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EMPIRICAL ARTICLE

# Metaverse applications in healthcare: opportunities and challenges

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## Abstract

This study examines the transformative potential of the Metaverse in healthcare, with a particular focus on identifying its ability to significantly improve healthcare delivery and patient outcomes. A total of 1226 videos and 55,919 comments were collected from YouTube and 4409 academic papers from January 2020 to April 2024. The data were analyzed by sentiment analysis, network analysis, and cluster analysis to delineate opportunities and challenges involved with Metaverse applications in the healthcare industry. We also interviewed medical experts to ascertain the current status of Metaverse applications and/or future plans in hospitals. The results indicate that Metaverse offers significant value creating opportunities, including enhanced medical training through immersive environments, personalized patient care through virtual experiences, and improved disease diagnosis and treatment through real-time data analysis.

**Keywords** Emerging technologies · Metaverse · Expert interviews · Healthcare industry

## 1 Introduction

The rapid diffusion of advanced digital technologies has empowered digital transformation (DX) across various fields, including healthcare services (Al Omar et al. 2019; Chin et al. 2023; Dautov et al. 2019a; 2019b; Thomason 2021), manufacturing and logistics (Chen et al. 2020; Maghazei et al. 2022), education (Chin et al. 2023;

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Dautov et al. 2019a; 2019b), retail (Chin et al. 2023), and nursing (Thomason 2021). Digital technologies have enhanced patient outcomes and improved the overall efficiency of the healthcare system (Guha and Kumar 2018; Lasi et al. 2014; Tortorella et al. 2020). As the potential value of DX in the healthcare industry is considered to be very high, there has been much emphasis on DX implementation in the industry (Bansal et al. 2022; Chengoden et al. 2023; Mozumder et al. 2023).

Despite its great potential, DX in healthcare services is viewed differently by providers and patients. For instance, the perspective of the healthcare provider on DX prioritizes the development of support systems that facilitate faster disease diagnosis, coordinated care for disease treatment, seamless and better communication with patients, and reduced regulatory burdens. However, patients may be more concerned about privacy issues, assurance of a safe environment for using technologies, and AI-assisted decision-making for disease treatment and prevention. In addition, healthcare employees may be concerned with technical issues, personal worries about the potential of human jobs being replaced by technology, and additional regulations and policies regarding the use of advanced technologies. Therefore, it is important to understand the expectations and requirements of each group of stakeholders when implementing advanced digital technologies, such as Metaverse, to ensure that opportunities and challenges are carefully considered from comprehensive perspectives.

Previous studies on DX in healthcare investigated from a variety of perspectives, depending on the researcher's objective. The impact of advanced technologies extends beyond diagnostics and treatment to other healthcare areas, such as patient monitoring, telemedicine, and personalized care using AI, biomedical/digital wireless sensors, IoT, 3D printing, robots, 'machine/deep learning, big data, cloud/fog computing, augmented reality/simulation, blockchain, and/or remote control/monitor. Given the rapid expansion and significant uses of these technologies, research into their healthcare applications has gained considerable attention. Furthermore, as platforms like YouTube grow in influence, recent studies have examined general public sentiment on DX through such media, providing valuable insights into the acceptance and potential of these technologies (Martínez et al. 2022).

While previous studies have provided valuable insights into the significance and potential applications of advanced technologies in the healthcare sector, a comprehensive investigation into which of these technologies are more essential and have a more significant impact on the users has yet to be conducted. In light of this knowledge gap, healthcare organizations need to identify the most effective technologies that can drive transformative improvements in healthcare delivery and public services, particularly in resource-limited environments. These resources include funding, expertise, and time (AlQudah et al. 2021; Geertsma et al. 2007; Morrow et al. 2023; Nguyen and Voznak 2024; Tortorella et al. 2020). Furthermore, as the significance of individual-centered care becomes increasingly recognized (Geertsma et al. 2007), there is a pressing need for more research to be conducted on which technologies are more practical and have greater potential from the perspectives of the users. Macnaghten et al. (2015) highlight the importance of considering general public narratives and sentiments when developing and deploying new technologies, as these perceptions significantly influence the acceptance and utilization of these

technologies. Damar and Koksalmis (2024) used network analysis to present trends, influential countries and universities, collaborations among authors, and common topics in the use of medical Metaverse, but did not examine the expectations of Metaverse users.

It is thus imperative to investigate advanced technologies from both the perspective of healthcare organizations and the public, evaluating their usefulness and potential in the healthcare field (Asan et al. 2018; Ofori and Wang 2024). As the influence of digital platforms continues to expand, it is now feasible to investigate more dynamic and representative methodologies for understanding general public preferences regarding emerging healthcare technologies. While a few studies have considered the usefulness and potential of these technologies from the public's perspective, they have primarily utilized general methodologies, such as surveys (Wei et al. 2024) and web news analysis (Li et al. 2019) to examine the significance of specific technologies in the healthcare industry. Although these studies provide valuable insights, they may include biases and might not fully capture individual opinions. To address these limitations, it is essential to consider methodologies that offer a broader and more detailed understanding of general public sentiment toward these technologies. This could include the analysis of content from social media, YouTube, and other online platforms.

Social media platforms, particularly YouTube, have emerged as valuable tools for exploring the application and adoption of new technologies across various domains (Arthurs et al. 2018; Burgess and Green 2018). Given its enormous user base and capacity for content sharing, YouTube represents a valuable platform for assessing general public interest and awareness of current trends in fields, such as the healthcare industry (Gupta et al. 2018; Jeong and Lee 2023; Lim et al. 2020; Martínez et al. 2022). However, despite its potential to capture the latest technology trends and usage, YouTube has not been effectively utilized in the healthcare sector. Not only have YouTube videos been overlooked, but also the rich data available in video comments has been underutilized. Analyzing YouTube comments provides a unique opportunity to collect real-time general public opinions and engage in-depth discussions on emerging technologies (So et al. 2024).

As a globally popular platform, YouTube can rapidly disseminate new information by providing insights about public perceptions and opinions on emerging innovative technologies (Arthurs et al. 2018; Burgess and Green 2018). Therefore, leveraging YouTube's capabilities to introduce the application of new technologies such as the Metaverse in healthcare can create an accessible environment for the public to adopt and utilize these advances. The Metaverse represents a convergence of the Internet, virtual worlds, and augmented reality that includes four core elements: virtual world, mirror world, life logging, and augmented reality (Lee et al. 2011). By combining virtual reality (VR), augmented reality (AR), mixed reality (MR), and extended reality (XR) technologies, the Metaverse creates interactive and immersive environments where users can engage in real-time experiences (Damar and Koksalmis 2024; Lee et al. 2011). In healthcare, this technology enables unprecedented opportunities for medical training, patient care, and innovative service delivery through virtualized environments (Lee et al. 2011). In other words, the Metaverse could lead to significant advances in patient-centered healthcare services, including

medical education and training, telemedicine and remote consultations, mental health services, patient education and engagement, and improved understanding of personal health conditions and treatment plans. From this perspective, it is important to understand how Metaverse technologies can evolve and expand within the YouTube.

The purpose of this study is to analyze user perspectives on Metaverse as an emerging technology in healthcare services to identify opportunities and challenges for its applications. The approach of this study includes the initial identification of advanced technologies in healthcare services that have a significant impact from the users' perspective. Then, we focus on the significance of Metaverse applications through interviews with experts in the health care sector. To ensure a rigorous analysis, a variety of methodologies were employed, including, sentiment analysis, network analysis, and cluster analysis. As a result, this study examines the impact of advanced technologies in healthcare, especially the Metaverse, for the development of public-centric healthcare services.

The rest of this study is organized as follows: Sect. 2 provides a literature review to provide theoretical support to the study, Sect. 3 outlines the research design and methodology, and Sects. 4 and 5 present the results and discussion, respectively.

## 2 Literature review

### 2.1 Application of advanced technologies in healthcare services

Advanced technologies have the potential to revolutionize healthcare services, improve patient care outcomes, and increase the overall efficiency of operational systems (Guha and Kumar 2018; Lasi et al. 2014; Tortorella et al. 2020). For example, AI-powered systems help improve diagnostic accuracy and predictive analytics (Hamidi 2019; Rejeb et al. 2023; Wan et al. 2018), while VR and AR provide immersive educational and therapeutic experiences (Dautov et al. 2019a; 2019b; Duan et al. 2024; Gorini et al. 2010; Habak et al. 2021; Munzer et al. 2019; Schmid et al. 2024). Blockchain technology ensures secure management of healthcare records (Al Omar et al. 2019; Hölbl et al. 2018; Rejeb et al. 2023; Yue et al. 2016), and the Metaverse facilitates enhanced collaboration in clinical care and education (Damar and Koksalmis 2024; Thomason 2021). IoT enables real-time patient monitoring (Catarinucci et al. 2015; Rejeb et al. 2023), 3D printing facilitates healthcare device customization (Malik et al. 2015), and robotic-assisted surgery improves precision (Stevenson 2011). In addition, advances in genomics, nanotechnology, 5G/6G networks, and quantum computing are fostering personalized medicine, drug delivery, and data analytics (Aslam et al. 2023; Bhattacharya et al. 2022; Cao et al. 2018; Freitas 2005).

Previous studies have focused on how advanced technologies can be used and applied in healthcare services, providing valuable insights into their potential applications and impacts (Chengoden et al. 2023). However, most of these studies approached the importance of advanced technologies primarily from the perspective of researchers and experts, without adequately reflecting public perceptions

and social awareness. It is essential to evaluate and prioritize technologies from the user's perspective (Fernholz et al. 2024; Yigitcanlar et al. 2024). This approach will enable the efficient allocation of limited resources, improve patient satisfaction, and lead to more effective health services.

