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ORIGINAL RESEARCH

The use of smart glasses in the healthcare metaverse: A systematic review

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Background: In recent times, discussion of the use of virtual reality and augmented reality for healthcare metaverse has remained confusing. In a busy healthcare setting, use of these technologies may be burdensome as they necessitate manual operation by healthcare professionals. Yet at the same time, smart glasses are becoming increasingly popular because of their benefits, such as allowing a degree of hands-free operation and enable video-based consultations that provide a live perspective. There have been studies that examined the use of smart glasses in various healthcare environments.

Aim: The research aimed to study the use smart glasses in virtual reality and augmented reality for the healthcare metaverse.

Methods: We searched three databases that encompass research in both the healthcare and computer science fields. We employed the PRISMA approach to conduct a review of papers. The search focused on articles published between 2019 and 2023.

Results: The findings of the study revealed that 28 out of the 81 publications reviewed utilised commercially available smart glass devices and videoconferencing software, demonstrating a high level of technological preparedness for the practical application and use of smart glasses in the healthcare environment. The research investigated typical system features, such as video and audio streaming, annotation, augmented reality and hands-free interactions.

Conclusion: Smart glasses and optical head-mounted displays with smartphone features are transforming the healthcare industry by enabling hands-free communication as well as instant information sharing among healthcare professionals. This technology enables remote cooperation and information sharing by transmitting audio and video, thus enhancing the quality of patient care.

Keywords: Smart glasses; virtual reality, augmented reality; healthcare metaverse; healthcare professionals

Die gebruik van slimbrille in die gesondheidsorgmetaversum: 'n Sistematiese oorsig:
Agtergrond: In onlangse tye was die bespreking van die gebruik van virtuele realiteit en geougmenteerde realiteit vir die gesondheidsorgmetaversum nogal verwarrend. Die gebruik van hierdie tegnologieë kan moeilik wees in 'n besige gesondheidsorgomgewing, aangesien gesondheidsorgpersoneel noodgedwonge hul hande daarvoor moet gebruik. Nogtans raak slimbrille al hoe gewilder as gevolg van die voordele daarvan, soos dat dit wel 'n groot mate handvrye gebruik daarvan toelaat en ook videogebaseerde konsultasies wat 'n lewende perspektief moontlik maak. Daar is wel vorige studies wat slimbrille in verskeie gesondheidsorgomgewings ondersoek het.

Doel: Die navorsing het ten doel gehad om die gebruik van slimbrille in virtuele realiteit en geougmenteerde realiteit vir die gesondheidsorgmetaversum te bestudeer.

Metodes: Ons het 'n soektog deur drie databasisse gedoen wat navorsing in beide die gesondheidsorg- en rekenaarwetenskapveld insluit. Ons het die PRISMA-benadering gevolg om 'n oorsig van referate te doen. Die soektog het op gepubliseerde artikels tussen 2019 en 2023 gefokus.

Resultate: Die studie het bevind dat 28 uit 81 publikasies wat in die oorsig gebruik is, kommersieel beskikbare slimbriltoestelle en videokonferensieprogrammatuur benut het, wat 'n hoë vlak van tegnologiese gereedheid vir die praktiese toepassing en gebruik van slimbrille in die gesondheidsorgomgewing demonstreer. Die navorsing het tipiese stelselkenmerke soos video- en oudiostroming, annotasie, geougmenteerde realiteit en handvrye interaksies ondersoek.

Gevolgtrekking: Slimbrille en optiese kopgemonteerde skerms met slimfoonkenmerke transformeer die gesondheidsorgbedryf deur handvrye kommunikasie sowel as die onmiddellike deling van inligting tussen gesondheidsorgpersoneel moontlik te maak. Hierdie tegnologie maak samewerking op 'n afstand en inligtingsdeling moontlik deur oudio en video te versend en sodoende die gehalte van pasiëntsorg te verbeter.

