. This graph illustrates that among the top ten authors, Lee, J. and Li, J. emerge as the most prolific contributors.

5) COUNTRY-SPECIFIC CONTRIBUTIONS

Bibliometric analysis identified the countries exhibiting the most robust research output are detailed in Table 6. In the realm of healthcare research, the United States (USA), England, Canada, Australia, Netherlands, and Germany as the top contributing countries in healthcare research by total publications. The United States, England, and Canada also led in total citations, while the People's Republic of China and Spain had the fewest. Moreover, the negligible Middle Eastern contribution indicates a knowledge gap this review can help fill by establishing a foundation for subsequent regional research on referrals and healthcare systems.

For example, the United States dominates publishing and citations, with over 179,000 citations far exceeding other countries. England published the second highest number of papers 4,617 with 103,620 citations. Analyzing citation rates per publication shows France, Germany, and Italy as the most citation-intensive countries, highlighting key global research hubs advancing healthcare knowledge. Strategic collaboration across these productive regions can catalyze advancements through knowledge sharing. Following the descriptive analysis, we have conducted bibliometric network analysis to discern bibliographic couplings, co-citations, and topic co-occurrences. The outcomes of this analysis are meticulously documented in the next section.

B. BIBLIOMETRIC NETWORK ANALYSIS

Bibliometric network analysis provides insights into research collaboration and influence through coupling and co-citation mapping across authors, organizations, countries, and journals [68]. This methodology summarizes contributions within a research topic by performing a literature review to identify key theme clusters while minimizing subjective bias. Network analysis thereby enables an objective assessment of research progress on a given topic to inform future agenda-setting. In this study, coupling and co-citation mapping will elucidate mutual research efforts and citation interdependencies in order to synthesize the current state of knowledge around improving referral processes and connectivity in healthcare delivery. We summarize the results of the analysis as follows.

1) BIBLIOMETRIC COUPLING OF AUTHORS

Bibliographic coupling identifies document pairs with the highest similarity based on shared references, reflecting related research areas and potential future directions [69]. Coupling between authors can elucidate collaborations and shared research foci in a field. This part conducts bibliometric author coupling analysis to extract insights into cooperative efforts advancing healthcare research and services, as illustrated in Table 7 and Figure 6. Examining coupling networks reveals connections between researchers that catalyze knowledge building and scientific progress.

According to Table 7, the author coupling analysis identified researchers with the most publications related to healthcare science and services research meeting a minimum citation threshold of 15. Of 140,807 authors in the WoS database, 15 met inclusion criteria. Analyzing authors who exhibit both prolificacy and influence sheds light on the pivotal contributors to knowledge advancement through collaborative research efforts. In this context, it is noteworthy that Lee, J. emerges as the most productive author, while Liddy, C. stands out for having the highest count of bibliographically linked authors within this research domain.

Authorship data from the WoS database identified leading researchers to map collaborations through bibliographic coupling visualization in VOSviewer, as shown in Figure 6. This generated 5 clusters, with Cluster 1 showing active collaborations among Kumar, Gupta, Patel, and Singh. Cluster 2 reveals linking between Keely and Liddy. Cluster 3 contains Lee, Kim, and Lee, while Cluster 4 includes Li, Li, and Wang. Finally, Cluster 5 consists of Liu and Wang individually, indicating no collaboration with other top authors in the field. Examining coupling networks in this way provides objective insights into research clusters and active collaborations advancing healthcare science. Targeted collaboration initiatives could help connect disparate clusters to share knowledge.

Nevertheless, it's important to note that this analysis remains incomplete, primarily because document clustering cannot be effectively applied to older publications. To address this limitation and enhance our understanding of the research landscape, it is advisable to supplement this approach with citation analysis and co-citation analysis, as suggested in [70].

2) ANALYSIS BASED ON ORGANIZATIONAL AFFILIATION

Organization-level analysis identified the top 10 most productive countries and their leading academic institutions by total citations and bibliographic coupling link strength illustrated in Table 6. The University of Toronto and Harvard Medical School were the most productive and influential

TABLE 5. Analyzing author's citations and publications over time.

Author	Affiliation	TP	TC	C/P	h-index	g-index	m-index
Lee, J.	University of Toronto	61	866	14.20	16	29	1.33
Li, J.	Palo Alto Medical Foundation Research Institute	56	876	15.64	15	28	1.25
Patel, A.	University of New South Wales Sydney	53	886	16.72	16	28	1.33
Wang, J.	University of South Alabama	52	1,019	19.60	12	31	1.00
Wang, Y.	Zhejiang University	52	450	8.65	9	20	0.75
Li, Y.	Shanghai Jiao Tong University	51	545	10.69	11	28	0.92
Liddy, C.	University of Ottawa	47	894	19.02	16	31	1.33
Liu, Y.	Harvard University	46	1,816	39.48	13	22	1.08
Kumar, A.	All India Institute of Medical Sciences	44	671	15.25	13	25	1.08
Keely, E.	University of Ottawa	43	851	19.79	15	28	1.25

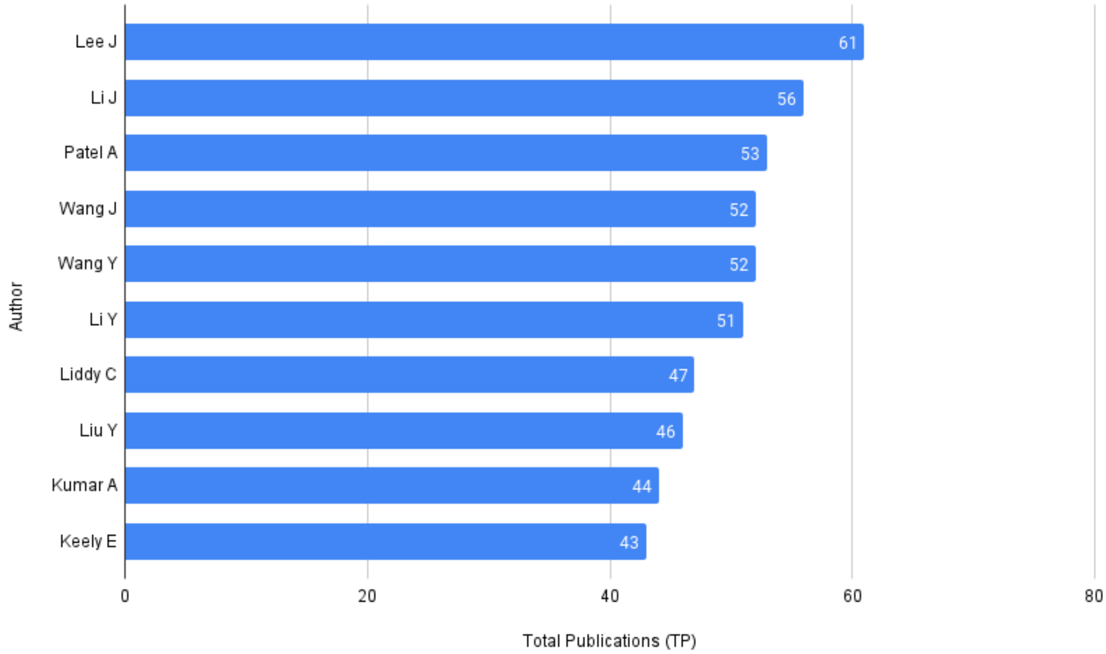

FIGURE 5. Top 10 productive authors (by number of contributions).

TABLE 6. Top 10 countries based on contributions and citations.