The general public, including patients, is gaining volumes of information about diseases through YouTube videos and consulting ChatGPT (Jeong and Lee 2023; So et al. 2024). The Metaverse offers a transformative opportunity for medical services by building on the trend of patients and the general public seeking health information through platforms like YouTube. The Metaverse provides an immersive and interactive environment that offers even greater advantages for healthcare services. Applying the Metaverse to healthcare leverages the growing trend of digital health engagement (Damar and Koksalmis 2024). It goes beyond traditional videos by creating immersive, interactive, and engaging environments where users can effectively learn, collaborate, and manage their health (Damar and Koksalmis 2024; Thomason 2021). This approach ensures that healthcare services are more accessible, personalized, and proactive, ultimately enhancing the quality of care and patient outcomes.

### 2.2 Application of YouTube to disseminate the Metaverse and other emerging technologies

Social media platforms are widely used to explore the application and use of new technologies in different practices (Arthurs et al. 2018; Burgess and Green 2018; Khan 2017). Started in 2005, YouTube has provided a platform for individuals and organizations to share their videos with a global audience (Arthurs et al. 2018; Khan 2017). YouTube has developed into a global leader in digital content consumption, with a huge audience engaging with the platform on a daily basis. YouTube TV has more than 8 million subscribers, and YouTube Shorts averages more than 70 billion daily views. YouTube's influence spans 100 countries and supports its content in 80 languages. Over 500 h of content is uploaded every minute, adding to the ever-growing collection of user-generated content (YouTube Official Blog 2024).

Given the perceived inadequacy of the existing literature, a few studies have used YouTube to examine multiple trends. For example, Jeong and Lee (2023) identified key issues and topics related to the service by analyzing YouTube videos. Lim et al. (2020) explored trends in nursing start-ups using text mining techniques for YouTube videos. Martínez et al. (2022) analyzed search trends on YouTube videos before and during the COVID-19 pandemic. However, these studies have some limitations in fully reflecting the social awareness and user perceptions when identifying specific trends. In other words, the existing studies on YouTube have yet to use the comments to identify the main trends related to a particular topic, which can fully reflect the opinions and engagement of users.

The comments on YouTube may indicate the level of interest, understanding, and acceptance of the topics discussed in the videos, providing valuable insights into how the general public receives, understands, and engages with these innovations (Lee et al. 2024). Therefore, the social awareness captured in YouTube videos and comments may reflect potential market demand and intelligent

information about application trends of advanced technologies in the healthcare industry. By analyzing YouTube videos and comments, we can better understand users' attention to and expectations for advanced healthcare technologies.

The Metaverse is expected to play a significant role in healthcare by creating immersive, interactive and collaborative environments that alleviate many of the limitations of current digital tools such as YouTube (Damar and Koksalmis 2024). While YouTube is an important source of public information and research insights (Jeong and Lee 2023; Martínez et al. 2022), the Metaverse offers a deeper, experiential dimension that can transform healthcare delivery and patient engagement (Bansal et al. 2022; Damar and Koksalmis 2024). For example, patients, medical students and healthcare professionals can engage in virtual simulations of diseases, surgeries, or treatment pathways to enhance their skills and also reduce the costs associated with physical training resources.

The Metaverse offers users the ability to experience health concepts first-hand, going beyond passive video consumption. In addition, the Metaverse enables virtual clinics and consulting rooms where patients can interact with doctors and visualize treatment plans and outcomes in 3D. It can help provide emotional support and reduce feelings of isolation, especially for patients undergoing cancer treatment. Through interactive 3D visualizations, patients can better understand their conditions and treatment plans. Patients can also join virtual health communities to meaningfully network with others facing similar health challenges. By integrating real-time health tracking through wearable devices and IoT technologies, the Metaverse can alert both patients and care providers to potential health risks and promote preventive care. In other words, using wearable devices with virtual environments, users can track their personal health conditions. These services will have a positive impact on proactive health management and personalized care services. The Metaverse can improve access to healthcare by overcoming spatial constraints through virtual consultations and therapy sessions to patients worldwide. Therefore, the Metaverse plays a key role in aligning healthcare services with patient needs, ultimately improving disease prevention, patient satisfaction and overall quality of care (Bansal et al. 2022; Damar and Koksalmis 2024). In addition, the Metaverse can also engender new possibilities for the delivery of healthcare services and experiences.

## 3 Methods

### 3.1 Analysis process

This study utilized YouTube video transcripts, comments, and academic papers to explore the status and potential of advanced healthcare technologies from the users' perspective. The research procedure is shown in Fig. 1.

*First phase*

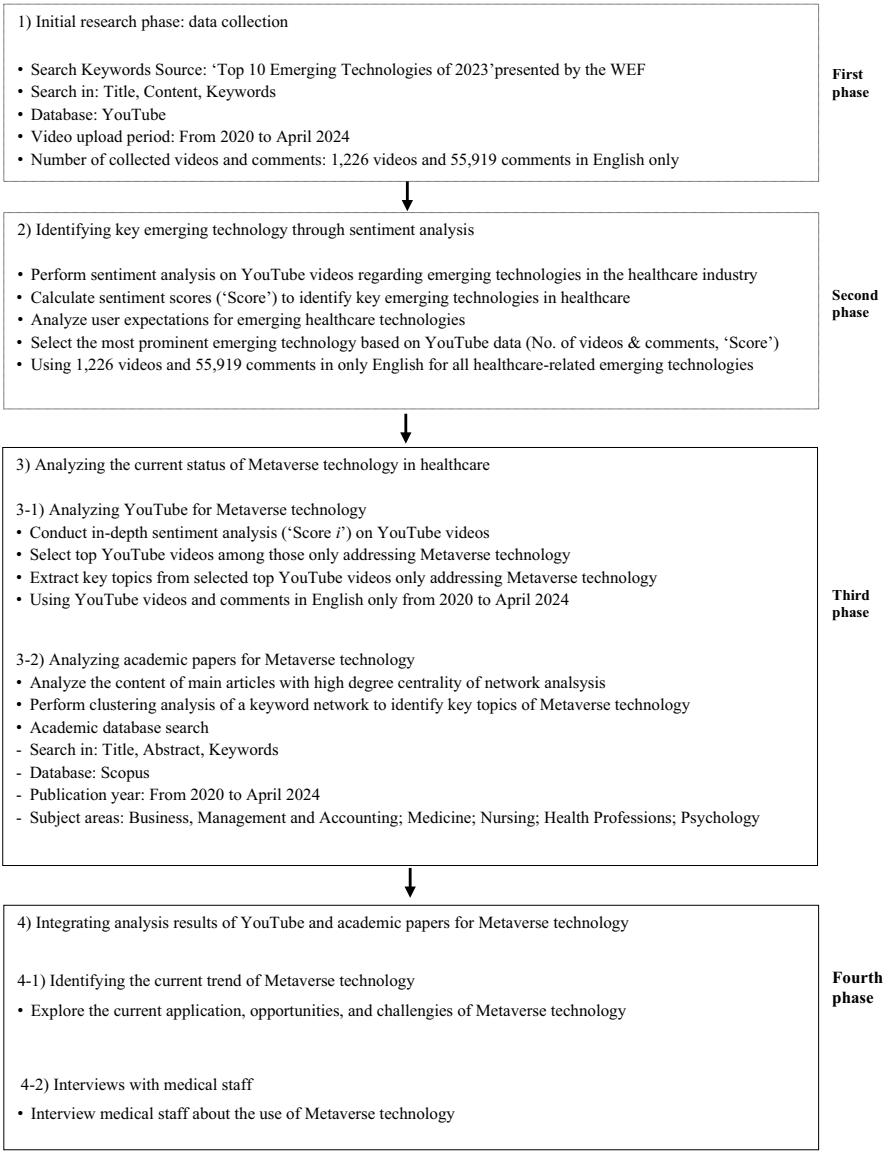


**Fig. 1** Research procedure

Step 1: a keyword search is conducted to analyze YouTube videos and comments based on the World Economic Forum's Top 10 Emerging Technologies for 2023

*Second phase*

Step 2: select emerging healthcare technologies after calculating the score measurement through sentiment analysis of YouTube videos and comments.

*Third phase*
Step 3: analyze the current status of Metaverse applications in healthcare by developing Score i through YouTube video.
Step 4: analyze academic papers for Metaverse applications in healthcare.
*Fourth phase*
Step 5: identify the current trend of Metaverse applications.
Step 6: interview medical staff about the use of Metaverse in healthcare.
Step 7: present the results of the study.

### 3.2 Data collection for extracting Metaverse technology-related words in healthcare

In the first phase, YouTube videos related to advanced healthcare technologies were collected using keywords derived from the World Economic Forum's (WEF) Top 10 Emerging Technologies of 2023.

WEF's top 10 technologies in 2023 include: AI-enabled healthcare, generative artificial intelligence, Metaverse, designer phages, spatial omics, sustainable computing, wearable plant sensors, sustainable aviation fuel, flexible batteries, and flexible neural electronics. Each year, the WEF ranks the most significant emerging technologies to predict future trends and assess their impact on the economy, society, and the environment. Therefore, this study selected the technologies identified by the WEF as emerging innovations that can support digital transformation in healthcare.

After evaluating these technologies for relevance to healthcare, Flexible Batteries and Flexible Neural Electronics were excluded due to their limited impact on direct patient care. The remaining eight technologies and their corresponding search terms are listed in Table 1.