Sleutelwoorde (slegs Engels is gebruik): Smart glasses; virtual reality, augmented reality; healthcare metaverse; healthcare professionals

Introduction

Healthcare encompasses the assessment and prediction of patients' physical, mental and cognitive well-being. In this study, healthcare metaverse refers to the convergence of many technologies such as artificial intelligence (AI), virtual reality (VR), augmented reality (AR), internet of medical things (IoMT) and others. Utilisation of smart glasses in healthcare metaverse technologies allows for the monitoring and enhancement of patients' health fitness (Bibri & Jagatheesaperumal, 2023). As a result, it facilitates surgical simulation, diagnostic imaging, rehabilitation and patient health management (Kadem *et al.*, 2023). Additionally, patients become the beneficiaries of the healthcare metaverse of AR and VR as it allows them for example to consistently perform the necessary physical exercises as outlined in their treatment protocols. Benefits can further be seen for example in the use of VR and AR, where healthcare professionals provide treatments with a non-pharmacological approach to address anxiety associated with trauma.

The current healthcare system employs the healthcare metaverse for storage of data in either a private or public cloud. The related intelligent judgements, which are based on VR and AR, are made based on the data that is exchanged with the individual nodes. The traditional healthcare system provides services to patients through the establishment of medical policies, such as the Health Insurance Portability and Accountability Act of 1996 (the HIPAA), a United States Act of Congress, and those by the World Health Organisation (WHO). Wearable gadgets such as smart glasses, which are in the class of AR and VR, allow a broader understanding for simulation purposes, which benefits healthcare professionals. Furthermore, AR and VR provide opportunities for data monitoring which further benefit healthcare professionals (Azodo *et al.*, 2020). To illustrate the improvements in effectiveness attained by healthcare practitioners when utilising intelligent eyewear, one just needs to consider activities such as information retrieval, record-keeping and interpersonal interchange (Romare *et al.*, 2022).

This article explored the use of smart glasses in the healthcare metaverse in VR and AR for healthcare professionals. Smart glasses possess a multitude of qualities that have the potential to bring about a revolutionary transformation in the healthcare sector (Pramanik *et al.*, 2020). This advanced technology will facilitate various tasks, including the capture of patient information, the recording and analysis of patient interactions through voice recognition and recording software, the administration of medication and the preliminary diagnosis of patients. In addition, the system will utilise facial recognition technology to accurately identify patients and get their comprehensive medical history, including information on allergies and other relevant characteristics. These features are particularly useful in situations where the patient is unresponsive or unable to communicate verbally. In this research, smart glasses are regarded as a type of wearable computer equipped with an optical head-mounted display (OHMD) (Baashar *et al.*, 2023). Its purpose was to create widely available computerised eyewear for the public. The device presents data in a hands-free format resembling that of a smartphone, and users interact with the internet via voice commands in natural speech (Chengoden *et al.*, 2023).

Literature review on the healthcare metaverse

This article examines the adoption of the healthcare metaverse for VR and AR. In the past, the use of internet of things (IoT) systems in the medical and healthcare industry resulted in patients devoting additional time and financial resources to clinic-related services (Akkaş, Sokullu & Ertürk Çetin, 2020). The adoption of VR has been motivated by the commercialisation of VR. However, there have been recent advancements in the use of AR and VR technologies that allow enhancement for quality healthcare, particularly in diagnosing and understanding the severity of patients' diseases.

According to Habibzadeh et al. (2020), more comprehensive recognition in healthcare should not solely concentrate on one aspect of IoT utilisation, but should rather strive to provide enhanced healthcare services to patients through healthcare professionals (Habibzadeh *et al.*, 2020). However, Taimoor and Rehman (2022) assert that IoT-based healthcare and medical systems that can utilise modern technologies such as big data, AI and fifth generation mobile technology have had a significant impact on the healthcare business worldwide (Mafabi *et al.*, 2017). These technologies provide a multitude of advantages to patients, hospitals and medical centres, such as automated health monitoring and remote collaborative medical diagnosis.

Virtual reality and augmented reality

The study elucidates that IoT-based healthcare systems collect many forms of healthcare and medical data, including sequential data like electroencephalograms, high-dimensional data such as ultrasound images, and documents such as electronic health records. This will allow the use of such gathered data by intelligent sensor-driven devices, including biosensors, wearable devices, smart gadgets and medical equipment, all of which are interconnected via the internet (Cilliers, 2020; Pramanik *et al.*, 2020). The data is initially kept on a local device, after which a replicated copy is transmitted to the data centre for cloud storage, provided that the data is obtained directly from devices. The data is processed and evaluated in the data centre utilising a range of AI technologies, including feature engineering and machine learning algorithms, to autonomously extract significant and pertinent information (Rathore *et al.*, 2021).

