# A Decade Of Telerehabilitation Using Virtual Reality: Bioethics Perspective


## Abstract

**Aims:** This study analyzes the development of virtual reality (VR)-based telerehabilitation over the past decade (2015–2024) through a bibliometric approach to 323 scientific publications.

**Instrument & Methods:** This study uses a qualitative method with a literature study approach emphasizing bibliometric studies. The research data is sourced from reputable international journals indexed by Scopus. The collected data is then thoroughly analyzed and visualized using the VOSviewer program.

**Findings:** The results reveal a dominance of technical and clinical studies with minimal attention to ethical aspects, indicating a disparity between technological advances and bioethical considerations. Keyword network analysis identified three main clusters: clinical effectiveness, immersive technology, and patient quality of life, while ethical issues such as informed consent, data privacy, and equitable access emerged as separate nodes. Key findings of the study include: (1) the dominance of research by developed countries (the US and Italy account for 44% of publications), reflecting global disparities in access to technology; (2) the risk of dehumanization in rehabilitation practices due to reduced therapeutic interaction, and (3) the lack of an ethical framework in the development of VR systems.

**Conclusion:** This study recommends an integrated approach encompassing the development of ethics-by-design principles, hybrid models that maintain human interaction, and inclusive funding schemes to reach marginalized populations. The study's implications emphasize the need for a paradigm shift in research that balances technical, clinical, and ethical aspects. Future research agendas should prioritize studies on patient experiences, evaluations of technological biases, and the development of regulations that protect user rights. These findings provide a conceptual foundation for the development of VR-based telerehabilitation that is not only clinically effective but also equitable and upholds human dignity.



**Keywords:** Bioethics, Telemedicine, Telerehabilitation, Virtual Reality, Human Dignity




## INTRODUCTION

Advances in information and communication technology have brought about significant transformations in various sectors, including healthcare (1). One of the most notable innovations in the last decade is the use of Virtual Reality (VR) technology in telerehabilitation services (2). Telerehabilitation, as part of telemedicine, offers rehabilitation services that patients can access remotely, providing a solution to the limitations of conventional healthcare services, particularly in remote areas or for those with mobility constraints (3). With the advent of VR, telerehabilitation approaches have become more interactive, immersive, and adaptive to the complex needs of patients, especially those with neurological disorders such as stroke, hemiplegia, fatigue, and upper limb disorders (4). VR enables the simulation of therapeutic environments that resemble real-world conditions (5). The combination of VR and telerehabilitation has been proven to enhance patient engagement in the therapeutic process, accelerate recovery, and reduce the burden on hospitals and rehabilitation clinics (6). However, amid the excitement surrounding these advancements, important questions have emerged regarding the ethical dimensions of applying technology in clinical practice, which have not received much attention in the scientific literature (7).

Bioethical issues become highly relevant when we consider that health technology not only addresses technical and clinical aspects but also concerns patient rights, equitable access, data privacy, and the quality of therapeutic relationships (8). In the context of VR-based telerehabilitation, a number of ethical challenges arise that need to be seriously considered (9). First, how can we ensure that all patients, regardless of their socioeconomic or geographic background, have equitable access to this technology? Second, how can we guarantee that health data collected through VR devices is secure and used ethically? Third, do patients truly understand and consent to (informed consent) this technology-based therapy, given its technical complexity?

Additionally, the use of VR in telerehabilitation raises questions about patient dependence on technology, the potential loss of humanistic aspects in the patient-therapist relationship, and the

validity and reliability of therapy outcomes that are not conducted face-to-face (10). In many cases, technology design is developed with a greater focus on functional and market aspects, while ethical dimensions tend to be marginalized (11). This reflects a gap in the literature, where studies on ethics, although important, have not yet become mainstream in VR-based telerehabilitation research (12).

In the initial literature review, it was found that most articles in the last decade discussing telerehabilitation and virtual reality focused on clinical, technical, and therapeutic effectiveness aspects (13). Publications that explicitly address ethical issues are still very limited in terms of both quantity and depth of discussion. However, to ensure that technological innovations in the field of health can develop responsibly and sustainably, bioethical issues must be an integral part of scientific discourse and professional practice (14). In response to this situation, this article aims to conduct a bibliometric analysis of scientific literature discussing VR-based telerehabilitation over the past ten years (15). The bibliometric method was chosen because it provides a quantitative overview of trends, collaboration patterns, and dominant keywords in academic literature (16). Through this approach, it is hoped that the extent to which bioethical issues have received attention in academic discourse on this topic can be identified (17). This analysis will not only reveal the dynamics of research from a geographical, institutional, and thematic perspective but also provide critical reflection on the position of ethical issues within the landscape of VR-based telerehabilitation research (18). Thus, this article does not merely present a research map but also offers conceptual and normative contributions regarding the importance of integrating ethical perspectives into the development and implementation of health technology (19).