Using the identified keywords, we retrieved relevant YouTube videos and user comments. This study collected transcripts and comments from 2020 to April 2024 to understand the adoption and discussion of these technologies within the healthcare sector. Table 2 shows the number of videos and comments for each technology.

As shown in Table 2, although the Metaverse had fewer videos, it generated a higher volume of user comments, reflecting significant engagement and user interest in its healthcare applications. In contrast, technologies, such as Designer Phages, Spatial Omics, Sustainable Computing, and Wearable Plant Sensors showed stable but limited activity during the study period.

## 4 Results

### 4.1 Identifying key emerging technologies through sentiment analysis

In the second phase, sentiment analysis was applied to YouTube video transcripts and comments to assess user perceptions of emerging healthcare technologies. The Python Natural Language Toolkit (NLTK) and TextBlob libraries were used

**Table 1** Searching keywords for identifying emerging technologies in healthcare services

| Main keywords | Specific searching keywords | |
|---|---|---|
| Context keywords | Healthcare; Health; Health care | |
| Emerging technology keywords | Generative AI | Generative AI; AI; ChatGPT; Chatbot |
| | Sustainable aviation fuel | Biojet fuel; Green aviation fuel; Eco-friendly aviation fuel; Renewable aviation fuel; Low-emission aviation fuel |
| | Designer phages | Engineered Bacteriophages; Tailored Phages; Customized Bacteriophages; Synthetic Phages; Bioengineered Phages; Custom Phages; Modified Bacteriophages |
| | Metaverse | Metaverse; Meta-verse; Virtual Reality Universe; Virtual Reality; VR; Digital Parallel Universe; Immersive Virtual World; Augmented Reality Space; Augmented Reality; AR; Virtual Shared Space; Digital Realm; 3D Internet World |
| | Wearable plant sensors | Plant Wearable Technology; Botanical Biosensors; Plant Health Monitoring Devices; Agritech Wearables; Crop Monitoring Sensors; Smart Plant Sensors; Precision Agriculture Sensors |
| | Spatial omics | Spatial Genomics; Spatial Transcriptomics; Spatial Proteomics; Location-based Omics; Spatially Resolved Omics; Spatial Molecular Profiling; Geospatial Omics |
| | Sustainable computing | Green Computing; Eco-friendly Computing; Energy-Efficient Computing; Environmentally Friendly Computing; Low-Impact Computing; Eco-efficient Computing; Responsible Computing |
| | AI-facilitated healthcare | Artificial Intelligence in Medicine; AI-Enhanced Healthcare; AI-Driven Healthcare Care; AI in Healthcare Delivery; AI-Integrated Healthcare; Healthcare Powered by AI; AI-Assisted Health Services |

**Table 2** Number of videos and their comments regarding emerging technologies in healthcare

| | | | 2020 | 2021 | 2022 | 2023 | April 2024 | Total |
|---|---|---|---|---|---|---|---|---|
| 1 | AI-facilitated healthcare | Video | 73 | 81 | 82 | 188 | 58 | 482 |
| | | Comment | 95 | 132 | 156 | 491 | 88 | 962 |
| 2 | Generative artificial intelligence | Video | 53 | 69 | 108 | 69 | 29 | 328 |
| | | Comment | 1539 | 7571 | 10,008 | 12,655 | 6430 | 38,203 |
| 3 | Metaverse | Video | 22 | 42 | 44 | 23 | 9 | 140 |
| | | Comment | 418 | 3149 | 2457 | 2414 | 2539 | 10,977 |
| 4 | Designer phages | Video | 36 | 22 | 19 | 20 | 4 | 101 |
| | | Comment | 105 | 471 | 403 | 250 | 25 | 1254 |
| 5 | Spatial omics | Video | 13 | 25 | 25 | 17 | 1 | 81 |
| | | Comment | 10 | 5 | 6 | 1 | 0 | 22 |
| 6 | Sustainable computing | Video | 7 | 13 | 9 | 12 | 9 | 50 |
| | | Comment | 443 | 676 | 361 | 1215 | 625 | 3320 |
| 7 | Wearable plant sensors | Video | 7 | 8 | 4 | 18 | 5 | 42 |
| | | Comment | 30 | 480 | 91 | 313 | 53 | 967 |
| 8 | Sustainable aviation fuel | Video | 0 | 1 | 0 | 1 | 0 | 2 |
| | | Comment | 0 | 174 | 15 | 14 | 11 | 214 |

to classify sentiments as positive, negative, or neutral and to calculate corresponding sentiment scores. A 'Score' metric was introduced to evaluate the alignment between users' expectations and how these technologies are portrayed in videos:

$$\text{Score} = \frac{\text{The average of sentiment analysis score for all comments of each video}}{\text{The average of sentiment analysis score for the transcripts of each video}}$$

This ratio assesses how user expectations align with video portrayals of each healthcare technology. By comparing the average sentiment of user comments with the sentiment of video content, the 'Score' metric highlights potential discrepancies or congruencies between user reactions and how technologies are presented in influential videos. For example, a score greater than 1 indicates that users' sentiment in comments is more positive than the sentiment expressed in the video content, suggesting the healthcare technology has exceeded expectations or generated interest beyond what was presented. Conversely, a score less than 1 implies that users express more reserved or critical reactions than how the healthcare technology is introduced in the video content. A score of approximately 1 indicates almost a perfect alignment between users' expectations and the presentation of healthcare technology in the video content. Therefore, videos with high scores are particularly noteworthy as they indicate healthcare technologies that generated greater users' interest and more positive reactions than presented in the video content. In other words, these high scores indicate that the healthcare technologies shown in the videos have significant potential for successful adoption and use, as users recognize more value and benefits than presented in the video content.

Table 3 provides a list of the technologies identified through this analysis.

**Table 3** Emerging healthcare technologies

| Ranking | Emerging technology | Video sentiment analysis score average | Comment sentiment analysis score average | No. of Videos | No. of Comments | Score |
|---|---|---|---|---|---|---|
| 1 | Sustainable computing | 0.172 | 0.365 | 49 | 1888 | 2.122 |
| 2 | Generative AI | 0.177 | 0.368 | 234 | 7108 | 2.079 |
| 3 | Metaverse | **0.238** | **0.423** | **93** | **3997** | **1.777** |
| 4 | Spatial omics | 0.142 | 0.226 | 71 | 21 | 1.592 |
| 5 | AI-facilitated healthcare | 0.155 | 0.188 | 251 | 512 | 1.213 |
| 6 | Wearable plant sensors | 0.197 | 0.173 | 38 | 450 | 0.878 |
| 7 | Sustainable aviation fuel | 0.117 | 0.097 | 2 | 119 | 0.829 |
| 8 | Designer phages | 0.251 | 0.151 | 44 | 466 | 0.602 |

As shown in Table 3, Sustainable Computing achieved the highest score (2.122), followed by Generative AI and Metaverse. These results indicate that users generally perceive these technologies positively, with expectations that they will enhance healthcare services. Although Sustainable Computing and Generative AI achieved higher scores, this study identified the Metaverse as the most promising emerging technology in healthcare. Sustainable Computing is general computing infrastructure, making it less accessible to general healthcare users. Meanwhile, Generative AI primarily provides individualized solutions for disease prevention and treatment, which limits its relevance to comprehensive healthcare delivery services.

In contrast, the Metaverse demonstrates broad and specific potential for healthcare applications. It garnered strong user engagement with 3997 comments, reflecting high public interest. In addition, the sentiment score of comments (0.423) exceeded that of video transcripts (0.238), indicating that users have positive expectations of the Metaverse's role in healthcare.

Despite having fewer videos compared to other technologies, the Metaverse generated substantial discussion, as evidenced by the high number of comments. This interest underscores the growing relevance of the Metaverse in healthcare, making it a compelling focus for further exploration. Therefore, this study selected the Metaverse as the emerging healthcare technology due to its strong public engagement, relevance to healthcare applications, and positive user sentiment.

### 4.2 Analyzing the current status of Metaverse applications in healthcare

After identifying the Metaverse as an emerging technology in healthcare through sentiment analysis in the second step, this phase explores its current status by analyzing the YouTube videos collected and literature review.

#### 4.2.1 Analyzing YouTube for Metaverse applications

To gain deeper insights, we conducted sentiment analysis on 93 YouTube videos, corresponding to 3,997 comments focused exclusively on the Metaverse in healthcare. Using the 'Score *i*' metric, influential videos were identified based on their alignment with user perceptions. Table 4 presents the top 10 YouTube videos ranked according to the 'Score *i*' measure.

$$\text{Score } i = \frac{\text{The average of sentiment analysis score for comments of video } i}{\text{The sentiment analysis score for the transcript of video } i}$$

Through sentiment analysis of the top 10 YouTube videos related to the Metaverse in healthcare, three prevalent topics emerged, which highlight its current applications and future developments in healthcare. As shown in Table 5, these topics are categorized as follows: (1) Treatment and Patient Care, (2) Healthcare Education and Visualization, and (3) Healthcare Innovation and Service Delivery.