The results obtained by AI in service-oriented computational activities are ultimately communicated to either the individual patients or the health service providers. Specific fundamental results can aid doctors and healthcare professionals in reaching a definitive medical diagnosis and formulating the most appropriate course of treatment. Security measures are essential across all stages, encompassing sensing, data collection and processing to protect sensitive health data, confidential information and diagnostic outcomes from cyber threats

(Butpheng, Yeh and Xiong (2020). These techniques should encompass the physical layer as well as the service and application layers to strengthen protection of sensitive data.

The healthcare metaverse is experiencing growth in multiple sectors and offers a multitude of prospects (Chengoden *et al.*, 2023). It utilises cutting-edge technology, such as AI, VR, AR, the internet of things, intelligent cloud, collaborative robotics, edge computing and quantum computing to transform healthcare and provide exceptional experiences. To provide an accurate definition of the healthcare metaverse, one needs to incorporate VR/AR glasses, which are facilitated by the internet of medical/health things (Damar, 2022). Augmented reality employs visual components and graphical characters to modify the physical world, enabling users to see their three-dimensional environment using AR devices, such as smart glasses. VR technology creates a fully computer-generated virtual environment with which users can interact, utilising VR headgear, gloves, controllers, and other digital sensors. Augmented reality is a technology that creates an interactive environment by overlaying virtual objects onto a real place in 2D or 3D, as highlighted by Javaid and Haleem (2020)

Due to the susceptibility of healthcare and medical data to theft, mostly because it is stored on centralised servers, service providers have recognised the necessity of creating a strong and secure health diagnostic platform to combat the increasing number of such events. There is a substantial amount of work to be done. Under this specific paradigm, the healthcare metaverse is already exhibiting significant benefits in the realm of digital healthcare, as it employs VR and AR technology to improve medical applications and services. This is accomplished by using haptic sensors and 3-D interaction (Azodo *et al.*, 2020).

The healthcare metaverse presents numerous substantial benefits that possess the capacity to fundamentally revolutionise the healthcare sector, such as in medical training and education. Service providers successfully interact with patients and clinicians remotely to jointly diagnose medical conditions, amplify the effectiveness of a recommended treatment and utilise personalised technologies such as VR, AR, telemedicine platforms and other customised technologies for enhanced diagnosis (Hartasanchez *et al.*, 2022). The utilisation of the subsequent technologies and approaches can facilitate effective interaction between service providers and patients in the healthcare metaverse. Patients employ VR headsets and AR glasses to enter a virtual clinic within the metaverse, where they can consult with a physician for medical guidance.

Real-time remote guidance and engagement on AR and VR

AR and VR allow surgeons to perceive three-dimensional (3-D) representations of a patient's bones and organs. This technology facilitates the careful organisation and accurate implementation of surgical procedures by providing a precise representation of the body's anatomy. AccuVein is an advanced gadget that improves the capability of healthcare professionals to detect veins, leading to less discomfort and improved accuracy while inserting needles into veins. The InnerOptic program aids in detecting abnormalities in the human body, measuring the size of tumours, monitoring the progression of diseases and predicting the response to treatment. InnerOptic provides precise categorisation of organs and tissues, allowing for a thorough imaging of the human body. Medical students and trainees can get a thorough comprehension of human physiology by utilising interactive holographic representations within the healthcare metaverse (Song & Qin, 2022).

Federated learning of the healthcare metaverse

The primary security obstacles in the healthcare metaverse environment encompass user identity spoofing and account hacking, leading to the unauthorised takeover of the avatar by outsiders. In the context of a healthcare metaverse, it is crucial to prevent intruders from accessing and exploiting data gathered from hospitals, patients and other healthcare providers. Data might be manipulated to alter disease diagnoses and decisions related to medicine. The use of federated learning as represented in Figure 1 states that it assists by utilising its secure aggregation algorithms to maintain the confidentiality of updates on edge devices (Song & Qin, 2022). In addition, the true value or origin of model updates is protected by minimising the probability of data attribution and inference attacks. Federated learning methods can provide additional security in healthcare metaverse automatisation and cognitive abilities.