The main objectives of this study are (1) to identify trends in publications related to telerehabilitation and VR over the past decade, (2) to reveal the relevance of bioethics themes in the analyzed literature corpus, and (3) to encourage further discussion on the need for an interdisciplinary approach that combines technology, health, and ethics in the development of telerehabilitation services. This article is intended to serve as an initial reference for researchers, policymakers, technology developers, and healthcare practitioners to be more sensitive to the ethical implications of the innovations they develop or use (20). Overall, this study emphasizes that technological innovations in healthcare cannot be separated from ethical considerations (21). Good technology is not only technically advanced or clinically effective but also fair and transparent and upholds human dignity (22). By incorporating bioethics into bibliometric analysis, this article seeks to bridge the gap between technological sophistication and moral integrity in modern healthcare practice.

## METHODS

This study uses a bibliometric approach to map the development of scientific literature related to “telerehabilitation” and “virtual reality” in the period 2015–2024. Data sources were taken from the Scopus database with the following search syntax: ( TITLE-ABS-KEY ( telerehabilitation ) AND TITLE-ABS-KEY ( “virtual reality” ) ) AND PUBYEAR > 2015 AND PUBYEAR < 2024 AND ( LIMIT-TO ( SUBJAREA , “MEDI” ) OR LIMIT-TO ( SUBJAREA , “HEAL” ) OR LIMIT-TO ( SUBJAREA , “SOCI” ) ) AND ( LIMIT-TO ( DOCTYPE , “ar” ) OR LIMIT-TO (DOCTYPE, “re”)) AND (LIMIT-TO (PUBSTAGE, “final”)) AND (LIMIT-TO (SRCTYPE, “j”)) AND (LIMIT-TO (LANGUAGE, “English”)), resulting in 387 initial documents. The documents were then filtered based on publication type, language, topic relevance, and subject area. From the initial 387 documents, filtering was conducted based on relevance to the research topic. This process included reviewing titles and abstracts to ensure relevance to telerehabilitation and the use of virtual reality, followed by excluding articles that only marginally mentioned one of the terms without a health rehabilitation context. The articles were then focused on three main areas aligned with the needs of interdisciplinary analysis: Medicine (MEDI), Health Professions (HEAL), and Social Sciences (SOCI). This was done to enrich the scope from clinical, health professional, and social/ethical perspectives. The selection process resulted in 323 final documents used as the basis for bibliometric analysis.