As shown in Table 5, there are three key categories that indicate the various potential uses of Metaverse in healthcare services. First, treatment and patient care covers the direct use of VR/AR technologies for pain management, mental health

**Table 4** Top 10 videos of Metaverse on YouTube according to sentiment analysis

| Ranking | Title of video* | View count | Comment count | Score *i* | Topic |
|---|---|---|---|---|---|
| 1 | Canadian surgeons using VR to help patients manage pain | 5217 | 13 | 5.262 | Application of Metaverse on reducing patients pain |
| 2 | The Future of Augmented Reality—AR in Healthcare | 43,351 | 609 | 3.720 | Introduction of the potential of Metaverse on healthcare field |
| 3 | How Meditation in VR Has Changed My Life \| VRN \| Well-Being \| TRIPP Oculus | 24,408 | 394 | 3.115 | Introduction of how virtual reality can enrich and enhance the meditation experience |
| 4 | Big Tech Providing Healthcare???—A Future Bit from The Medical Futurist | 2802 | 109 | 3.043 | Introduction of major tech companies' expansion into healthcare services |
| 5 | Introducing Octonic VR for Treadmill | 5213 | 40 | 3.037 | Application of Metaverse for workout |
| 6 | 4 Healthcare Use Cases for VR | 14,136 | 76 | 2.842 | Application of Metaverse on healthcare through real cases |
| 7 | How AR is revolutionizing healthcare – and how it could one day save your life | 14,733 | 248 | 2.708 | Introducing how Metaverse can save lives in emergency situations |
| 8 | CREAL's breakthrough AR display: real depth with a classic lens! | 5609 | 155 | 2.654 | Introducing CREAL's AR display technology |
| 9 | Sharecare YOU VR—Taking a deeper look inside the human body through virtual reality | 6829 | 54 | 2.629 | Introducing Metaverse program for a detailed look inside the human body |
| 10 | Human Anatomy VR—Launch Trailer \| PS VR2 Games | 67,252 | 494 | 2.370 | Introducing Human Anatomy |

*Title of video is exactly the same as the title displayed on YouTube

**Table 5** Key topics by YouTube videos

| | Topic | Title of video* |
|---|---|---|
| 1 | Treatment and patient care | Canadian surgeons using VR to help patients manage pain |
| | | How Meditation in VR has Changed My Life \| VRN \| Well-being \| TRIPP Oculus |
| | | Introducing Octonic VR for Treadmill |
| | | 4 Healthcare Use Cases for VR |
| | | How AR is revolutionizing healthcare—and how it could one day save your life |
| 2 | Healthcare education and visualization | The Future of Augmented Reality—AR in Healthcare |
| | | Sharecare YOU VR—Taking a deeper look inside the human body through virtual reality |
| | | Human Anatomy VR—Launch Trailer \| PS VR2 Games |
| 3 | Healthcare innovation and service delivery | Big Tech Providing Healthcare???—A Future Bit from the Medical Futurist |
| | | CREAL's breakthrough AR display: real depth with a classic lens! |

*Title of video is exactly the same as the title displayed on YouTube

therapy, emergency response, and fitness programs. These applications demonstrate the tangible benefits of the Metaverse in enhancing patient care and advancing healthcare practices. Second, healthcare education and visualization emphasize the educational potential of the Metaverse, such as AR/VR-based human anatomy education, healthcare training, and the visualization of diagnostic images. These technologies offer transformative tools to redefine healthcare education and professional development. Third, healthcare innovation and service delivery explore new service delivery methods enabled by the Metaverse, including telemedicine and remote consultations. These innovations are revolutionizing healthcare by providing new frameworks for patient interaction and service improvement.

### 4.2.2 Analyzing academic papers on Metaverse

To complement the information extracted from the YouTube data, a literature review was conducted by collecting relevant studies from SCOPUS. The search focused on English-language articles across diverse fields such as Medicine, Nursing, Psychology, and Business. Table 6 shows the number of publications on the Metaverse from 2020 to April 2024.

As shown in Table 6, the number of published papers on the Metaverse has increased significantly, indicating growing research interests across various disciplines during the observed period. The field of medicine has demonstrated particular interest, with publications rising from 578 papers in 2020 to 476 through April 2024, a sustained growth in interest on the Metaverse in healthcare.

The fields of business, management, and accounting have also shown substantial growth, with publications increasing from 77 in 2020 to 248 through April 2024, reflecting the recognition of the Metaverse's potential in these domains. Similarly, psychology has experienced a notable increase in publications, indicating growing interest in the mental health applications of the Metaverse. Conversely, nursing publications have slightly declined, from 30 in 2020 to 25 in April 2024, while research in health professions has remained relatively stable, with a slight increase from 11 to 12 publications. However, the data for April 2024 is incomplete, suggesting that further growth in these fields is likely by the end of the year.

To gain insights into the current status of Metaverse research, we conducted a keyword network analysis using 4,409 academic papers published between 2020 and

**Table 6** Number of selected papers related to Metaverse in healthcare area on SCOPUS database

| | 2020 | 2021 | 2022 | 2023 | April 2024 | Total |
|---|---|---|---|---|---|---|
| Medicine | 578 | 690 | 625 | 661 | 476 | 3,030 |
| Business, management and accounting | 77 | 104 | 107 | 189 | 248 | 725 |
| Psychology | 72 | 73 | 73 | 121 | 109 | 448 |
| Nursing | 30 | 37 | 31 | 22 | 25 | 145 |
| Health professions | 11 | 16 | 10 | 12 | 12 | 61 |
| Total | 768 | 920 | 846 | 1005 | 870 | 4409 |

April 2024. Keyword network analysis is a valuable method for identifying research trends by mapping the connections between key concepts. This involves treating the authors' keywords as nodes and examining their co-occurrence across different papers to form links. The analytical process summarized in Table 7 was used to assess the current status of the Metaverse as an emerging technology in the healthcare sector.

As shown in Table 7, after identifying Metaverse as a key emerging technology through our initial analysis of the WEF Top 10 Technologies (see Sect. 4.1), we conducted a focused keyword network analysis of academic publications specifically related to Metaverse technology in the healthcare industry. For the keyword network analysis, we used search terms by combining only healthcare-related keywords with Metaverse derived from WEF's list of emerging technologies (see Table 1). Using these search terms, we then collected academic publications from leading international journals across multiple disciplines, including Business, Management and Accounting; Medicine; Nursing; Health Professions; and Psychology. This initial search yielded 4,409 papers for detailed analysis (see Table 6).

After filtering out papers missing author keywords, a total of 4,175 papers remained, containing 13,806 keywords. These keywords were used to build the keyword network focusing on the Metaverse in healthcare. Prior to constructing the network, the keywords were refined to ensure consistency and coherence. The following keyword refinement criteria were applied:

- Standardization into singular forms
- Elimination of redundant keywords

**Table 7** Keyword network analysis process

| | Analysis process |
|---|---|
| Initial search attempts | Searching keyword: 'Healthcare' OR 'Health' OR 'Health care' AND 'Metaverse' OR 'Meta-verse' OR 'Virtual Reality' OR 'Virtual Reality Universe' OR 'VR' OR 'Digital Parallel Universe' OR 'Immersive Virtual World' OR 'Augmented Reality Space' OR 'AR' OR 'Virtual Shared Space' OR 'Digital Realm' OR '3D Internet World' |
| | Search in: SCOPUS |
| | Publication year: From 2020 to April 2024 |
| | Searching areas: Business, Management and Accounting; Medicine; Nursing; Health Professions; Psychology |
| | Initial search results: 13,806 keywords |
| Keyword network construction | Refinement of author's keywords: 12,913 keywords |
| | Construction of keyword network based on the frequency of keyword co-occurrence |
| | Construction of commonly addressed keyword network based on component analysis |
| Keyword network analysis | Network centrality analysis (Degree, betweenness, closeness) |
| | Clustering analysis |

- Removal of hyphens
- Avoidance of abbreviations
- Unification of synonyms
- Separation of multiple words combined into a single keyword

Following refinement, the final set consisted of 12,913 keywords. This refined dataset was used to build the keyword network based on the co-occurrence frequency of keywords, emphasizing those that appeared frequently across multiple papers. To ensure the network's relevance, only keywords with top 10% link weights and a co-occurrence frequency greater than 10 were included, resulting in a network of 133 interrelated keywords.

A component analysis was conducted to identify clusters of interconnected nodes, each representing prominent topics and issues within the field. Figure 2 illustrates the resulting keyword network of Metaverse applications in healthcare.

Finally, key network metrics-degree centrality, betweenness centrality, and closeness centrality-were applied to explore the primary themes related to the healthcare Metaverse. Additionally, clustering analysis was performed to identify both core issues and prevalent topics based on keyword associations within and between clusters.

The results presented in Table 8 highlight the top 10 keywords based on three centrality measures: degree centrality, betweenness centrality, and closeness centrality. These keywords capture key issues relevant to Metaverse applications in healthcare services.

Degree centrality reveals the keywords most connected with others, reflecting their importance as primary research topics. The top keywords in this category include 'effectiveness,' 'asthma,' 'sublingual immunotherapy,' 'randomized controlled trial,' 'biomarkers,' 'telepresence,' 'kidney transplant,' 'anxiety,' 'stress,' and 'depression.' Their high connectivity indicates these topics are central to discussions on the healthcare Metaverse.

Betweenness centrality emphasizes keywords that act as bridges between different research areas, facilitating cross-disciplinary connections. Notable keywords in this category are 'efficacy,' 'sublingual immunotherapy,' 'biomarkers,' 'systematic review,' 'interactivity,' 'mental imagery,' 'randomized controlled trial,' 'extended reality,' and 'immersive technology.' These terms indicate critical intersections between various fields of study.

Closeness centrality highlights keywords closely linked to most other terms, placing them at the center of the network. The top-ranking keywords by closeness centrality are 'efficacy,' 'sublingual immunotherapy,' 'biomarkers,' 'systematic review,' 'interactivity,' 'telepresence,' 'house dust mite,' 'allergic rhinitis,' and 'safety.' These keywords reflect central concepts in healthcare Metaverse research, emphasizing topics closely aligned with most ongoing studies.