Country	TP	TC	C/P
USA	11,709	179,341	15.32
England	4,617	103,620	22.44
Canada	2,653	59,186	22.31
Australia	2,617	52,913	20.22
Netherlands	1,799	38,366	21.33
Germany	1,476	36,916	25.01
Peoples R China	1,377	18,257	13.26
Italy	1,327	30,935	23.31
Spain	975	19,346	19.84
France	946	24,242	25.63

TABLE 7. List of authors in terms of bibliographic coupling.

Author	Total link strength
Liddy, C	6,114
Keely, E	6,090
Li, Y	1,544
Wang, J	1,545
Li, J	1,514
Wang, Y	1,337
Liu, Y	1,020
Kumar, A	439
Patel, A	411
Lee, J	380
lee, S	365
Singh, S	356
Kim, J	324
Gupta, A	312
Patel, S	289

organizations. The University of Toronto, Canada had the highest total link strength of 54,528 despite Canada not affiliating any top authors, highlighting this research group's significant contributions to advancing healthcare innovation. The USA followed with 43,698 total link strength from Harvard Medical School. The University of Sydney led Australia in third with 43,251 link strength. Examining productive research institutions provides insights into key hubs driving progress through impactful scholarship. Targeted collaboration could synthesize strengths across organizations to accelerate healthcare advancements.

Moreover, to elucidate the collaborative dynamics among various countries/regions within the realm of healthcare research, we crafted a country collaboration network graph, as depicted in Figure 7. The connecting lines within the

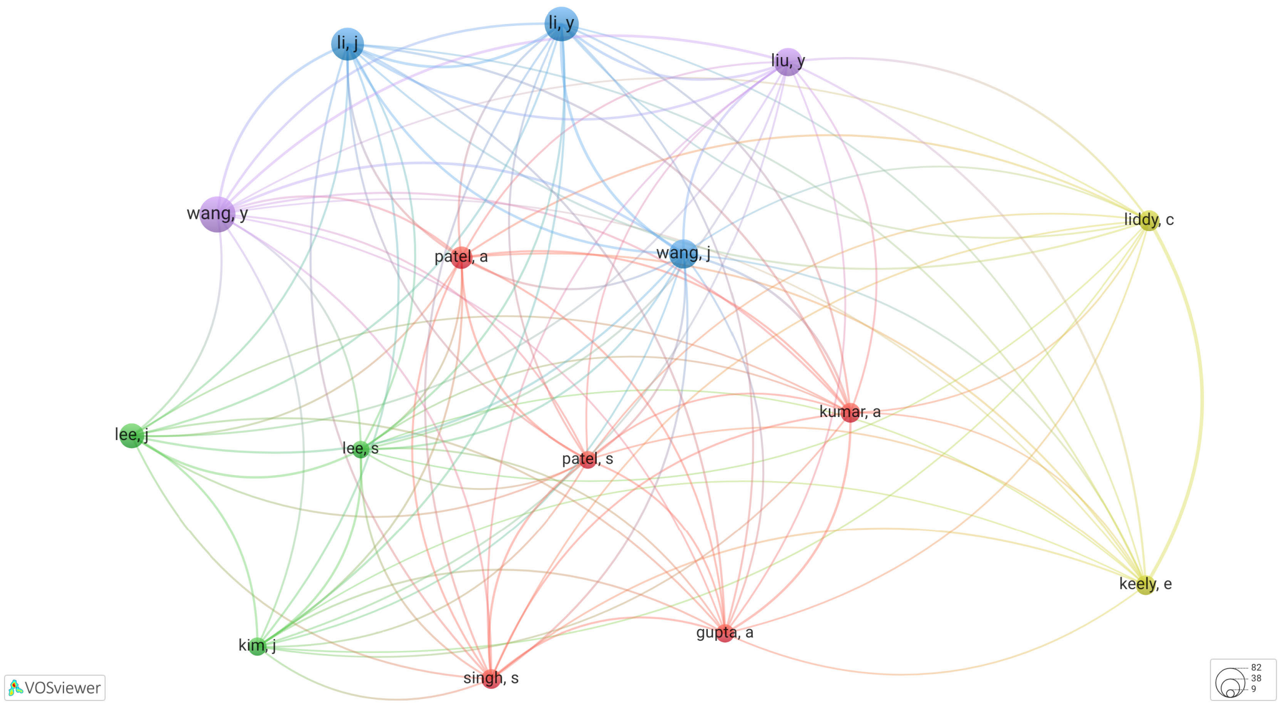

FIGURE 6. Author coupling.

TABLE 8. Top 10 universities/organizations in terms of bibliographic coupling.

Organization	Country	Total link strength
University of Toronto	Canada	54,528
Harvard Medical School	USA	43,698
University of Sydney	Australia	43,251
University College London	England	36,732
University of Ottawa	Canada	34,920
University of Melbourne	Australia	34,234
University of Oxford	England	33,913
King's College London	England	33,757
University of Washington	USA	32,516
University of California San Francisco	USA	32,403

graph visually represent instances of co-authorship between countries and regions. Upon examination of node size and the thickness of connection lines, it becomes apparent that the United States exhibits remarkable activity levels, engaging in substantial collaborations across the continent. Following closely in terms of active involvement are England and Canada, as indicated by their prominently sized nodes. Conversely, Italy, Spain, and France appear to have made comparatively limited strides in fostering collaborative research efforts.

A visualization depicting collaborations among various universities/organizations within the research field is presented in Figure 8. Notably, some of the most prolific universities identified in this analysis also hold positions in the top 100 universities according to the QS World University Rankings for 2023. These notable institutions include the University of Oxford (ranked 3rd), the University of Melbourne (ranked 14th), the University of Sydney (ranked 19th), the University of Toronto (ranked 21st), and King's College London (ranked 40th), among others. This observation underscores the significant textitasis placed by top universities on research within the medical and health service ecosystem.

3) KEYWORD CO-OCCURRENCE ANALYSIS

In the following subsection, we conduct co-citation analysis, an approach aimed at revealing thematic commonalities among publications and facilitating the clustering of documents based on their conceptual structures. This analysis serves as the foundation for semantically clustering related documents within the same domain [71], [72]. To further enhance our understanding, we complement co-citation analysis with a co-word analysis, which assists in identifying keyword co-occurrences. Keywords play a pivotal role in the retrieval of specific information during literature searches, effectively linking search topics with relevant research content. The resulting keyword network visually represents the knowledge domain, offering insights into key research themes and illustrating the interrelationships among these topics. In this study, we employ VOSviewer for the construction and visualization of the keyword network.

Keyword co-occurrence analysis was conducted on author-assigned keywords using a threshold of 5 minimum occurrences, optimized through experiments for visual clustering. Singular and plural keyword forms were consolidated (e.g.