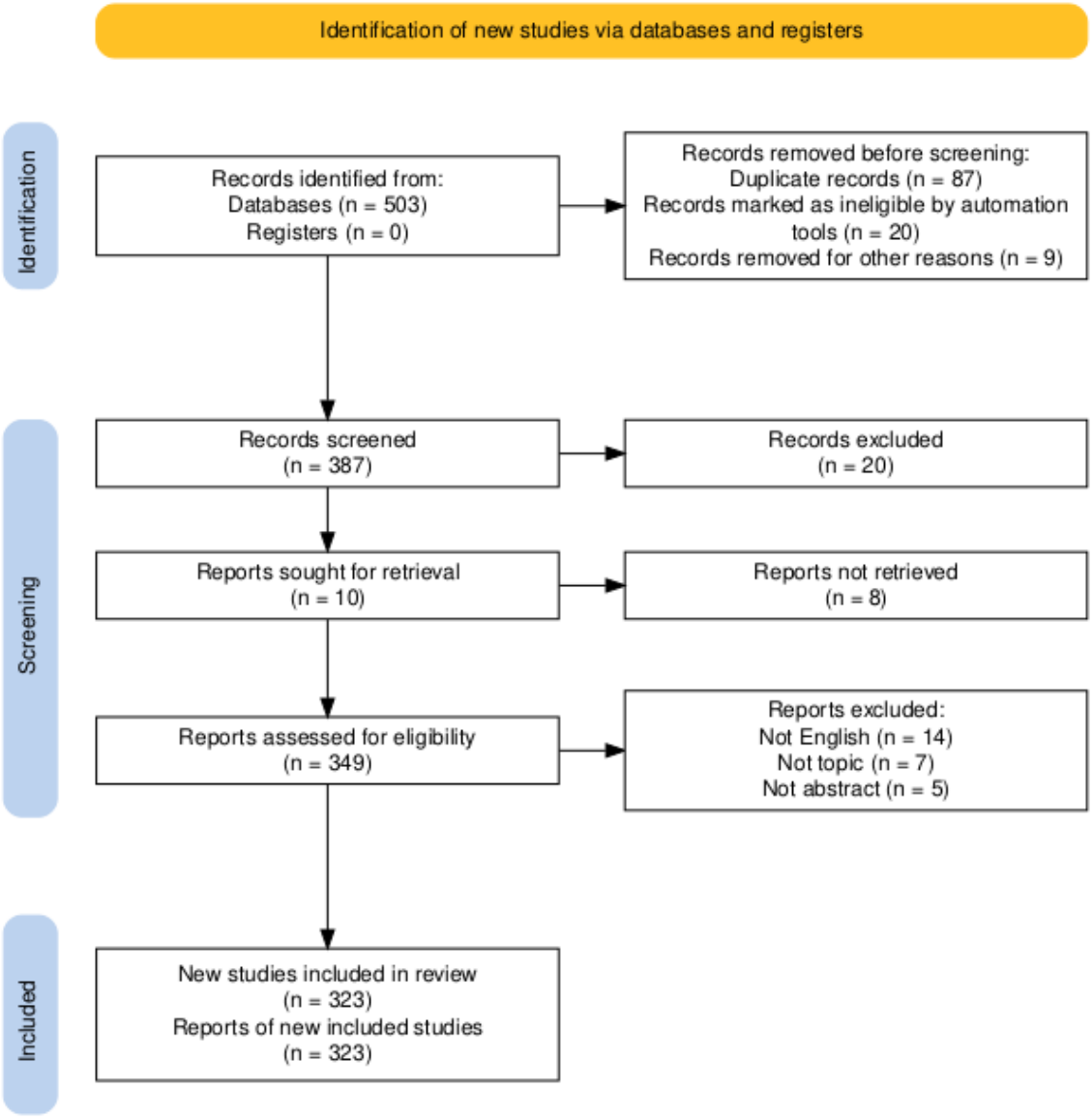


Figure 1. The PRISMA flow diagram is used to identify, screen, and include papers for our bibliometric review (2025)

All documents were exported in CSV format, including metadata such as author names, affiliations, keywords, abstracts, citation counts, and the journals where they were published. This data was then analyzed using VOSviewer software for visualization of collaboration networks and keyword mapping. The analysis process was conducted in two main stages: first, descriptive analysis to identify annual trends and geographical distribution; second, visual analysis using VOSviewer to map keyword co-existence relationships and identify thematic clusters. Additionally, to explore the bioethics dimension specifically, a manual search was conducted for terms such as "ethics," "bioethics," "consent," "privacy," and "justice" that appeared in keywords or abstracts. This study aims to capture the representation of ethical values in VR-based telerehabilitation literature while acknowledging that bibliometric methods have limitations in measuring the depth of ethical substance in each article (23–26) Therefore, further exploration can be conducted through a qualitative approach to documents that explicitly mention ethical or normative dimensions. Additionally, the use of the keywords “telerehabilitation” and “virtual reality” in TITLE-ABS-KEY may exclude articles that use synonyms or more technical terms. However, this decision was made to maintain the specificity and focus of the search.

**RESULTS**

This study analyzes the development of literature on the use of virtual reality (VR) in telerehabilitation through a bibliometric approach. This section presents the main findings, including annual publications over the past decade, the most impactful articles, demographic distribution, and visual analysis using VOSviewer to map keyword co-occurrence relationships and identify thematic clusters. As an initial step, Figure 1 shows the distribution of the number of scientific publications per year from 2014 to 2025. This data provides an initial overview of the dynamics of research productivity and critical phases in the adoption of VR technology for remote rehabilitation.