The presence of 'effectiveness' across all three centrality measures suggests it is a key theme in Metaverse-related healthcare research, with a focus on evaluating how Metaverse can improve service delivery. The Metaverse is recognized for its capability to enhance healthcare delivery by offering cost-effective, safe, and immersive training environments. The technology facilitates realistic simulations,

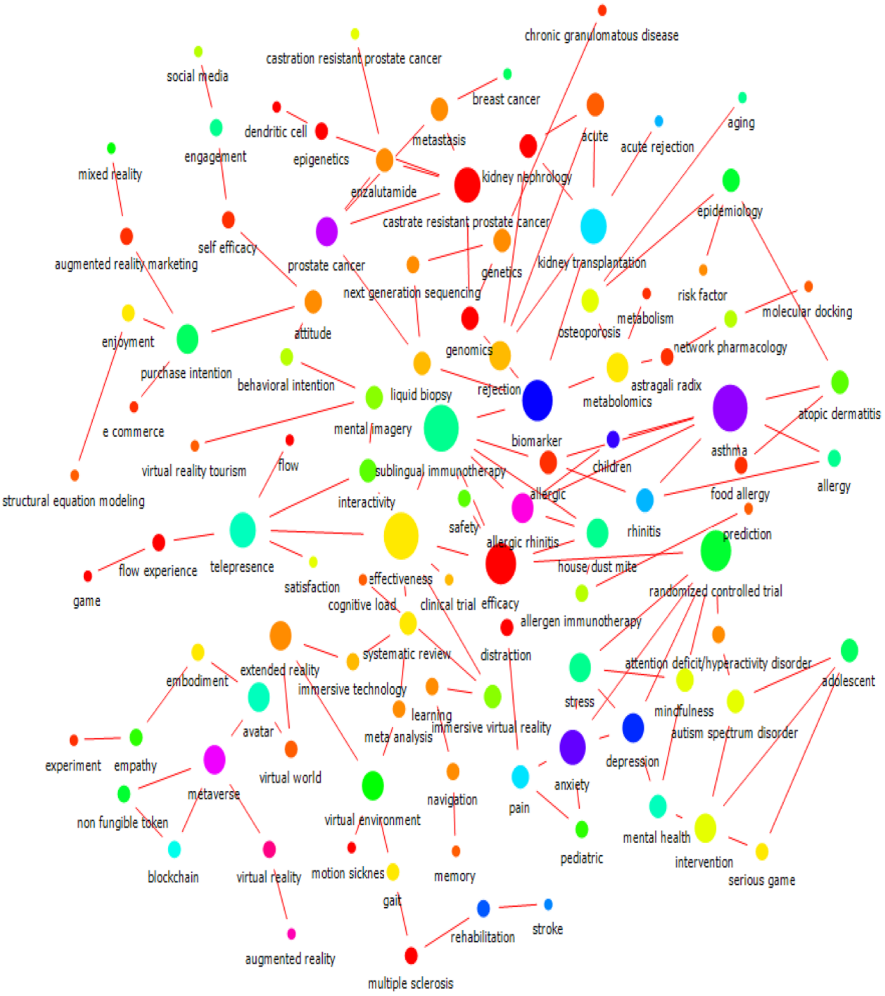


**Fig. 2** A keyword network of Metaverse applications in healthcare industry

strengthen safety protocols, and improve outcomes in nursing education and clinical procedures (Joshi et al. 2021; Ma et al. 2024; Pot-Kolder et al. 2020). Additionally, the Metaverse contributes to better long-term outcomes and higher motivation among healthcare professionals, while reducing training costs without compromising effectiveness (Contoli et al. 2023; Kirk et al. 2021).

To further explore the relationships among emerging topics, clustering analysis was performed. This analysis identified five distinct clusters with stronger keyword associations within clusters than across them, as shown in Fig. 3 and Table 9. These clusters offer insights into major themes driving the development and application of the Metaverse in healthcare services.

**Table 8** Top 10 keywords across network centrality measures

| | Degree centrality | Betweenness centrality | Closeness centrality |
|---|---|---|---|
| 1 | Effectiveness | Effectiveness | Effectiveness |
| 2 | Asthma | Sublingual immunotherapy | Sublingual immunotherapy |
| 3 | Sublingual immunotherapy | Biomarker | Efficacy |
| 4 | Randomized controlled trial | Systematic review | Biomarker |
| 5 | Biomarker | Efficacy | Systematic review |
| 6 | Telepresence | Interactivity | Interactivity |
| 7 | Kidney transplant | Mental imagery | Telepresence |
| 8 | Anxiety | Randomized controlled trial | House dust mite |
| 9 | Stress | Extended reality | Allergic rhinitis |
| 10 | Depression | Immersive technology | Safety |

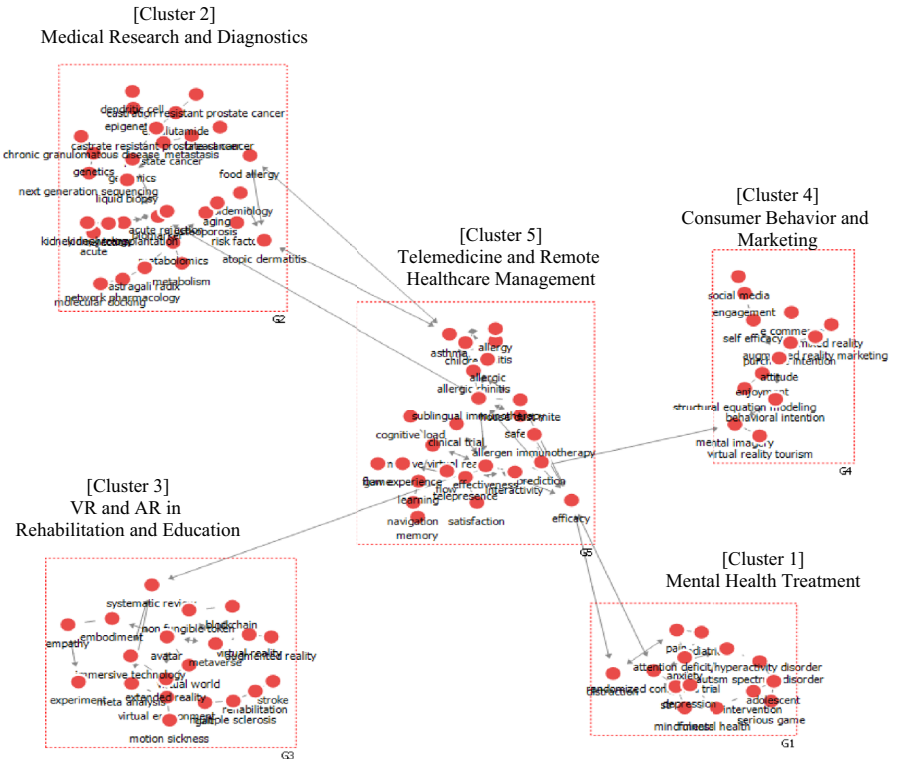


**Fig. 3** The result of cluster analysis for keyword network

As shown in Table 9, Cluster 1 focuses on mental health treatment. Randomized controlled trials have examined the effectiveness of Metaverse-based interventions. VR relaxation shows promise in the treatment of anxiety disorders (Gorini et al. 2010). Schmid et al. (2024) reported that a previous VR experience significantly

**Table 9** Top 10 keywords by clustering analysis

| | Cluster 1: mental health treatments | Cluster 2: healthcare research and diagnostics | Cluster 3: VR and AR in rehabilitation and education | Cluster 4: Consumer behavior and marketing | Cluster 5: telemedicine and remote healthcare management |
|---|---|---|---|---|---|
| 1 | Randomized controlled trial | Biomarker | Virtual environment | Purchase intention | Effectiveness |
| 2 | Anxiety | Kidney transplant | Extended reality | Mental imagery | Asthma |
| 3 | Stress | Castrate-resistant prostate cancer | Avatar | Attitude | Sublingual immunotherapy |
| 4 | Intervention | Prostate cancer | Rehabilitation | Self-efficacy | Efficacy |
| 5 | Depression | Metabolomics | Virtual world | Enjoyment | Telepresence |
| 6 | Pain | Epidemiology | Multiple sclerosis | Engagement | Allergic rhinitis |
| 7 | Mindfulness | Metastasis | Gait | Behavioral intention | House dust mite |
| 8 | Mental health | Osteoporosis | Non-fungible token | AR marketing | Rhinitis |
| 9 | Autism spectrum disorder | Genetics | Blockchain | Mixed reality | Interactivity |
| 10 | Adolescent | Enzalutamide | Empathy | e commerce | Navigation |

reduced preoperative anxiety in gynecologic oncology patients. In addition, VR-based interventions have shown efficacy in stress management and potential to enhance well-being in patients with depression or suicidality (Habak et al. 2021).

Cluster 2 focuses on healthcare research and diagnostics, where the Metaverse shows significant potential value. For example, VR environments improve the visualization and analysis of biomarkers and facilitate virtual simulations for healthcare training and surgical planning (Kirk et al. 2021). In addition, the Metaverse can provide immersive environments for the study of complex diseases and enable intuitive exploration of metabolomics data (Duan et al. 2024).

Cluster 3 presents the role of VR and AR in rehabilitation and education. The Metaverse can provide immersive rehabilitation experiences, expanding healthcare education and training opportunities, and facilitating therapy sessions through avatar-based interactions (Duan et al. 2024). VR-based programs provide customized exercises and safe environments for exposure therapy and cognitive training, particularly useful for patients with conditions such as multiple sclerosis (Pot-Kolder et al. 2020).