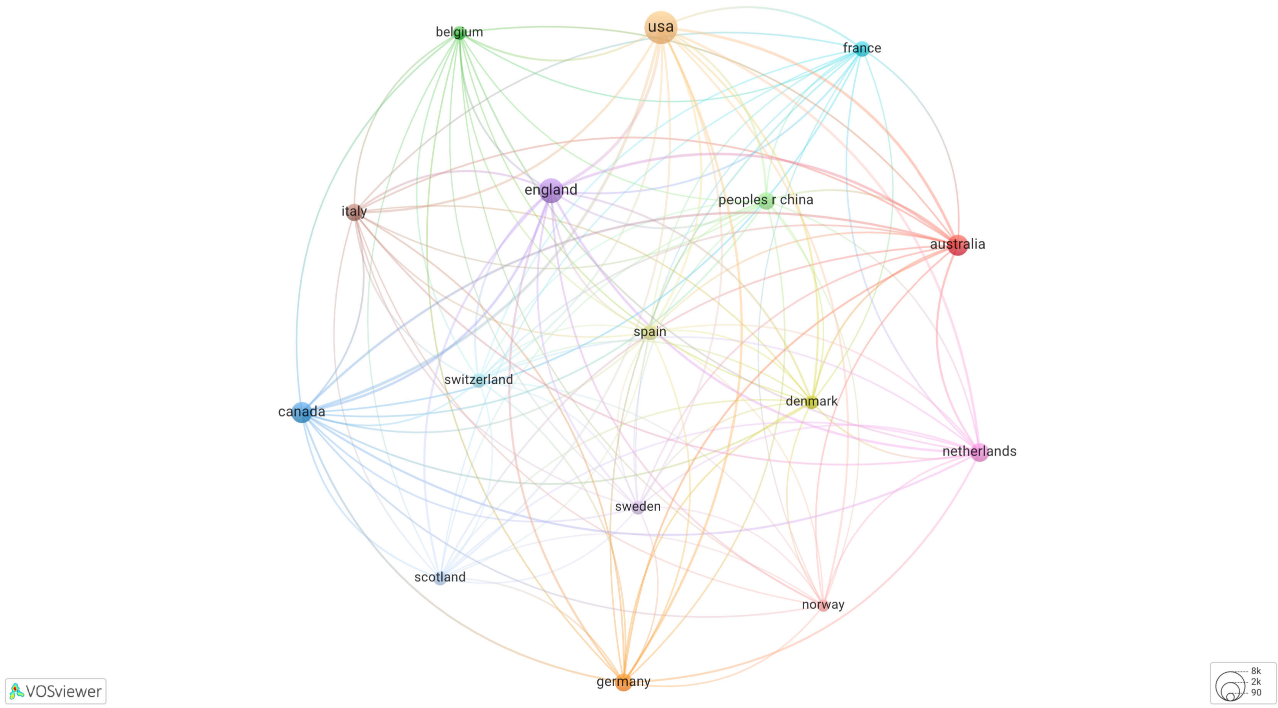

FIGURE 7. Visualization for collaborations between countries/regions.

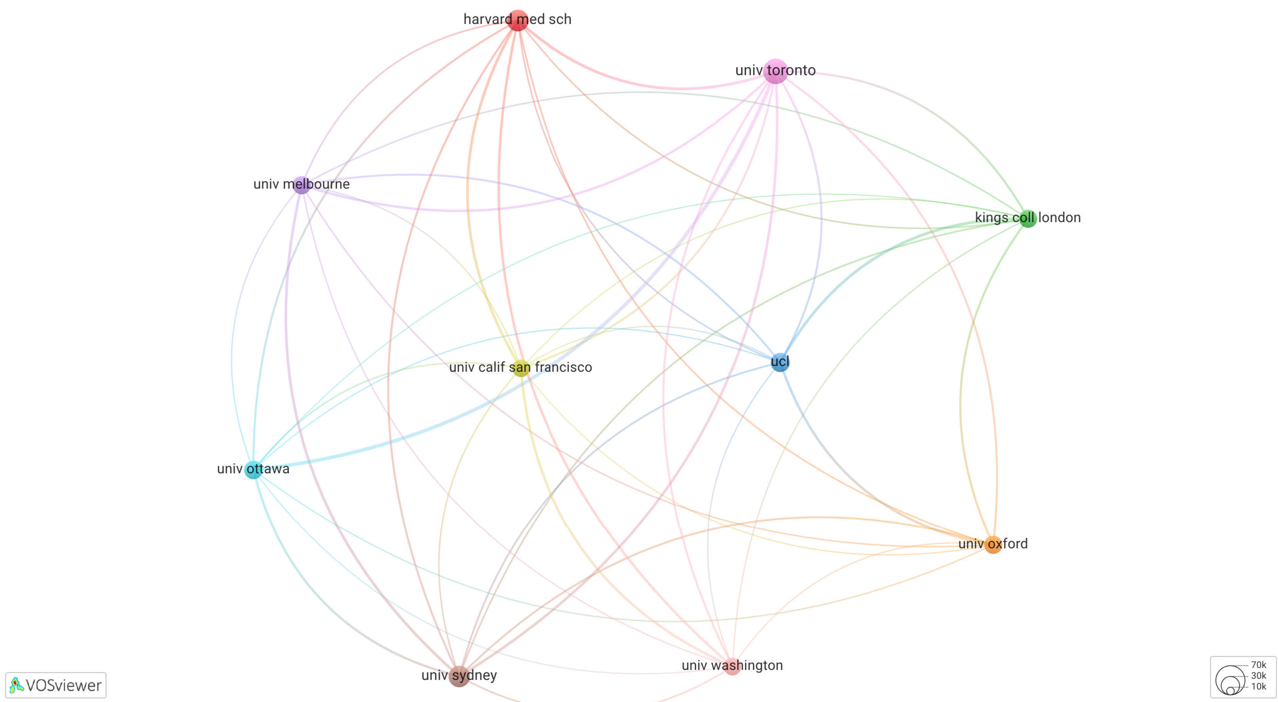

FIGURE 8. Visualization for collaborations between universities/organizations.

wait-times, wait-time; health services, health service), along with abbreviations and full forms (e.g. ICU, intensive care unit; coronavirus, sars-cov-2 and COVID19). Of 42,214 initial keywords, 3,628 met the threshold. Notably, synonymous terms emerged, including ''health care'' and ''health-care'', ''primary care'' and ''primary-care'', ''quality of life'' and ''quality-of-life'', ''computer-aided diagnosis'' and ''computer aided diagnosis'', ''decision making'' and ''decision-making'', and ''Virtual reality'' and ''Virtual-reality'' etc. To enhance relevance and minimize noise from generic topics, certain regular keywords unrelated to the research theme were removed through manual screening and post-processing. This yielded a 150 node keyword network with 5,629 links and 9,865 total link strength presented in Figure 9. Salient terms like ''primary care,'' ''telemedicine'', and ''virtual reality in health'' occurred frequently, suggesting telemedicine is integral to healthcare quality while virtual reality is a widely adopted technique. Eliminating tangential keywords focuses the analysis on core topics and technologies advancing healthcare research. Network mapping enables objective visualization of research clusters to inform opportunities for collaboration across disciplines.

Precise keyword analysis was obtained through quantitative measurements in VOSviewer. Label size denotes occurrence weight. Links represent connections between keywords, and total link strength indicates the cumulative link weights for a given keyword [22]. Merging application and technology keywords investigated their relationships. Current expectations indicate a shift from healthcare to health and wellbeing is motivating changes in service offerings and delivery channels. Thus, organizations encourage implementing virtual care, health tracking, digital diagnostics, decision support systems, prescription delivery, and self-service health applications, with enthusiastic adoption of virtual healthcare systems and related digital innovations. Density visualization revealed 5 clusters of application and technique keywords (Figure 9). The objective keyword mapping techniques enable researchers to chart connections between healthcare applications and enabling technologies to inform future priorities at the intersection of health system needs and technical capabilities.