The healthcare metaverse facilitates the delivery of high-quality medical services to patients, overcoming previous challenges posed by geographical constraints. Due to the progress made in major enabling technologies such as AR/VR, AI, digital twinning (DT) and blockchain, automation may now be implemented in several areas of healthcare within the metaverse (Bashir *et al.*, 2023).

Revolutionary advancement: intelligent eyewear

As shown in Figure 2, smart glasses seamlessly combine the physical world with virtual data that is superimposed on or incorporated into a user's field of vision. Notable instances include Google Glass, Elbit/Everysight Raptor, Microsoft HoloLens and Epson Moverio. Smart glasses utilise many sensors, such as GPS, microphones and cameras, to analyse and acquire an understanding of the user's environment (Dulishkovych *et al.*, no date).

The integration of virtual information through internet technologies on mobile devices can enhance a user's real-world experience. Google Glass, for example, includes a prism that is placed in front of the user's eye. Smart glasses provide a range of control options, including speech recognition, touchpad input on the device, head motion or virtual displays (e.g. holographic buttons) that may be accessed by external devices like smartphones (Kim & Choi, 2021).

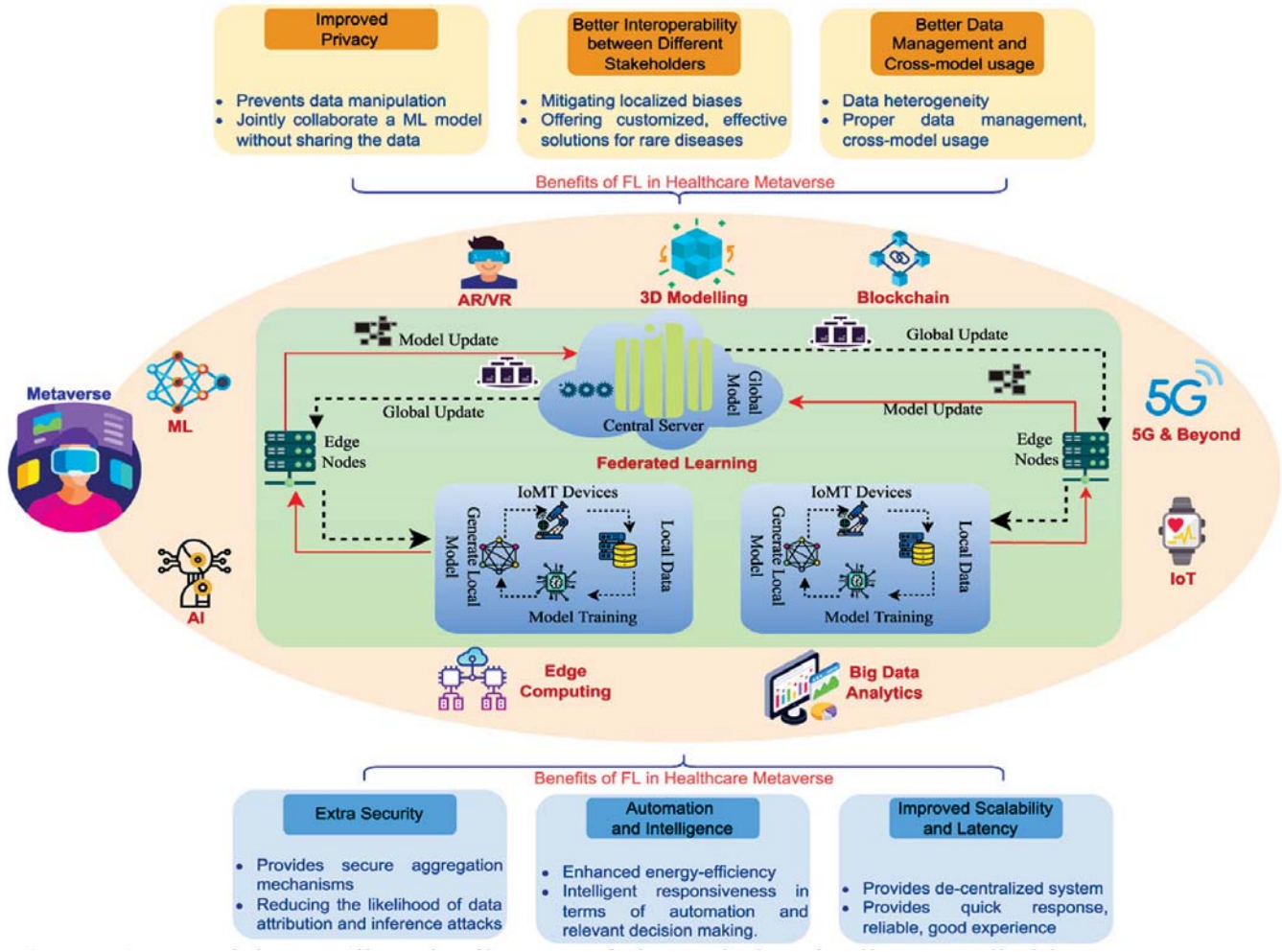

Figure 1: Advantages of using federated learning in the healthcare metaverse (Bashir *et al.*, 2023)

Figure 2: Example of smart glasses

Improving communication and data access through the utilisation of smart glasses in the healthcare system

In this study, the articles reviewed acknowledge the potential of this groundbreaking technology but also highlight several barriers that need to be addressed before it can be widely adopted in complex healthcare systems (Zhang *et al.*, 2023). These challenges primarily pertain to data security, user training and acceptance of the technology. Explicit protocols must be established to guarantee the secure incorporation of smart glasses in the transformative healthcare industry.

Influence on patient care

Enhancing diagnosis and treatment through the utilisation of intelligent eyewear

A study by Bui et al. (2021) mentions that smart glasses were implemented as an intervention at three health clinics located in rural areas. Throughout the entire project, smart glasses were utilised many times during health centre consultations for telemedicine. Individuals involved were mostly healthcare professionals working in hospitals, offering guidance, diagnosis and treatment for curative consultations. During the course of the study, there was a significant increase in the utilisation of smart glasses for outpatient consultations at the three rural health institutions. The increase in interest was primarily due to the passion for (and the curiosity generated by) the outreach programmes, which were designed to educate the community about the project. After several months, the number of consultations stabilised, although it remained high, showing a rise compared to the period before the initiative (Diaka *et al.*, 2021).