Cluster 4 is about consumer behavior and healthcare marketing. Studies have explored how VR experiences influence healthcare service decisions and improve patient engagement. The Metaverse enables mental imagery and immersive VR scenarios, and studying patient attitudes and behaviors in healthcare contexts (Schmid et al. 2024). In addition, AR is emerging as a tool for patient education and product demonstration in healthcare marketing.

Finally, Cluster 5 deals with telemedicine and remote healthcare management. The Metaverse is transforming telemedicine by improving patient health outcomes through VR-based education, game-like engagement programs, and realistic avatar-based remote consultations. These technologies increase the accessibility and effectiveness of remote healthcare services, especially for underserved populations (Contoli et al. 2023; Kirk et al. 2021). Considering the relationships among clusters, Cluster 5 serves as a central hub highlighting the critical role of telemedicine in bridging the gap among different Metaverse application areas in healthcare services.

### 4.3 Integrating YouTube analysis and academic papers on the Metaverse

#### 4.3.1 Identifying the current trend of Metaverse applications

Based on a comprehensive analysis integrating academic literature (see Tables 4, 5, 8, 9, Fig. 3), this study identifies and summarizes key use cases and applications of the Metaverse in healthcare. Table 10 provides a systematic overview of how Metaverse-related technologies are applied across multiple dimensions within the healthcare industry.

#### 4.3.2 Identifying the opportunities of Metaverse applications in healthcare

As shown in Table 10, the Metaverse is used in various healthcare services, including education, training, patient care, and innovative service development.

**Table 10** The current application of Metaverse in healthcare industry

| Application area | | Specific application area | Cases |
|---|---|---|---|
| Provision of healthcare services and treatments | Cluster 1 | Anxiety disorder treatment<br>Stress reduction techniques<br>Depression management<br>VR-assisted pain management | VR Therapy for Mental Health: Bump Galaxy, a VR environment explored in Minecraft, is used as 'game world therapy' to help patients manage conditions, such as depression, anxiety, and trauma (Mozumder et al. 2023)<br>VR Therapy for Pain and Stress: KindVR is developing VR therapies to help patients manage pain and stress, particularly for children and adolescents undergoing complex treatments (Bansal et al. 2022)<br>VR for Labor Pain Management: The National Health Service (NHS) in the UK provided pregnant women with VR headsets to virtually transport them to comfortable environments, such as beaches or even the planet Mars, effectively distracting them from labor pain situations (Bansal et al. 2022) |
| | Cluster 1 & Cluster 3 | Gait training for multiple sclerosis patients<br>Avatar-based therapy<br>Cognitive rehabilitation exercises | Augmented Reality for Stroke Rehabilitation: An AR system, 'Kick Ball', was used to engage a stroke patient in virtual soccer kicking exercises, to improve muscle strength and functional ability of the paretic lower limb during early rehabilitation (An and Kim 2019) |

**Table 10** (continued)

| Application area | | Specific application area | Cases |
|---|---|---|---|
| Delivery Service of Education and Visualization | Cluster 2 & Cluster 3 | VR anatomy lessons<br>Surgical procedure simulations<br>3D visualization of healthcare imaging<br>VR/AR emergency training | Surgical Training: At Seoul National University Bundang Hospital, surgeons use XR, AR and VR to train for complex surgeries, allowing for detailed visualization and practice in a virtual environment (Mozumder et al. 2023)<br>VR Midwifery Training: University of Newcastle developed a VR platform to teach midwifery students about pregnancy and childbirth, providing an immersive learning experience that covers everything from common pregnancy issues to labor and delivery techniques (Bansal et al. 2022)<br>VR Training for COVID-19 Response the Gordon Center at the University of Miami is using VR and AR platforms to train healthcare workers in various emergency scenarios, including COVID-19 response. The use of VR/AR technologies allows for realistic simulations that improve the effectiveness of emergency medical education (Bansal et al. 2022) |
| | Cluster 2 | Metabolomics data analysis | Digital Twin Technology for Diagnostics: The University of Chicago Healthcare Center is using a Metaverse platform to share raw tomography data with research collaborators to advance AI-driven healthcare imaging research and drive innovation in diagnostic techniques (Wang et al. 2022) |

**Table 10** (continued)

| Application area | | Specific application area | Cases |
|---|---|---|---|
| Development of Innovative Healthcare Services | Cluster 5 | Virtual consultations<br>Telepresence for remote patient monitoring<br>VR-based patient education | HoloLens in Surgical Visualization: A healthcare device company used Microsoft HoloLens in its OptiVu software to allow surgeons and patients to visualize and interact with 3D representations of surgical procedures (Bansal et al. 2022)<br>Telemedicine with VR Glasses: Epazz Slims used VR glasses with nanocameras and motion sensors to create 3D representations of patients, enabling real-time telemedicine consultations with full sensory engagement (Bansal et al. 2022) |
| | Cluster 3 & Cluster 4 | Virtual product demonstrations<br>AR-enhanced healthcare device marketing<br>Health behavior simulations | Virtual Jewelry Showroom: Several luxury jewelry brands, including Bulgari, have created virtual showrooms in the Metaverse that allow customers to explore and interact with their collections in a 3D environment. This immersive experience allows potential buyers to visualize products in a realistic setting, increasing customer engagement and driving sales (Kang 2022) |

Below are the key opportunities for implementing Metaverse-related technologies in healthcare:

**4.3.2.1 Enhanced healthcare training and education** The Metaverse offers immersive, interactive platforms for healthcare education, enabling students and professionals to practice procedures in realistic virtual environments (Duan et al. 2024). One of its key advantages is accessibility, as highlighted in the telemedicine and remote healthcare management sections (Tables 5 and 9). The Metaverse bridges geographic gaps by expanding access to high-quality education for healthcare students in remote areas, reducing disparities in educational resources, and fostering continuous professional development (Munzer et al. 2019; Zhang et al. 2023). Additionally, it facilitates continuous learning and collaboration, enabling healthcare professionals from various regions to engage in case discussions, share expertise, and participate in virtual conferences (Yang et al. 2023). This collaborative exchange enhances the global skills and knowledge base, promoting better patient care and healthcare innovation.

Furthermore, the Metaverse supports the design of multiple treatment options and preoperative simulations, allowing healthcare professionals to practice complex procedures without risking patient safety. Surgeons can refine their techniques, explore innovative methods, and prepare for rare or high-risk scenarios within these virtual environments. These simulations can also be recorded and reviewed, offering valuable learning opportunities for practitioners, teams, and students, ultimately improving surgical outcomes, reducing medical errors, and accelerating the adoption of new technologies (Yang et al. 2023).

Healthcare organizations can also leverage the Metaverse to deliver disease prevention education to patients. This includes chronic disease management strategies and preventive care guidelines, which can be easily accessed by patients, caregivers, and family members. Additionally, public health services can use the virtual world to disseminate infectious disease prevention information, extending their outreach and promoting healthier communities.

**4.3.2.2 Advanced patient care service and treatment** The Metaverse offers innovative, immersive platforms for patient care, enabling healthcare providers to deliver services in realistic virtual environments. Specifically, the Metaverse enhances patient engagement and reduces anxiety through interactions within controlled virtual settings (Damar and Koksalmis 2024; Rutkowski et al. 2021). As shown in Tables 5 and 10, the Metaverse holds significant potential for mental health treatment, as well as VR and AR applications in rehabilitation.

VR, in particular, provides distraction therapy by diverting patients' attention from pain (Damar and Koksalmis 2024). For instance, children undergoing chemotherapy can immerse themselves in interactive games or soothing VR environments, while pregnant mothers facing anxiety during labor benefit from calming virtual scenarios that promote relaxation (Bansal et al. 2022). This tailored approach not only alleviates pain but also makes the treatment process more manageable by addressing individual patient needs.

Additionally, VR-based rehabilitation programs effectively engage patients in therapeutic exercises that mimic real-world environments. These virtual settings foster patient-professional interactions, improve engagement, and reduce anxiety. They also enable continuous, personalized monitoring of patient progress, enhancing both treatment outcomes and long-term care.

**4.3.2.3 Improved healthcare research** The Metaverse facilitates new forms of healthcare service delivery and research through virtual collaboration and advanced data visualization. As shown in the healthcare innovation and service delivery section (Table 5) and the healthcare research and diagnostics category (Table 10), the Metaverse enables real-time analysis of patient data, enhancing both service delivery and research. Its virtual environments eliminate geographic barriers, allowing healthcare providers and researchers to collaborate seamlessly, which fosters innovation and improves operational efficiency (Lin et al. 2022; Yang et al. 2023).

The Metaverse's ability to visualize and analyze complex data supports more effective decision-making. Healthcare professionals can use these tools to simulate clinical trials, analyze patient data in real-time, and conduct interdisciplinary research. These capabilities contribute to improved healthcare outcomes and the development of new treatments and technologies, reinforcing the transformative potential of the Metaverse in advancing healthcare practices (Lin et al. 2022; Yang et al. 2023).

**4.3.2.4 Personalized and remote health monitoring** Integrated with IoT devices, the Metaverse is transforming personalized and remote health monitoring by enabling real-time healthcare treatments. Unlike traditional approaches, such as periodic check-ups, the Metaverse supports continuous monitoring of patient health, offering highly individualized care, as highlighted in the healthcare innovation and service delivery sections (Table 5 and Table 10). Personalized virtual environments dynamically adapt to patients' needs, allowing healthcare providers to track vital signs, activity levels, and other indicators in real time through wearable devices and IoT technologies (Hassani et al. 2022; Yang et al. 2023). For example, in chronic disease management, patients can be immersed in virtual environments where their health conditions are continuously monitored, enabling immediate adjustments to medication or therapy as needed (Nguyen and Voznak 2024). This ensures that care remains responsive to each patient's unique and evolving needs.