- Cluster 1 reveals digital health services have become essential for optimizing patient satisfaction by enabling health tracking, monitoring, and medication adherence, relating to e-health, hospital quality, and telemedicine applications. In several ways, human-computer interaction enabled healthcare stands to gain better medical services including illness prevention, tele-healthcare, physical examinations, diagnosis, treatment, rehabilitation, chronic disease management, in-home care, and first aid. In summary, keyword clustering highlights connections between digital health applications and quality, satisfaction, and access improvements, underscoring technology's role in advancing healthcare services. Targeted initiatives synthesizing applications and technical capabilities can further accelerate development along these high-need areas.
- Cluster 2 encompasses quality of healthcare keywords related to connected healthcare, diagnosis, critical care, and medical decision-making, which rely on human experts and knowledge engineers to construct domain-specific rules, thereby enhancing patient trust in modern healthcare. Whereas communication research previously focused solely on provider interactions, patient involvement in communications is now a pillar of quality. Collaboration between human expertise and technical capabilities can further advance drug discovery, disease forecasting, emergency response, and overall health system performance. In summary, keyword analysis highlights trust, communication, and human-AI collaboration as critical facets of improving healthcare quality through technology integration. A balanced, patient-centered approach synthesizing human and technical strengths is key to optimization.
- Cluster 3 shows the patient referral network relates to patient-centered care, waiting lists, referral payment, e-referrals, e-consultations, and health record access, with studies assessing alliances between public and specialized hospitals using reverse referrals to balance loads and reduce wait times. Digital technologies can rapidly analyze referrals to offer immediate, trustworthy recommendations to doctors. This trend emerged from advances in computer programming and information technology enabling simulation-based analysis of system issues. In summary, keyword clustering spotlights how referral innovations, collaboration between care settings, and technical capabilities in computation and simulation can improve coordination and outcomes. Further synthesizing emerging solutions across the referral process life-cycle represents an impactful area for optimization.
- Cluster 4 indicates healthcare delivery relates to stretchable electronics, strain and temperature sensors, the Internet of Healthcare Things (IoHT), and the Medical Internet of Things (MIoT) for measuring biological parameters and monitoring real-time patient data, especially when integrated with remote sensing. Healthcare and medical data like ECG, heart rate, blood pressure, glucose, and cholesterol are gathered and preprocessed via edge computing using noise removal and deep learning for pattern recognition. Diagnostic reports from deep models at the edge are then transmitted to cloud servers, institutions, and patients. Edge computing enables real-time analysis for MIoT while ensuring low latency, highlighting how emerging sensor and IoT technologies can transform point-of-care diagnostics and data sharing. However, challenges prompt development of information management technologies to facilitate seamless integration. In summary, keyword analysis provides research insights into how frontier sensing, edge computing, and cloud architectures can collaborate to enable next-generation data-driven healthcare.
- Finally, cluster 5 indicates quality of life improvement relates to AR and VR in health, AI, ML, and computer vision to take telemedicine to the next level, solving referral process problems and enabling new research possibilities. Virtual care technologies can aid providers

TABLE 9. List frequently top occurring authors keywords by co-occurrence analysis.

Keyword	Occurrences	Total link strength
telemedicine	1,316	1,055
primary care	870	649
covid-19	838	631
telehealth	486	445
mobile health	469	379
clinical decision support	423	315
machine learning	474	302
health-care	445	294
qualitative research	376	283
palliative care	351	270
patient-based	322	263
primary health care	349	258
mental health	316	256
virtual reality in health	337	254
diagnosis	358	247
artificial intelligence	303	230
quality of life	295	225
depression	243	214
systematic review	255	212
quality improvement	319	208
referral payment	295	208
randomized controlled trial	265	203
surgery	317	197
digital health	216	193
healthcare coordination	271	191
health communication	236	188
public health	241	188
health monitoring	242	185
patient referral network	258	176

in effective planning and diagnosis. AI and ML empower computers to automatically learn from data without explicit programming, applying to precision medicine by analyzing patient attributes to predict and recommend optimal treatments. In summary, keyword clustering highlights the monumental potential of emerging technologies like extended reality, AI, and ML to transform referral systems, care delivery, diagnosis, treatment planning, and personalized care. However, thoughtfully addressing integration challenges will be critical to unlocking the full potential of human-AI collaboration in revolutionizing health outcomes.

This work is centered on the comprehensive review of state-of-the-art technologies facilitating the realm of digital and smart healthcare. The analysis of keywords associated with these techniques and applications has provided valuable insights. Table 9 presents a compilation of author-assigned keywords, ranked by total link strength. The primary terms, ranked in descending order of overall prominence, include telemedicine, primary care, and COVID-19. Additionally, there are supporting technologies such as telehealth, mobile health, metaverse and ML. The lively interaction of these key technologies supports autonomous learning and ongoing enhancements, empowering these systems to increasingly replicate human expertise with growing accuracy. This transformation is crucial for the development of healthcare access, that is more scalable, less humans are involved and significantly improves the service quality.

Among the various healthcare technologies examined in this analysis, telemedicine emerges as a dominant and highly prevalent technology in the academic landscape. It is noteworthy for its highest occurrence count (1,316), highest link count (143), and highest total link strength (1,055) compared to other healthcare technologies. This observation aligns intriguingly with findings in the context of smart healthcare 5.0, which underscores telemedicine's role in ambient patient tracking, emotive telemedicine, telesurgery, wellness monitoring, virtual clinics, and personalized care. Furthermore, the evolution of primary care has played a pivotal role in driving transformation within the digital healthcare industry. The advent of digital health services utilizing digital tools and internet-based technologies has significantly impacted the dynamics of patient-physician interactions on a large scale. Notably, technologies such as virtual care have brought about substantial changes in this regard. In spite of the rapid advancements within the healthcare sector, several enduring challenges persistently loom large. These encompass the formidable burden posed by long-term chronic conditions, the relentless escalation of healthcare costs, the demographic shift toward an aging population, a persistently inadequate healthcare workforce, and the ongoing challenge of resource scarcity. These salient issues have catalyzed a pressing need to revolutionize healthcare delivery, extending services directly into the homes of individuals [73].

The advent of the COVID-19 pandemic has imposed an unprecedented strain on the global healthcare sector, extending its impact to encompass workforce dynamics, infrastructure readiness, and the management of supply chains. Indeed, the pandemic has emerged as the primary catalyst for the rapid transformation of the healthcare ecosystem, compelling stakeholders to expedite the adoption and adaptation of cutting-edge technologies within the sector [74]. Consequently, the post-pandemic era has witnessed significant foundational shifts within the healthcare landscape. Notably, the contemporary generation of healthcare consumers has assumed a proactive role in healthcare decision-making, showcasing an enthusiastic embrace of virtual healthcare systems and associated digital innovations. Their paramount preferences revolve around the development of digitally-empowered, on-demand, and seamlessly integrated patient-clinician interactions, facilitating the delivery of patient-centric services that transcend geographical constraints and socio-economic disparities [75]. It is crucial to acknowledge the intrinsic uniqueness of each individual's healthcare journey, underscoring the imperative to tailor specific services and elevate each interaction to the pinnacle of a personalized healthcare experience [8].

The imperative to incorporate advanced digital tools and services has become paramount, aimed at enhancing consumer satisfaction, enabling health status tracking and monitoring, and improving medication adherence. Healthcare consumers are increasingly open to sharing confidential data, necessitating organizations to establish interoperability,