User experience and training of healthcare professionals in use of smart glasses

Healthcare professionals sometimes lack experience with new technologies but they can be taught how to effectively utilise smart glasses (Popov et al., 2022). The clinical examples used should illustrate a significant level of satisfaction. When teaching healthcare personnel in the use of smart glasses, it is essential to monitor signals of either, or both, subjective and objective sentiments of anxiety or worry.

Their was predominantly good consensus about the comfort of smart glasses (Herz & Rauschnabel, 2019). One challenge to smoothly incorporating use of smart glasses was that some healthcare professionals wore prescription glasses but this could be overcome.

To facilitate acceptance, smart glasses can be utilised to demonstrate the process of acquiring knowledge and skills. Consequently, various testing scenarios should be implemented to illustrate their benefits when transitioning to real-life situations, as highlighted by Caria et al. (2020).

In this research study, Figure 3 illustrates a healthcare professional (nurse) wearing smart glasses that are utilised for consultation and patient safety. Smart glasses are recommended as a complement to existing monitoring equipment and patient routines, for example when patients undergo routine checkups for a disease such as hypertension. Besides consultations in healthcare, smart glasses are also used for training of healthcare professionals. The need for user training in complex healthcare environments for the successful integration of smart glasses is important, as it contributes to the provision of high-quality treatment and patient safety (Romare *et al.*, 2022).

Figure 3: A healthcare professional using smart glasses

Methods

A systematic literature review (SLR) is a method used to discover, assess and analyse all existing research related to a specific research question, topic area or phenomenon of interest (Mutunhu et al., 2024). Initially, research questions (RQs) were formulated to investigate the existing research on smart glasses. The second phase involved creating a search strategy to gather articles that could offer suitable responses to the research questions. The third step set three criteria, apart from the first stage, to choose studies appropriate for this research. During the fourth stage, the abstracts of the chosen papers were reviewed to determine if the research could offer relevant information related to the study objectives. The study aimed to address the following three research questions:

RQ1 What are the effects on patient care of incorporating smart glasses into healthcare environments, encompassing aspects such as diagnosis, treatment and overall satisfaction?