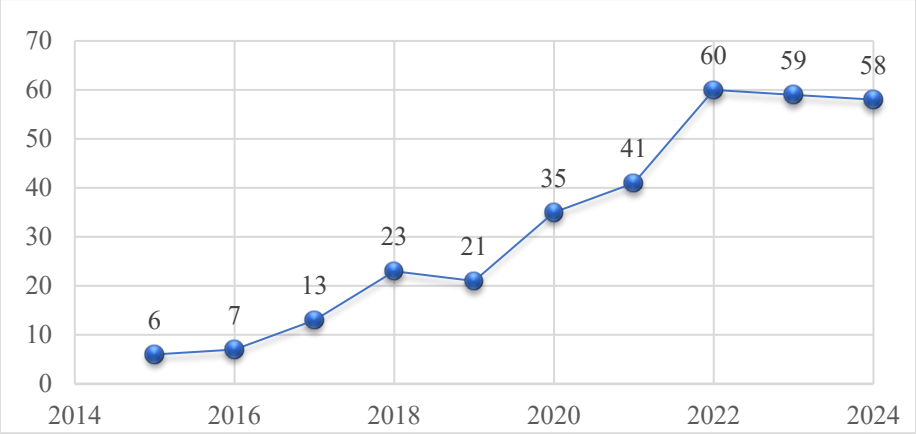

Figure 2. Publication by Year, (2015-2024)

The field of virtual reality (VR)-based telerehabilitation has shown dynamic research development over the past decade. In 2015, research in this field was just beginning to take shape, with only 6 publications. The following year (2016) saw a slight increase to 7 publications, followed by a significant surge in 2017 with 21 publications—an increase of over 200%, indicating a sudden surge in research interest. The period from 2018 to 2023 represents a phase of stable and consistent growth, with the number of publications increasing from 23 (2018) to 60 (2023). Annual growth ranged from 1.7% to 52.2%, with the greatest acceleration occurring between 2019 and 2021. The peak of research productivity was reached in 2023 with 60 publications, indicating the maturity of this research field.

However, 2024 saw a drastic decline of 78.3%, with only 13 publications. This sharp decline requires further investigation (27–30), with several possible causes, including (1) research saturation in the field of VR for telerehabilitation, (2) a shift in focus toward new technologies such as augmented reality or the metaverse, (3) changes in research funding priorities, or (4) delays in indexing the latest publication data (31–34). This development pattern provides important insights into the dynamics of research in the field of digital health, particularly in the application of immersive technology for remote rehabilitation. These findings also raise new questions about the factors influencing the lifecycle of a research field in health technology.

Table 1. Categorization of Research Focus (n = 323 articles)

| Main Theme | Focus | Findings | Number of Articles (Cluster) | Percentage (%) | Keywords | Citation Range in Articles |
|---|---|---|---|---|---|---|
| Clinical Effectiveness | Stroke rehabilitation, motor function, physiotherapy | The majority of studies show that VR-based telerehabilitation effectively improves motor function and clinical outcomes | 110 | 34% | stroke rehab, motor recovery, physiotherapy | (23,24,33,123–132,34–42,25,43–52,26,53–62,27,63–72,28,73–82,29,83–92,30,93–102,31,103–112,32,113–122) |

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|---|---|---|---|---|---|---|
| VR Technology & Innovation | Immersive VR, exergaming, AI integration | Focus on the development of VR systems, user interfaces, and integration of emerging technologies | 75 | 23% | virtual reality, immersive tech, serious games | (133,134,143–152,135,153–162,136,163–172,137,173–182,138,183–192,139,193–202,140,203–207,141,142) |
| Quality of Life & Patient Experience | QoL, patient satisfaction, engagement | VR enhances patient motivation, adherence, and overall experience | 48 | 15% | quality of life, patient satisfaction, engagement | (186–233) |
| Digital Health & Telemedicine | Telehealth, remote monitoring, IoT | Integration of VR into digital health systems and home-based care | 32 | 10% | telemedicine, remote care, digital health | (255,256,265–274,257,275–284,258,285,286,259–264) |
| Implementation Barriers & Challenges | Cost, usability, technology access | Key challenges include high costs, digital literacy, and infrastructure limitations | 26 | 8% | barriers, cost, usability, access | (287,288,297–306,289,307–312,290–296) |
| Adherence & Motivation | Treatment compliance, behavioral factors | Technology improves adherence but does not replace human interaction | 12 | 4% | adherence, motivation, compliance | (313,314,323,324,315–322) |
| Bioethics & Regulation | Data privacy, informed consent, equity of access | A minor theme, not yet well integrated into mainstream research | 10 | 3% | ethics, privacy, consent, justice | (325–334) |
| Medical Education & Training | VR for healthcare training | Use of VR in simulation and clinical education | 5 | 2% | medical education, simulation | (335–339) |
| Pandemic & COVID-19 Context | Healthcare access during pandemic | VR as a solution to limitations in physical healthcare services | 5 | 2% | pandemic, COVID-19, remote therapy | (340–344) |