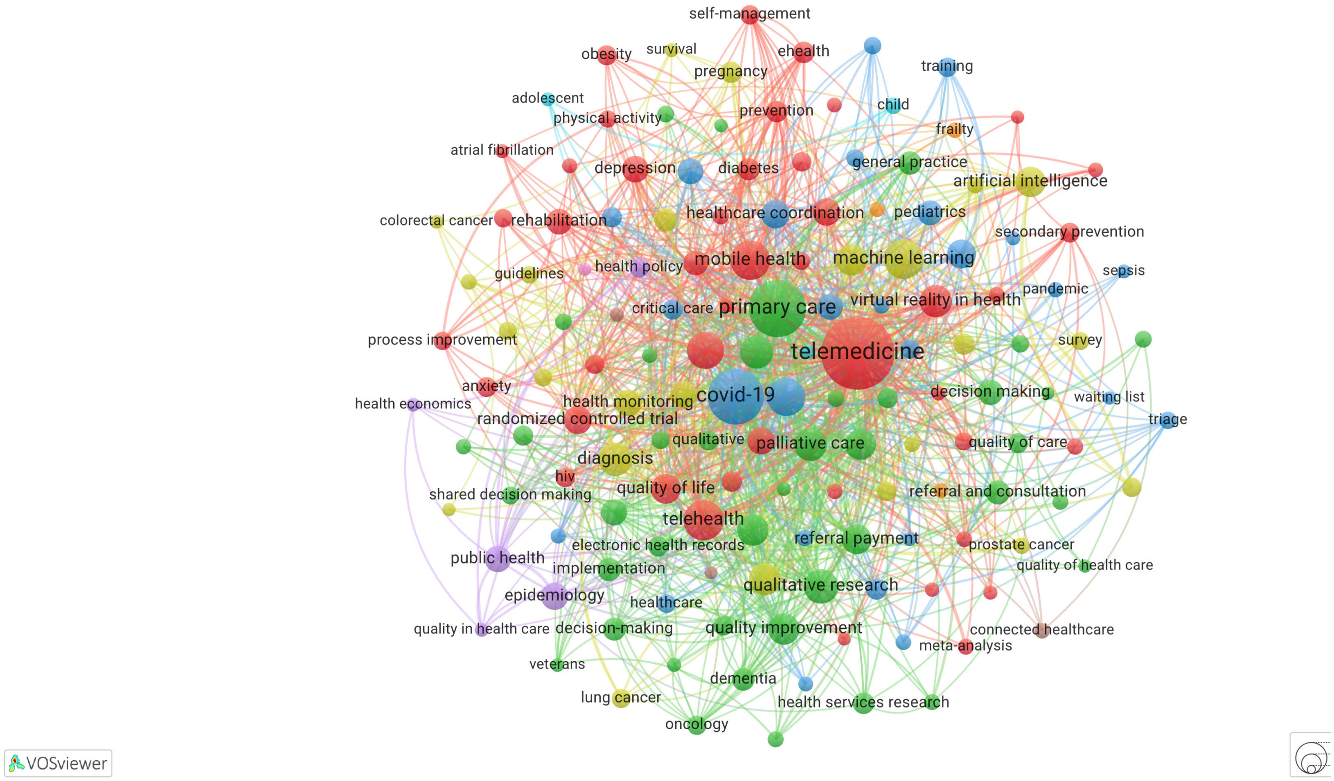

FIGURE 9. Visualization author keywords by co-occurrence analysis for 150 keywords.

thereby maintaining consumer trust through demonstrated reliability, transparency, and empathy in their operations [9]. The current paradigm shift textitasizes a transition from healthcare to a broader focus on health and well-being, prompting changes in the design of service offerings and delivery channels. Organizations are actively endorsing the implementation of VR and AI technologies to empower healthcare professionals in effective disease planning and diagnosis [76].

For instance, in 2020, neurosurgeons at Johns Hopkins Hospital conducted surgery using an AR headset developed by Augmedics. This pioneering procedure involved the use of a see-through eye display projecting patients' anatomical images akin to X-ray vision, facilitating the fusion of six vertebrae in the patient's spine to alleviate chronic back pain [77]. VR applications in healthcare offer advanced surgical pre-operative planning by transforming CT scans into accessible 3D reconstructions through headsets. Surgeons can use this technology to precisely view, isolate, and manipulate anatomical regions, facilitating intricate surgeries with precision. Additionally, VR tools show potential in enhancing prescription treatments, particularly in contexts like plastic surgery, where patients can visualize potential surgical outcomes on virtual avatars, gaining insights into the surgeon's abilities. Successful VR surgical procedures require a profound understanding of human anatomy and proficiency in using highly dexterous and individually adjustable instruments [78].

Furthermore, AI in healthcare encompasses a broad spectrum of applications, employing ML algorithms to replicate human cognitive processes, including the presentation, analysis, comprehension, and learning from complex medical and healthcare data [79], [80]. It is worth noting that ML, a subset of AI, comprises a set of statistical algorithms capable of learning from data during a training phase and making predictions during an inference stage.

The keyword network highlights that primary care and telemedicine have become popular due to the covid-19 with the enabling technologies that are mobile, VR, ML, etc. This has indeed formed an ecosystem, as evident from the studies in JAMA Network Open. Up to 25% of the hospital readmission can be reduced with the help of AI-based disease management tools that incorporate self-learning algorithms and friendly user interaction. The persistent adaptive cycle, underscored by Stanford Medicine's research revealing a 70% precision rate in AI-driven virtual mental health assessments, empowers these platforms to imitate human expertise with remarkable faithfulness. The groundbreaking capacity for transformation opens up unparalleled scalability, as demonstrated by the World Health Organization's initiative program employing mobile health interventions to connect with remote communities. This sets the stage for decreased reliance on human resources, ultimately broadening the accessibility of high-quality healthcare for everyone.

Based on our investigation, the results suggest that the identified domains seek to promote the application of analytical methodologies. These endeavors primarily focus on facilitating decision-making, improving patient results, optimizing resource distribution, and tackling ethical concerns within the healthcare sphere.

IV. POTENTIAL APPLICATIONS AND FUTURE DIRECTIONS

Historically, the healthcare industry has exhibited a cautious approach to adopting and implementing emerging information technologies, marked by meticulous evaluation of their impact on patients. This careful assessment encompasses various challenges, including technological considerations (interoperability, portability, stakeholder customization), human factors (skills, resistance, distrust, cyberattacks), as well as legal and regulatory aspects.

A. POTENTIAL APPLICATIONS IN HEALTHCARE

The healthcare industry has begun adopting remote patient monitoring through modern telemedicine techniques in an efficient and effective manner, ensuring optimal service delivery for patients. Specifically, virtual care presents numerous potential applications in medicine ranging from research, physical examination, and diagnosis to insurance. Some plausible implementations of the HM that may gain momentum in the near future include virtual physiotherapy, virtual biopsy, virtual counseling, and virtual alert response systems. Virtual biopsy involves non-invasive tissue characterization through image acquisition and processing. Virtual physiotherapy can guide rehabilitation patients through therapeutic movements and exercises. The convergence of telepresence, digital twinning, and blockchain stands to yield substantial benefits from HM, especially for patient monitoring. Moreover, medical diagnosis involves determining a patient's medical condition based on symptoms. Adopting healthcare and medical applications can significantly assist efficient diagnosis of patient conditions through advanced technologies like AR, VR, extended digital twins, blockchain, 5G, etc. Table 10 summarizes potential healthcare applications.

Recent technology trends in healthcare have begun leveraging revolutionary techniques like metaverse and big data integrated with AI in software and hardware to enhance medical device efficacy, reduce health service costs, improve healthcare operations, and expand access to medical care [101]. HM enables immersive learning, understanding, and sharing of patient health issues and medical data with clinicians, while AI analyzes and diagnoses patient health data. For example, AR and VR, aided by AI, provide doctors with high-quality 3D patient images and scans required for interventions. AI can offer crucial insights to prioritize critical patients, minimize potential electronic health record analysis errors, and enable more accurate diagnoses [102]. The vast volume of health data and records can overwhelm doctors trying to stay current on the latest medical advancements and provide quality, patient-centered care. AI algorithms in the HM can rapidly analyze electronic records and biomedical data collected by medical facilities and professionals, offering doctors prompt and reliable recommendations [103]. The HM and AI collaboration can also assist drug discovery, disease forecasting, and emergency response. While an AI-enabled Metaverse may significantly risk patient privacy and ethical issues, or even cause medical errors that mislead doctors' treatment decisions, it can also open new healthcare data insights and expedite clinician-patient interactions [104]. The lack of result justification poses a major adoption challenge for the AI-enabled Metaverse. Future medical VR applications will require high-precision multimodal medical information standards based on patient conditions.