RQ2 What is the impact of smart glasses on infection management and the potential mitigation of cross-contamination in healthcare facilities?

RQ3 What are the various strategies that can be employed to promote the adoption and use of smart glasses among healthcare professionals in the healthcare system?

To comprehend the latest research on the use of smart glasses in VR and AR in the healthcare metaverse, a research question was formulated specifically for this study. RQ1 displays the current research status by identifying the effects on patients of incorporating smart glasses into healthcare environments, encompassing aspects of addressing issues such as diagnosis, patient treatment and quality of services provided through overall satisfaction. RQ2 determined the impact of smart glasses on the detection and management of infection while mitigating cross-contamination in healthcare facilities. Lastly, RQ3 examined various strategies that can be employed to promote the adoption and use of smart glasses by healthcare professionals in the healthcare system.

Search methods

The researchers used the search phrases to review the subject with a focus on research related to smart glasses (Klinker, Wiesche & Krcmar, 2020; Özdemir-Güngöret al., 2020). The keywords that were utilised were "smart glasses," "virtual reality and 'augmented reality' in healthcare" and "metaverse." In this research, the three most common search engines were used, namely PubMed, Google Scholar and Web of Science. This search was employed based on the published articles from 1 January 2019 to December 2023. The focus on novel uses of smart glasses for VR and AR produced 28 reviewed articles.

Selection criteria

The research used the selection criteria to eliminate those studies that were irrelevant. The common language of English was used to search to search for conference presentations, published books and accredited journal articles. Other languages were not considered for the search phrase due to the difficulty of assimilating information in languages not spoken by the authors. Through this filtering process, the researcher discovered that some of the studies were based on other healthcare technologies, such as telemedicine specifically, while some focused on VR images only. Such studies were not suitable for the study and were eliminated. The three relevant search items, namely smart glasses, VR and healthcare metaverse, were found. Some metaverse topics were of general relevance in other fields of study but were also considered for this study because there were general lessons to be learnt from them. Most reviewed papers were excluded because they were too broad, dealing with multiple products and for various other reasons, all of which finally resulted in 28 papers directly relevant to the study as presented in Figure 4 (based on the PRISMA approach).

Results

The annual research publication rate on the topics of VR and AR in healthcare was studied to determine tendencies. This study found that in the context of the healthcare metaverse, where studies integrated cognitive treatment and rehabilitation services, a new era was being ushered in. Figure 5 shows the number of papers published over the five-year period from January 2019 to December 2023. Research on VR in general has grown, and even more so on VR in healthcare, showing a steady increase during this period (Rojas-Sánchez et al., 2023). 263 articles have been published about VR and AR, illustrating the ongoing development in these fields. In total 81 papers were selected for possible relevance to the study. A criterion was set of publication within the five years from January 2019 to December 2023. Of the 45 papers remaining, five were duplicates, 12 were excluded on other grounds, and the remaining 28 were selected.

Discussion

The healthcare metaverse has the potential to solve patient issues, while it allows healthcare professionals to communicate using advanced technology, such as smart glasses. AR and VR are used for the simulated environment to allow this application of technology to interact with the 3D virtual world. This is done through the simulated screen, engaging with and seeing the perceived 3D environment (Javaid & Haleem, 2020). Therefore, healthcare professionals develop and implement the technology in training, allowing diagnosis or virtual treatment to be performed on patients using smart glasses (Bhugaonkar et al., 2022). The VR application is utilised to expedite the training process without involving apprehension or hazards. It is furthermore utilised in the actual medical field to treat a variety of diseases. This technology is crucial in enhancing the efficiency of the medical industry (Dulishkovych *et al.*, no date). Furthermore, it is a beneficial and functional technology that enhances trainee and patient comfort. VR and AR remain crucial technology in the development process that utilises tailored and sophisticated software and hardware.