Moreover, Metaverse empowers patients by providing personalized health dashboards that offer insights into their progress, fostering a deeper understanding of their condition and encouraging adherence to treatment plans (Hassani et al. 2022; Nguyen and Voznak 2024). Real-time remote monitoring enhances healthcare efficiency, especially for remote or underserved populations, reducing the need for in-person visits. This allows healthcare providers to manage larger patient populations while maintaining high-quality, personalized care (Yang et al. 2023).

**4.3.2.5 Efficient management of healthcare resources** The integration of the Metaverse and other technologies, particularly through digital twin technology,

marks a significant advancement in optimizing healthcare resource management (Yang et al. 2023). Digital twins-virtual replicas of physical entities-facilitate the simulation and analysis of complex healthcare systems, leading to better decision-making and resource allocation. Hospitals can leverage these technologies to simulate workflows, optimize operations, and minimize bottlenecks. Predictive maintenance powered by digital twins further reduces downtime, ensuring that critical tools and equipment remain available (Yang et al. 2023). Moreover, the Metaverse enhances patient flow management, allowing providers to allocate resources more effectively based on real-time needs. This optimization not only improves patient care but also boosts overall operational efficiency.

**4.3.2.6 New business models and economic opportunities** Metaverse applications in healthcare are not only transforming care delivery but also fostering new business models and economic opportunities (Bhatia 2021; Nguyen and Voznak 2024). The Metaverse supports the development and promotion of advanced healthcare applications and platforms. For example, healthcare companies can design and offer virtual healthcare devices and tools tailored to the needs of providers operating in virtual environments.

In addition, the Metaverse facilitates virtual consultation services, enabling patients to consult with specialists worldwide without leaving their homes (Bhatia 2021). This greatly improves access to healthcare, especially for individuals in remote or underserved areas. Another promising opportunity lies in monetizing healthcare education and training programs within virtual environments. Professionals can develop and refine their skills in immersive, risk-free simulations, reducing the risks typically associated with real-world practice (Bansal et al. 2022).

The growing relevance of Metaverse-enabled healthcare services aligns with industry forecasts. For instance, the global telemedicine market is projected to grow at a compound annual growth rate (CAGR) of 24.78% from 2022 to 2029, with market valuations expected to exceed $396.14 billion by 2029 (Kanhere 2024). This reflects the increasing demand for remote healthcare education and services enabled by the Metaverse.

Furthermore, insurance models are evolving to accommodate virtual healthcare services, ensuring coverage for treatments received within the Metaverse (Lee and Lee 2021). Some insurers now offer policies that cover virtual consultations and teletherapy sessions, with potential extensions to include virtual reality-based physical therapy or mental health treatments. These developments underscore the growing recognition of virtual healthcare as a key component of advanced healthcare delivery.

### 4.3.3 Identifying the challenges of Metaverse in healthcare industry

While the Metaverse offers significant opportunities for healthcare innovation, several challenges must be addressed to realize its possible potential. These

challenges span technical, regulatory, and ethical dimensions, posing obstacles to the successful adoption of the Metaverse in healthcare.

**4.3.3.1 Technical complexity and infrastructure** Implementing the Metaverse in healthcare presents substantial technical challenges. Developing high-quality, immersive virtual environments requires advanced hardware and software capable of real-time, detailed simulations (Ullah et al. 2022). Additionally, processing and visualizing large amounts of healthcare data must occur seamlessly. A robust, high-speed network infrastructure is essential, especially for remote or underserved areas, where access to healthcare is already limited (Lee and Lee 2021). Without reliable infrastructure, the real-time delivery of Metaverse-based healthcare solutions would be hindered, emphasizing the need for targeted infrastructure investments to ensure seamless operations.

**4.3.3.2 Security and privacy concerns** The adoption of the Metaverse in healthcare raises significant security and privacy issues due to the sensitive nature of healthcare data (Wang et al. 2022). Ensuring the protection of patient information in virtual environments is essential for widespread adoption (Ali et al. 2023). Balancing the accessibility of healthcare data for providers while maintaining robust privacy protections presents a considerable challenge. Collaboration between healthcare providers and technology developers is crucial for creating systems that optimize data usage while safeguarding privacy.

A dynamic, adaptive cybersecurity strategy is necessary to address emerging threats as the healthcare Metaverse evolves. This involves continuous monitoring and updating of security measures to maintain the trust of patients and healthcare staff (Ali et al. 2023). The success of Metaverse adoption will depend on robust security protocols that prevent data breaches and maintain patient confidentiality.

**4.3.3.3 Regulatory and legal frameworks** The rapid advancement of Metaverse and related technologies in healthcare has outpaced existing regulatory frameworks, creating an urgent need for updated guidelines (Skalidis et al. 2023; Théard-Jallu 2023). Key regulatory challenges include addressing vulnerabilities in virtual healthcare procedures, ensuring the qualification of virtual education programs, and securing insurance coverage for Metaverse-based treatments (Yoon and Lee 2021).

Developing comprehensive frameworks that balance innovation with patient safety is critical (Solaiman 2023). This requires collaboration among technology developers, healthcare providers, legal experts, and policymakers to create adaptable regulations that support healthcare innovation while minimizing risks. Policymakers must play a proactive role in establishing new guidelines that align with the evolving landscape of virtual healthcare.

**4.3.3.4 Digital divide and accessibility** The Metaverse has the potential to improve access to healthcare but also risks exacerbating disparities due to the digital divide (Yang et al. 2023). Effective utilization of Metaverse-based healthcare services

requires access to high-speed Internet and advanced devices, which are not universally available.

Addressing this divide requires a multi-faceted approach, including infrastructure development in underserved areas, technology access programs for disadvantaged populations, and promoting digital literacy across demographics (Yoon and Lee 2021). Policies must ensure equitable access to digital health technologies, and collaboration between public and private sectors is essential to bridge the gap. If left unaddressed, the digital divide could become a significant healthcare issue, where only those with access to advanced technology benefit from virtual healthcare services. Conversely, effective strategies could transform the Metaverse into a tool for reducing disparities and improving health outcomes.

#### 4.3.4 Interviews with medical staff

After the analyzing current status to gain additional insights into the opportunities and challenges of applying Metaverse in healthcare, we conducted interviews with experts from three hospitals. These interviews provided insider perspectives on developing effective implementation strategies for Metaverse-based healthcare services. The experts also shared activity plans reflecting their hospitals' unique contexts.

The three interviewees were team leaders with over 10 years of experience at leading digital transformation hospitals in South Korea, each with more than 700 beds. Despite differences in their digital transformation levels, technological adoption, and operational scale, these hospitals demonstrated similar patterns in utilizing emerging technologies, particularly Metaverse platforms. The experts shared their general opinions and experiences with Metaverse applications in their organizations, offering real-world examples of both opportunities and challenges.

From a broad perspective, the Metaverse offers diverse applications in healthcare, including education, diagnosis, treatment, and patient management. In medical education, virtual reality (VR), augmented reality (AR), and extended reality (XR) are already extensively used for surgical and clinical training. The Metaverse also facilitates teleconsultation and remote treatment, unconstrained by geographical limitations. Additionally, it has significant potential in mental healthcare and psychotherapy. VR has proven effective for reducing stress and providing psychological relief by simulating therapeutic environments, aiding the treatment of anxiety and trauma. Similarly, Metaverse-based rehabilitation allows patients to perform exercises in safe, virtual spaces with customized programs, promoting motor skill development for individuals with limited mobility.

The Metaverse further enhances patient education by visually demonstrating disease progression, treatment procedures, and medication guidelines, reducing anxiety and improving patient comprehension. Below are summaries of how the three healthcare institutions utilize the Metaverse.

**4.3.4.1** ***Hospital A*** *(*https://www.youtube.com/watch?v=V1mPYwhjvc8*)* The hospital integrates digital technologies to improve patient experiences and streamline operations. The hospital produces instructional videos to guide patients

through medical procedures, hospital admissions, and diagnostic exams, reducing the need for repeated explanations. It has also developed a smart operating room that enables real-time surgical scene reproduction, facilitating clinical skill acquisition for students and staff. Additionally, the hospital actively explores the potential of Metaverse and related technologies in clinical education, with future plans to offer virtual surgical simulations and other clinical scenarios to enhance patient and practitioner preparedness.

**4.3.4.2** ***Hospital B*** *(*https://zep.us/play/8ARB3O*)* Hospital B identified its health promotion center as an ideal setting for digital transformation. The center offers comprehensive services-appointments, treatments, and diagnostic tests—consolidated within a single location. Operated through the NAVER ZEP Metaverse platform, the virtual health center allows prospective patients to explore facilities and obtain detailed information about tests. The virtual environment recreates the hospital's physical layout (e.g., lobby, exam rooms) and provides users with a sense of familiarity. Users can also access the hospital's YouTube channel and homepage directly from the virtual environment, engaging with hospital-generated medical content.

**4.3.4.3** ***Hospital C*** *(*https://zep.us/play/8rKv3W*)* The hospital operates a digital health counseling center through the ZEP platform, offering disease prevention, management services, and ongoing health guidance in the Metaverse. This virtual space allows individuals with health concerns or queries to access professional counseling without physical contact. The convenience of remote counseling, unrestricted by time or location, has contributed to the popularity of the center.

Although these hospitals may have different perspectives on Metaverse adoption, the experts agreed on the potential of the Metaverse to transform healthcare services. They highlighted both opportunities and challenges, aligning with the findings discussed in Sects. 4.3. Table 11 summarizes their insights, including examples from their institutions.