The use of technologies has the potential to revolutionize healthcare experiences within environments. A study explores applications such, as tracking, emotive telemedicine, telesurgery wellness monitoring, virtual clinics and personalized care through healthcare 5.0 and the Metaverse. The integration of technology in the nature of the Metaverse could enhance transparency and immutability for healthcare transactions [81]. Another research article critically examines how the Metaverse can be integrated with IoT, blockchain, AI and other technologies to unlock its potential in healthcare [82]. Additionally, there is a study in [83] that focuses on AR and VR glasses with the Medical Internet of Things (MIoT) for Metaverse healthcare applications. However challenges such as costs, privacy concerns, ethical considerations and organizational adoption issues still need to be addressed [84]. In conclusion the Metaverse holds promise in transforming healthcare through technologies like AI, blockchain, IoT and extended reality. Further research is necessary to overcome implementation barriers for its impact on medical education quality improvement care delivery and health outcomes. Private partnerships will play a role, in improving accessibility security interoperability and clinical integration to unleash the disruptive potential of the Metaverse in democratizing global personalized healthcare.

For instance, disease coding will use three-dimensional virtual entities, not text like ICD codes, to precisely describe each information type [105]. However, processing and standardizing multimodal medical information poses significant challenges [106]. Various medical and health services built in the HM should consider developing multimodal medical information standards based on existing mature and authoritative standards. The HM connects stakeholders like doctors, patients, administrators, and governments, with virtualized, gamified user relationships [107]. Medical stakeholders utilize medically meaningful virtual images, 3D models, MR, spatial environments, and other asset categories with metadata to form secure, encrypted content packages that construct the HM. Moreover, combined with hospital equipment information, immersive experiences in a virtual world allow students to replay actual operations as if they were the surgeon [108]. During patient operations, the HM

TABLE 10. The contribution of productive articles in potential applications.

Title of the article	Contributions
Metaverse assisted telesurgery in healthcare 5.0: An interplay of blockchain and explainable AI [82]	Advancing smart healthcare through metaverse, blockchain, explainable AI, and telesurgery integration while evaluating challenges.
Overview: Technology roadmap of the future trend of metaverse based on IoT, blockchain, AI technique, and medical domain metaverse activity [83]	Metaverse integrates IoT, blockchain, AI to enable immersive virtual healthcare overcoming real-world limitations.
Holographic elysium of a 4D ophthalmic anatomical and pathological metaverse with extended reality/mixed reality [86]	Extended reality holograms innovatively advance ophthalmic education and counseling as immersive pedagogical tools.
Training in lung cancer surgery through the metaverse, including extended reality, in the smart operating room of Seoul National university Bundang hospital [87]	The application of metaverse technology in lung cancer surgery training within an advanced smart operating room at Seoul National University Bundang Hospital, South Korea, featuring voice-activated controls for operating room equipment and facilitating real-time discussions with pathologists.
CardioVerse: Thecardiovascular medicine in the era of metaverse [88]	The pandemic expedited the adoption of telemedicine and the metaverse in cardiovascular health, with CardioVerse holding transformative healthcare potential.
Prediction of user's intention to use metaverse system in medical education: A hybrid SEM-ML learning approach [89]	The study evaluates students' perceptions of implementing Metaverse in UAE medical education, incorporating technology and individual factors. Employing ML and Structural Equation Modeling (SEM), it highlights User Satisfaction's importance, offering insights for educational stakeholders and methodological contributions to Information Systems literature.
Application of active learning strategies in metaverse to improve Student engagement: An immersive blended pedagogy bridging patient care and scientific inquiry in pandemic [90]	The COVID-19 pandemic has prompted the development of innovative online teaching methods to foster student engagement and bridge the gap between patient care and scientific inquiry. An assessment gauged their effectiveness in enhancing self-directed learning, communication, collaboration, problem-solving, innovation, reflection, and clinical skills.
Delivery of pre-operative patient counseling services in surgery via metaverse technology [91]	Virtual counseling has the potential to significantly transform future sessions by offering in-depth surgical information, enhancing patient comprehension, empowering informed decision-making, safeguarding patient rights, surmounting language barriers, accommodating busy schedules, and assisting patients with physical limitations. Further research is warranted to advance pre-operative counseling practices.
Development and implementation of a Metaverse-based social skills training program for children with autism spectrum disorder to enhance social interaction: A Randomized controlled Trial protocol [92]	Autism spectrum disorder (ASD) presents challenges in social communication. The utilization of a metaverse-based Program for the Education and Enrichment of Relational Skills (PEERS) can significantly improve social skills in children with ASD, offering accessibility and affordability for home-based use. Additionally, early detection of emotional changes through wearable biometric devices may proactively address issues such as anxiety and anger in these children.
Into the spine metaverse: Reflections on a future metaspine (uni-)verse [93]	In the realm of next-generation spine care, VR, ML, and AI are emerging as transformative digital technologies, revolutionizing data acquisition, decision-making processes, and patient interactions.
World's First Health Metaverse & NFT Store [94]	Establishing a blockchain-based platform, devoid of considerations related to race, religion, and ethnicity, provides an opportunity for global collaboration towards a common and meaningful goal. By prioritizing healthcare, dietary enhancements, and physical fitness, we collectively contribute to a healthier and more contented world.
World's First Healthcare Dehealth Metaverse [95]	The DeHealth Metaverse leverages VR, AR, and MR technologies, facilitating doctor-patient communication in a collaborative virtual environment. It supports professional interactions and offers users the opportunity to generate virtual currency by trading anonymized healthcare data.
Using immersive technologies to develop medical education materials [96]	Immersive educational resources, incorporating 3D printing, Augmented Reality (AR), and 360-degree video, are shared to enhance pediatric surgery student training. These materials provide practical experience and offer valuable insights applicable to various medical specialties.
Virtual reality cerebral aneurysm clipping simulation with real-time haptic feedback [97]	A haptic-based VR simulator, the Immersive Touch Aneurysm Clipping Simulator (ITACS), was developed to improve neurosurgical residents' understanding of patient aneurysm anatomy.
Exploring the Potential of Metaverse Technology in Healthcare: Applications, Challenges, and Future Directions [98]	There are diverse applications of the metaverse within healthcare systems, textitasizing its potential to improve patient clinical management. The study reports an in-depth exploration of the metaverse fundamentals, key enabling technologies, and its applications, covering areas such as emergency response learning, hands-on anatomy education, orthopedics, pediatrics, and beyond.
Unveiling the Metaverse: Exploring Emerging Trends, Multifaceted Perspectives, and Future Challenges [99]	Metaverse faces challenges such as privacy, security, fair access, and ethical considerations, highlighting the need to establish strong legal and ethical frameworks for the benefit of everyone. The paper textitasizes the urgent need to deal with legal and ethical aspects as we transition into this new digital era.
HealthLock: Blockchain-Based Privacy Preservation Using Homomorphic Encryption in Internet of Things Healthcare Applications [100]	Employment of blockchain integration and homomorphic encryption for healthcare application to enhance security and data privacy.
Blockchain-based Multiparty Computation System [101]	A systematic overview on security and privacy enhancement in healthcare data management using blockchain and AI algorithms.

platform can also provide students with suggestions and domain knowledge to reduce actual operation error risks.

Based on our investigation, the results point to several key domains seeking to promote the potential applications of

TABLE 11. The summaries of the future domain aim of potential applications.