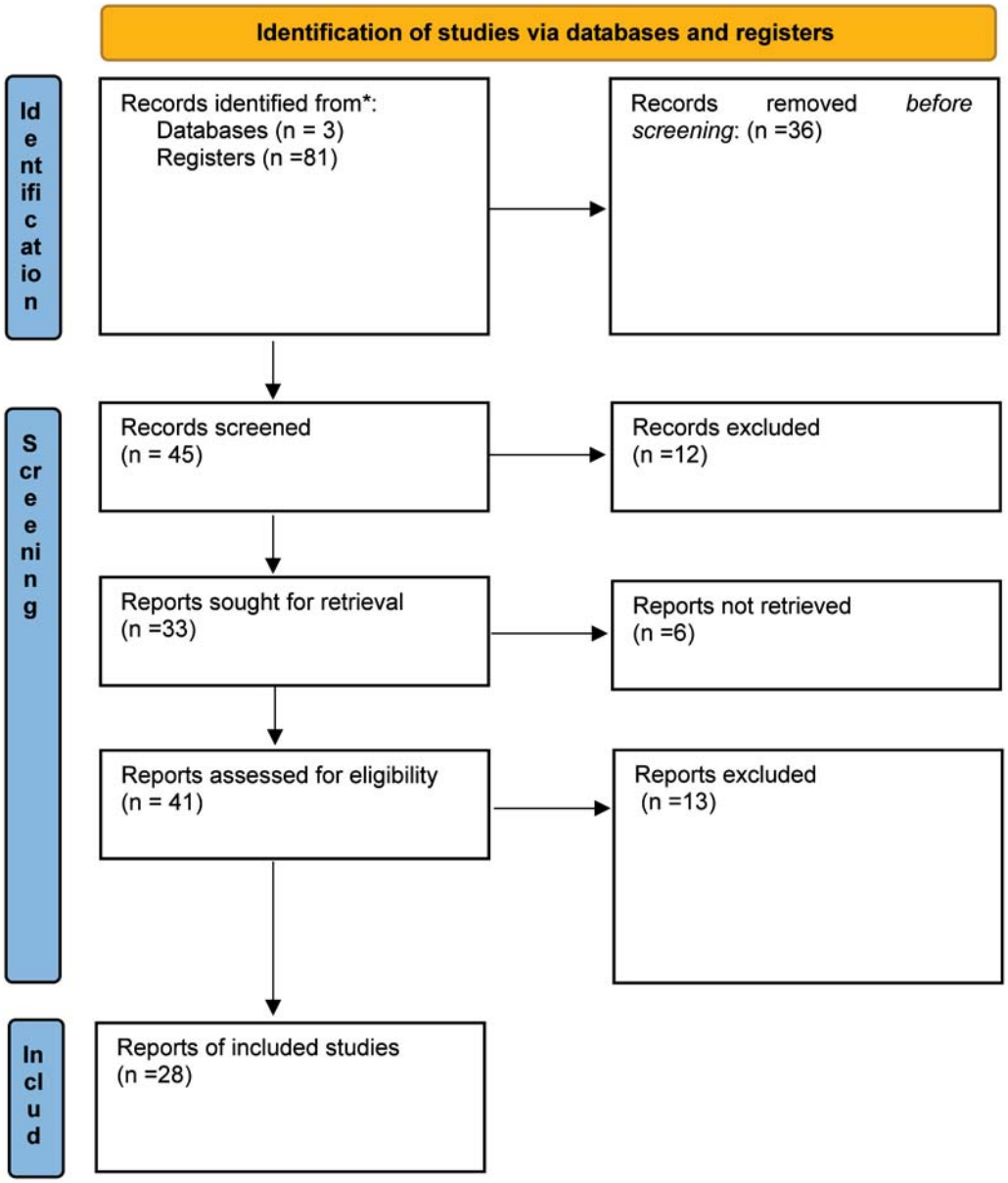

Figure 4: PRISMA approach applied

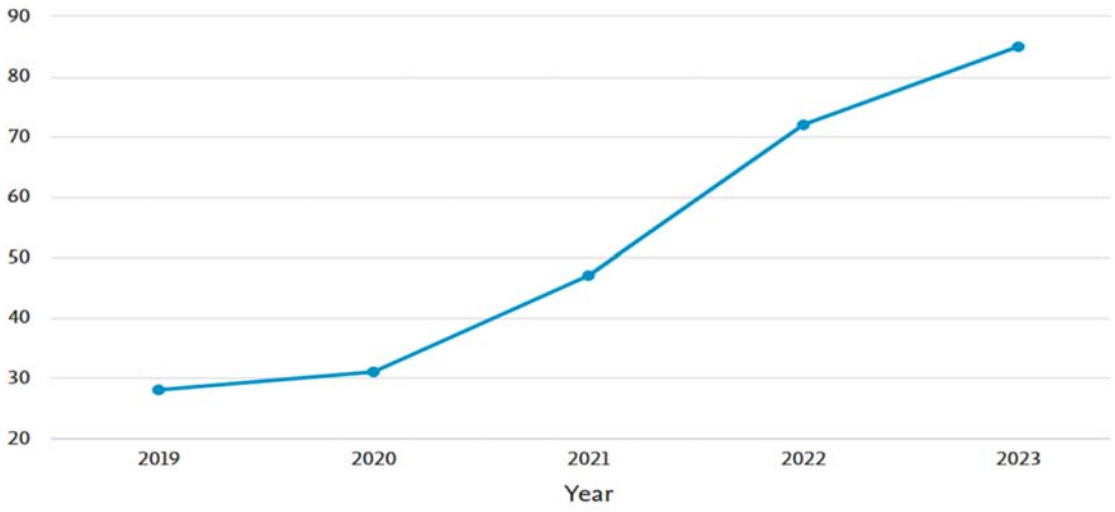

Figure 5: Graph of increase in publication over the relevant years

The results of the study showed that smart glasses were very successful in facilitating information sharing and visual communication between medical teams that were located in different places. Moreover, the research investigation defined the specific objective of the necessary treatment and gathered pertinent background information. Diverse hardware and software techniques are employed to produce 3D simulated data, culminating in the formation of a 3D virtual environment (Dean et al., 2020). The requisite medical data is precisely produced and identified in a VR environment utilising the most efficient technique (Chang et al., 2022). This procedure is employed to formulate treatment and finally to facilitate the execution of the actual surgery. VR is essential for improving the efficiency of the medical field. This technology is currently employed to investigate muscles, nerves, skin, bones and blood vessels. Medical students can now effectively record a patient's information and evaluate diverse medical conditions (Azodo et al., 2020). The technology for example enhances the experience of knee arthroscopy training. It is also employed to assess and analyse a surgeon's proficiency. The literature study concentrated on the study's year, keywords, methodology, conclusions and research gap(s) in order to summarise the research findings.

In overview, this study observed that VR is an evolving three-dimensional computer technology that finds application in a wide variety of medical procedures and therapies. VR is used for example in cardiology to administer chemotherapy. A surgeon can now readily visualise bones, blood vessels and other anatomical structures. This technology is utilised for the strategic planning of diagnoses and mitigation of risks in intricate surgical procedures (Chang *et al.