## 5 Discussion and conclusions

The adoption of the Metaverse in healthcare offers significant opportunities and challenges. By creating immersive and interactive virtual environments, the Metaverse has the potential to revolutionize healthcare education, patient care, and management. This study highlights the transformative potential of emerging technologies in the healthcare industry through a comprehensive analysis that integrates keyword network analysis and sentiment analysis of YouTube videos and comments. To assess the state of Metaverse applications, we analyzed studies published in SCOPUS journals from 2020 to April 2024, as well as YouTube videos and comments from the same period.

The results of this study summarized as follows: First, the Metaverse achieved a high 'Score' measurement of 1.777 on YouTube, reflecting broad public

**Table 11** Opportunities and challenges of Metaverse applications through Interviews

| | Key areas of application | Interviews with medical staff |
|---|---|---|
| Opportunities | Enhanced healthcare training and education | The Metaverse transforms healthcare training and education by creating immersive, safe, and globally accessible environments. Medical students and professionals can interact with virtual patients, practice surgeries, and collaborate with peers worldwide, significantly enhancing their learning experiences and preparedness for real-world healthcare challenges<br>Ex): At hospitals like Seoul National University Bundang Hospital, surgeons use the Metaverse to broadcast surgeries, allowing students to virtually "enter" the operating room |
| | Advanced patient care and treatment | The Metaverse has the potential to advance patient care by providing immersive experiences, personalized treatment plans, enhanced patient education, and even remote surgery capabilities<br>Ex): Severance Hospital is developing a Metaverse hospital project that aims to offer remote consultations with doctors using avatars. Patients can receive treatment advice and diagnosis in a more engaging and interactive virtual environment, reducing the need for physical hospital visits |
| | Improved healthcare research | The Metaverse allows researchers to simulate clinical trials in virtual environments, using digital twins or virtual patients, including enabling researchers to test hypotheses and treatments more quickly and safely in ways that were previously impossible<br>Ex): Researchers can use Metaverse environments to create predictive models of how diseases spread or how different treatment approaches affect populations, helping to anticipate challenges and guide public health decisions |
| | Personalized and remote health monitoring | By integrating wearable data, AI analysis, and immersive virtual consultations, the Metaverse allows for continuous, tailored healthcare services<br>Ex): A patient with diabetes could have their blood sugar levels continuously tracked by a wearable device that sends real-time data to their virtual Metaverse health dashboard. The healthcare provider can then make adjustments to the patient's insulin treatment plan through virtual consultations |
| | Efficient management of healthcare resources | By utilizing the Metaverse, healthcare systems can manage resources more efficiently through virtual infrastructure, real-time data analysis, and global collaboration<br>Ex): Severance Hospital have begun implementing Metaverse systems to integrate patient data and provide consultations remotely, reducing the strain on physical resources such as hospital beds and allowing healthcare facilities to serve more patients |

**Table 11** (continued)

| | Key areas of application | Interviews with medical staff |
|---|---|---|
| | New business models and economic opportunities | The Metaverse presents vast economic opportunities across industries, including healthcare, education, real estate, retail, entertainment, and remote work<br>Ex): Inha University's School of Nursing has provided immersive learning experiences through virtual campuses and classrooms based on Metaverse technology, with schools and corporations using the Metaverse for training simulations, workshops, and seminars |
| Challenges | Technical complexity and infrastructure | The technical complexity and infrastructure requirements for the Metaverse are immense, involving cutting-edge technologies such as advanced computing, real-time rendering, high-speed networks, blockchain, and hardware devices<br>Ex): In the Seoul National University Bundang Hospital, 5G networks are essential to supporting their smart operating rooms |
| | Security and privacy concerns | The Metaverse presents unique privacy and security challenges, especially in sensitive areas like healthcare. Ensuring data protection, strong authentication, secure data sharing, and robust cybersecurity defenses will be critical to prevent breaches, protect personal information, and maintain trust in virtual environments. To address these challenges, developing strong encryption methods, standardized security protocols, and clear data ownership policies will be crucial.<br>Ex): Severance Hospital employs encryption methods to protect patient data during virtual consultations, ensuring that personal health information is safeguarded from unauthorized access |
| | Regulatory and legal frameworks | The development of the Metaverse, especially in sectors like healthcare, is raising critical questions regarding regulatory and legal frameworks. These issues center around privacy, data security, intellectual property, and jurisdictional challenges, among others<br>Ex): Severance Hospital must comply with Personal Information Protection Act-like regulations in Korea and other privacy laws to ensure patient data remains secure during these virtual consultations |
| | Digital divide and Accessibility | Many people in developing countries or underserved areas still lack broadband access or reliable mobile data services, which limits their ability to participate in Metaverse experiences<br>For the Metaverse to be truly accessible, platforms must implement features like text-to-speech for visually impaired users, closed captions for the hearing impaired, and controller options for those with mobility issues<br>Ex): Severance Hospital is exploring ways to ensure that their Metaverse platform is accessible for all patients, including those with disabilities |

engagement with 3997 comments (see Table 3). This indicates that the public has strong interest and high expectations for the role of Metaverse in healthcare. Second, Metaverse-related research in healthcare increased from 768 publications in 2020 to 870 in April 2024, highlighting expanding interest in both healthcare applications and psychological well-being (see Table 6). Third, keyword network analysis identified key concepts like effectiveness as central to discussions about the Metaverse in healthcare services (see Fig. 2 and Table 8), emphasizing the importance of evaluating its impact on healthcare delivery. Fourth, clustering analysis identified five core topics in Metaverse healthcare research: (1) Mental Health Treatment, (2) Healthcare Research and Diagnostics, (3) VR and AR in Rehabilitation and Education, (4) Consumer Behavior and Marketing, and (5) Telemedicine and Remote Healthcare Management (see Fig. 3 and Table 9). Fifth, sentiment analysis of the top ten YouTube videos identified three key themes: (1) Treatment and Patient Care, (2) Healthcare Education and Visualization, and (3) Healthcare Innovation and Service Delivery (see Table 5). Sixth, based on the analysis results presented above, this study categorizes Metaverse applications into three key dimensions: (1) Provision of Healthcare Services and Treatments, (2) Delivery Service of Education and Visualization, and (3) Development of Innovative Healthcare Services (see Table 10). These dimensions provide a comprehensive view of how the Metaverse is currently being applied in healthcare. Finally, this study proposes opportunities and challenges for the Metaverse, which offer several opportunities, including enhanced healthcare training through immersive environments, improved patient care through personalized virtual experiences, real-time data-driven treatment, and remote health monitoring. In addition, the Metaverse enables new business models for healthcare services and promotes global collaboration (see Table 11).

However, several challenges must be addressed to optimize the benefits of these technologies, such as the need for a robust, high-speed network infrastructure, safeguarding patient data in virtual environments, developing comprehensive legal frameworks to govern virtual healthcare services, and ensuring equitable access to the Metaverse across different regions. Therefore, addressing these challenges is essential to unlock the full potential of the Metaverse. Doing so will not only enhance healthcare service delivery but also contribute to public health, disease prevention, and the development of healthier communities through greater patient engagement.

### 5.1 Theoretical and practical implications

This study contributes to both the literature and practical application of the Metaverse in the healthcare industry by examining trends from academic research and public sentiment through YouTube videos and comments. As theoretical contributions, this study adopts an interdisciplinary approach by combining sentiment analysis and keyword network analysis to explore public perception and technological trends. The use of the 'score' measurement from YouTube videos and comments provides nuanced insights into public expectations by capturing the alignment

between video content and audience sentiment. The study also highlights the transformative potential of Metaverse applications in healthcare, offering a framework for their adoption. Moreover, it identifies key challenges that require further academic exploration, encouraging researchers to develop solutions that facilitate the successful integration of these technologies in healthcare services.

As a practical contribution of this study, as the healthcare industry embraces digital transformation, new service models are emerging to meet the evolving needs of consumers. This study provides foundational insights for healthcare organizations, developers, practitioners, and policy-makers. It highlights potential opportunities and challenges related to the adoption of the Metaverse, equipping organizations with the knowledge needed to navigate this transition. Additionally, the research outlines the critical challenges that must be addressed to ensure implementation, such as infrastructure requirements, privacy concerns, and regulatory considerations. Furthermore, the study provides practical insights for strategic guidance to improve healthcare delivery through Metaverse applications, enhancing patient care, education, and innovation.

### 5.2 Limitations of the study and future research

Although the study provides valuable insights both academic and practical perspectives, several limitations must be considered. First, this study analyzed Metaverse-related studies in healthcare using only the SCOPUS database for academic research, which may have excluded relevant studies from other academic sources, potentially limiting the scope and conclusions of the analysis. Second, while sentiment analysis of YouTube videos and comments offers a unique perspective on public perception, it may not fully capture the complexity of user expectations. Sentiment scores, though informative, may lack the depth required to reflect nuanced opinions accurately. Third, keyword network analysis, though effective in identifying trends, may not equally represent keywords unique to specific fields such as business, psychology, or nursing. Limited overlap between disciplines could result in bias, emphasizing frequently co-occurring terms while underrepresenting other valuable perspectives in Metaverse-related healthcare research. Given the rapid evolution of digital technologies, continuous research is essential to stay updated with emerging developments and regulatory frameworks. Therefore, the findings of this study will need periodic reassessment to ensure their relevance, as new technologies and regulations shape the future of Metaverse applications in healthcare.

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## Declarations

**Conflict of interest** The authors declare no conflict of interest.

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