Domain aim	Descriptions
Healthcare Metaverse	The goal of the engagement between healthcare experts and decision analytics tools is to improve usability, user trust, and satisfaction. Scholars concentrate on creating user-friendly interfaces, guaranteeing the clarity of analytics results, and promoting efficient cooperation between individuals and computer algorithms.
Healthcare predictive analytics	Leveraging real-time data feeds from various sources (wearable gadgets, electronic health records, etc.) can facilitate prompt decisions and interventions. Irregular patterns, trends, and anomalies in information can be predicted with predictive analytics, providing valuable perspectives for decision-making in healthcare.
Decision-making processing	Advanced tools utilize advanced analytical approaches, such as machine learning and optimization, can significantly aid healthcare practitioners in making effective decisions. These tools can be used for planning treatment, allocating resources, and forecasting the risks during treatments.
Ethical concerns	The moral aspects of utilizing decision analytics in healthcare involve a spectrum of considerations, encompassing accountability, transparency, privacy, and bias. Continuous research is committed to advance equality, ethical integrity, and fairness in making the decision.
Blockchain Technology Integration in Healthcare	Blockchain-based applications integrated with Internet of Medical Things (IoMT), AI, and other technologies to leverage data privacy and security in healthcare.
Encrypted Data Analysis	Using AI to analyze encrypted data without the need to decrypt it. This helps extract useful knowledge without compromising privacy in the health metaverse scenario.
Privacy security and authentication technology	These technologies are essential for securing the personal data of individuals when they use digital identities to enter Metaverse. Eventually, it helps to gain trust of society and users and attract them to the space.
Crypto-privacy Solutions	Elevating blockchain and cryptography for privacy and security issues in the Health Metaverse.
Greater systemic usage of big data in health research	Utilizing big data health research is highly beneficial and could raise the awareness of the public sector in the Health Metaverse

analytics methods. Table 11 shows the domain aim include supporting decision-making, improving patient outcomes, optimizing resource allocation, and addressing ethical concerns in the healthcare sector.

B. FUTURE DIRECTIONS

The modern digital transformation of healthcare systems with telemedicine services and remote patient monitoring has increased the gap between patients and doctors. With the development of communications and virtual technologies in an efficient and effective manner to ensure optimal service delivery for patients using modern telemedicine techniques, doctors can now suggest remote treatment procedures after collecting the necessary patient history and current conditions or reviewing digital health records without directly examining patients. Thus, quality healthcare can be provided by aligning treatment procedures with standards set by medical agencies. Integrating blockchain technology in the Metaverse enables efficient storage and exchange of health-based digital assets across platforms, facilitating more informed and precise diagnosis of various medical conditions by practitioners.

HM represent an emerging field expected to spur disruptive transformations across healthcare. However, adopting HM will enhance present patient monitoring services by changing how people interact with healthcare systems, adding interactive features in a virtual world using technologies like VR for medical training and AR in surgical procedures. While showing promise for healthcare, Metaverse still faces challenges summarized in Table 12. Future directions should explore mitigating these challenges through research on improving AR/VR accuracy and realism, developing intuitive user interfaces, and establishing robust data security and privacy protections. Successful HM integration requires collaboration between technology companies, healthcare providers, regulators, and patients to co-design human-centered systems that balance innovation, ethics, and accessible care. In conclusion, these cutting-edge healthcare technologies hold the potential to deliver effective and satisfactory care on a global scale. Continuous interdisciplinary research and thoughtful governance are essential for harnessing the full benefits of VR/AR within the healthcare Metaverse while actively mitigating associated risks.

C. SAFETY AND PRIVACY

As individuals explore the virtual world further, more unexplored territories within it will reveal new and diverse security and privacy issues. This calls for clever solutions, demanding careful user protection. The metaverse presents unique challenges in security and privacy due to the increasing creation of sensitive personal data [118]. The extensive interconnectedness of the metaverse will inevitably create vulnerabilities, raising questions about the appropriate surveillance methods for effective navigation [119]. These risks jeopardize the personalized relationships between physicians and patients [120]. As a result, concerns about patient safety and privacy become significant at personal, public, and societal levels [11], [121].

Enhancing experiences through communication and virtual technologies in the metaverse involves integrating the physical and virtual realms [122]. While this integration enables physiological monitoring and the gathering of patient data, concerns about privacy and security arise [123]. Innovations like "clone clouds" and "private copies" have the potential to mitigate risks of exploitation and data leaks [124]. It is crucial to prioritize privacy in the development of healthcare solutions in the metaverse, considering sensory, communication, and behavioral dimensions [125]. As the virtual universe undergoes further evolution, robust security measures should be in place to safeguard user privacy and data, unlocking the transformative healthcare potential of the metaverse through ongoing research [115]. This ensures a

TABLE 12. The summaries challenge issue and future directions.

Issue	Challenge	Future Directions
Cyber-Security	The rapid adoption of digital health technologies and virtual environments in healthcare raises critical concerns regarding patient privacy and data security, necessitating rigorous safeguards to protect confidential patient information from unauthorized access as sensitive data is increasingly exposed through multiple communication pathways [110], [111]	To mitigate privacy and security risks associated with emerging digital health technologies, healthcare organizations must implement robust cyber security protocols including network segmentation, access controls, enhanced encryption and consensus techniques enabled by federated learning or blockchain architectures to safeguard sensitive patient data including brain signals, biometrics, medical records, and preferences.
Healthcare Interoperability	Establishing proper communication among heterogeneous devices in healthcare will open doors to new challenges by incorporating various hardware and software components with wearable equipment in a virtual environment ensuring there will be no delay, no data loss is a challenging task. [112], [113]	To enable a smooth transition from traditional healthcare services to 6G-enabled virtual care while avoiding severe unintended privacy consequences, future research should focus on developing proper communication protocols and data governance strategies, including incentive-based blockchain mechanisms and auction-based deep reinforcement learning to optimize communication efficiency, in order to establish robust standards for ethical data sharing and adoption.
High cost of technology	Due to new medical innovations, healthcare technology is constantly evolving, leading to digital transformations by incorporating robotic surgeries and VR in various medical services in an effective manner requires high end-to-end connectivity for an efficient operation, the cost of infrastructure will also be very high for the healthcare providers [114], [115].	To build sustainable and economically-viable healthcare systems, future efforts should prioritize developing durable and cost-efficient devices, decentralized cloud storage, and off-chain blockchain models leveraging Web3.0 infrastructure to reduce storage and computational costs compared to traditional Web2.0 centralized systems.
Quality-of-Service (QoS)	The uneven distribution of shared computational and communication resources across different entities poses significant challenges to ensuring optimal QoS, which could potentially be addressed through a self-balancing federated learning approach in an edge-cloud HM that leverages edge nodes as brokers of equitable resource sharing to enhance patient outcomes and satisfaction [116].	To enhance QoS in future virtual healthcare ecosystems, Advancements in healthcare technology facilitate the gathering of increased personal data, thereby highlighting pressing privacy concerns that demand prompt attention. Further research should investigate edge-edge, edge-cloud, and edge-end collaboration mechanisms that strengthen security and privacy through lightweight AI models at the edge to improve predictive analytics while reducing computational costs.
Personal-of-Experience	The transition to impersonal digital treatment modalities can negatively impact patient experience and recovery by eliminating the unique therapeutic rapport and bonding of face-to-face care, posing a challenge of patient isolation and decreased satisfaction that must be proactively addressed. [115], [116].	To restore personal connections in virtual care, future research should explore contextualized approaches leveraging metaverse technologies like immersive 3D environments, avatar embodiments and auction-based deep reinforcement learning to simulate empathetic face-to-face interactions, enhancing communication and relationships between patients and providers.
Legal and Technological	The proliferation of smart health technologies and inclusion of diverse healthcare stakeholders creates confusion around intellectual property rights, trust, and accountability stemming from lack of defined legal and regulatory frameworks governing collaborations among providers, insurers, vendors and educational institutions, posing barriers to equitable growth [118].	To balance user rights and technological growth, future work should develop legal frameworks with policies that leverage contextual analysis to constrain information flow via big healthcare data, blockchain incentives and explainable AI for prediction, defining regulatory scopes and enforcement mechanisms to control unlawful virtual operations beyond existing government standards. Furthermore, establishing and implementing robust methods is crucial to minimize the risk of privacy and security breaches. Ensuring secure and safe utilization of technology, patient health data, and machines remains a significant concern.

safe environment for interactions, transactions, and digital experiences within the metaverse [126].