*, 2022). Doctors can observe every treatment procedure as well as other health conditions in great detail. It aids in comprehending patient anatomy and strategising heart surgery with precision. It creates a 3D virtual environment for efficient interaction (Bhugaonkar, et al., 2022). VR is also utilised to alleviate discomfort during healthcare and surgery. An analysis of the application of VR in the medical sector has been presented, highlighting its important advantages. The procedural processes during adoption in the medical profession have been demonstrated and analysed (Rejeb *et al.*, 2021).

Conclusion

The study's findings indicate that, within the healthcare industry, smart glasses are a feasible and effective tool for enhancing visual communication and information exchange among remotely located medical teams. Despite this innovative technology's significant potential, the examined research underscored certain issues that complicate the application of smart glasses in VR and AR within the healthcare sector. Healthcare professionals require comprehensive training prior to utilising VR and AR (Chang et al., 2022). In this study, strategic system design that included end users from the start used enhanced and reliable hardware and software as essential aspects to enhance the effectiveness as well as user-friendliness of smart glasses for healthcare professionals. More user-centred design and evaluation research is required to analyse and assess the demands and perceptions of medical professionals and to identify how to develop smart glass technology to cater for their requirements. Furthermore, additional research is needed to clarify the impact of smart glasses on the workflow of healthcare professionals in intricate care settings. It also has to include the healthcare metaverse in detail.

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