In academic research, it is crucial to avoid a singular, all-encompassing solution for addressing all data-related challenges in the metaverse. Instead, specialists in health metaverse privacy and security should tactically choose, create, or complement authenticity-based and privacy-enhancing mechanisms with inventive approaches. Essential goals and issues related to privacy and security must be carefully identified and solved. Some concerns about privacy and security issues are listed below.

- *Confidentiality of trained AI models:* AI model will contain sensitive user data in the Health Metaverse. Therefore, it is essential to prevent the trained AI model from leakage and unauthorized access to models [127].
- *Security analysis of the proposed protocol:* The protocol proposed for any health system should undergo an extensive security analysis, whose security and privacy can be significantly improved with blockchain and AI technologies [128].
- *Homomorphic encryption:* Healthcare data can be analyzed in encrypted form to preserve privacy while valuable insights can be extracted [129].
- *Anti-man-in-the-middle and anti-replay attack security attributes:* Blockchain-based solution can prevent personal health data tampering and protect privacy effectively [130].
- *The vulnerability of IoMT devices to cyber-attacks due to a lack of built-in security:* It should be emphasized the significant role of identity verification and AI-driven error detection in IoMT systems [131].

- *Smart contracts for data access* Smart contracts enabled by blockchain can manage and reinforce privacy-preserving data access rules in the Health Metaverse [130], [132].
- *Seamless interactions between data suppliers:* Ensuring the seamless, fast, and easy interaction between data suppliers using blockchain-based digital platforms is crucial for enhancing privacy and data security for patients [133].
- *Secure identity verification:* Blockchain, encryption, and cryptographic can be employed for identity verification in the Health Metaverse [134], [135].
- *Novel contract for patient data search:* New contracts should support data searching in a controlled and consent-based approach [136].
- *Blockchain's immutable data records:* The immutable structure of blockchain technology can facilitate and secure comprehensive data records in healthcare [137].
- *Building trusted AI models over Blockchain:* Integration of AI and blockchain can open the door to a transparent platform for data sharing which is consent-based and highly confidential [138].
- *Blockchain-based privacy solutions in healthcare* More novel blockchain-based solutions integrated with AI can improve significantly the data management in healthcare [137], [138], [139].
- *Access to EHRs free from treatment website and service providers:* Patients can access their Electronic Health Records (EHRs) on any websites and service providers [140].
- *Personal health data sovereignty:* Individuals are empowered to control their own health data in the Health Metaverse [100], [135].
- *Biometric security measures:* AI-driven biometric authentication along with other dynamic security models can enhance security and privacy concerns in the Health Metaverse [141].
- *Privacy Challenges in virtual clinics:* Given that data privacy laws may not allow data sharing between virtual clinics and other parties, and healthcare AI models contain extensive medical data, they are subject of malicious actors in the metaverse [142].
- *Privacy and security in healthcare solutions:* The awareness about privacy and security requirements has to be raised for cloud computing environments [143].

To sum up, in the landscape of digital healthcare and metaverse, security and privacy are crucial. We have examined it from various perspectives, such as IoMT, blockchain technology, medical algorithms based on ML/AI, data access and usage, and human-centric interactions. From the evaluation, it is possible to chart novel pathways to realize metaverse healthcare services. Future perspectives can be dedicated to offering valuable insights to network designers and engineers in the era of the metaverse. The solutions have to be lightweight and scalable while not compromising the security and privacy aspects. Deeper analysis of these critical issues can optimize the transformative potential of the metaverse in healthcare delivery while responsibly addressing emerging risks.

V. CONCLUSION

In conclusion, the key findings have answered the research questions with bibliometric study. Regarding the focus of current healthcare research (RQ1), due to the covid-19 boost, modern healthcare is moving in the direction of telemedicine for primary care with enabling technologies such as mobile, ML, VR, etc. The keyword and cluster studies (RQ2) reveal the exponential growth of publication in the field of remote healthcare in recent years. It can also be observed the profilic contributors in terms of countries, organization, authorship, and the list of highly prestigious publishers with highly cited research. The top ten countries with a high number of contributions also show the characteristics and direction of research funds in the field. Detailed insights drawn from the bibliometric study can be found at the end of all the subsections in Section III. Emerging themes can be categorized into five clusters. In Cluster 1 (digital health services), the clustering of keywords emphasizes the connections between digital health applications and advancements in quality, satisfaction, and access, highlighting the role of technology in the progress of healthcare services. In Cluster 2 (quality of healthcare) the analysis of keywords underscores trust, communication, and collaboration between humans and AI as crucial elements to improve healthcare quality through integration of technology. Cluster 3 (the patient referral network) highlights how innovations in referrals, collaboration in care settings, and technical capabilities in computation and simulation can enhance coordination and outcomes. In Cluster 4 (healthcare delivery), the analysis of keywords offers insights into how frontier sensing, edge computing, and cloud architectures can collaborate to facilitate the next generation of data-driven healthcare. Lastly, Cluster 5 (quality of life improvement) emphasizes that emerging technologies such as extended reality, AI, and machine learning possess significant potential to revolutionize healthcare, provided integration challenges are effectively addressed. Furthermore, in response to RQ3 regarding the potential for future research, a conceptual framework was developed in Section IV. The current advancements in modern telehealthcare have laid the groundwork for the Health Metaverse, presenting an opportunity to overcome significant healthcare challenges and revolutionize care delivery across various applications. These applications range from medical education and training to immersive clinical care and surgical procedures. The forthcoming research domains, along with their associated issues, have been discussed, emphasizing state-of-the-art enabling technologies, security, and privacy, as we progress towards a scalable, secure, affordable, and more human-centric healthcare system.

Summarized from our findings, the rapid digitization and automation of healthcare has catalyzed the emergence of innovative models that create new channels for delivering cost-effective treatment. It has also provided invaluable impetus for advancing medical education, surgical procedures, and connections between providers and patients. This is evidenced by the focus on multimodal medical information standards, biomedical and social data fusion, health metaverse, telemedicine and online health management systems, and medical AI applications. However, there are salient challenges including technology upgrades, ethical gamification of medical services, safeguarding patient privacy, and preventing escapism from reality. This bibliometric study has provided a holistic overview and granular insights into past, current, and future research trends in smart health using articles from the Web of Science database. A total of over 3000 research articles from 2012-2023 were analyzed using VOSviewer. It was found that the publication volume follows a power trendline of publications $y = 966.39 \times e^{0.1444x}$ with corresponding R^2 values of 0.9801, indicating the rapid proliferation of research in health metaverse. The leading authors, countries, and institutions were discussed, demonstrating the dominance of USA and England which accounted for 64% of total publications. This research aims to identify evidence-based best practices that enhance operational efficiency, care quality, patient satisfaction, population health outcomes, and financial sustainability across diverse healthcare settings. This is achieved through five cluster research streams integrating healthcare management perspectives from medicine, public health, business, psychology, informatics, and other relevant disciplines to develop practical and theoretical knowledge. This knowledge can inform ongoing health system improvement efforts to create sustainable, patient-centric, equitable and value-based care models. In conclusion, this bibliometric analysis provides a foundation for stakeholders to advance health metaverse adoption to transform care delivery while mitigating risks through ethical guidelines and iterative human-centered design.

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