The analysis of 323 articles shows a clear imbalance in VR-based telerehabilitation research, with strong dominance of clinical effectiveness (34%) and technological innovation (23%). While evidence confirms that VR improves motor function and rehabilitation outcomes, the focus remains largely technocentric and outcome-driven, with limited attention to real-world implementation and patient context. Emerging themes such as quality of life (15%) and digital health integration (10%) indicate a gradual shift toward patient-centered and remote care models, yet these remain secondary and fragmented.

A critical gap is evident in implementation barriers (8%), highlighting disparities between evidence and practice due to cost, infrastructure, and digital literacy limitations. Most notably, bioethical considerations (3%) are significantly underrepresented, revealing an ethical blind spot in the literature. This suggests that technological advancement is outpacing ethical and human-

centered integration, emphasizing the need for more balanced, inclusive, and context-aware future research.

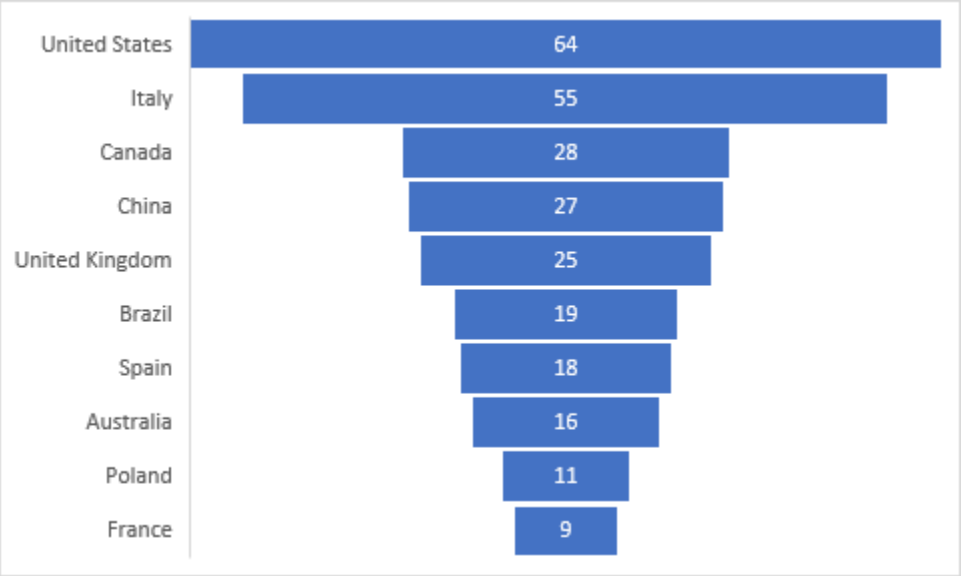


Figure 3. Academic Production by Country, from 2015-2024

The top 10 countries that have conducted the most research on telerehabilitation and virtual reality, the United States contributed 23.5% (64 publications), making it the leading contributor to virtual reality-based telerehabilitation research. Italy follows with 20.2% (55 publications), indicating that these two countries collectively account for nearly 44% of global publications. Contributions from other countries vary significantly, with Canada and China each contributing 28 (10.3%) and 27 (9.9%), respectively. The United Kingdom contributes 9.2% (25 publications). These countries play a crucial role in the development of scientific literature and the implementation of VR technology for remote healthcare services.

Interestingly, contributions from non-Western countries are also beginning to emerge, such as Brazil (19 publications), Spain (18), and Australia (16), each contributing around 6–7%. Although smaller, their presence indicates promising market potential and technological development in the Global South (158–161). On the other hand, countries like Poland and France each contributed 11 and 9 publications, respectively, or less than 4% of the total. This fact highlights the research gap between developed and developing countries while also opening opportunities for international collaboration to expand the distribution of VR knowledge and practices in telerehabilitation services.

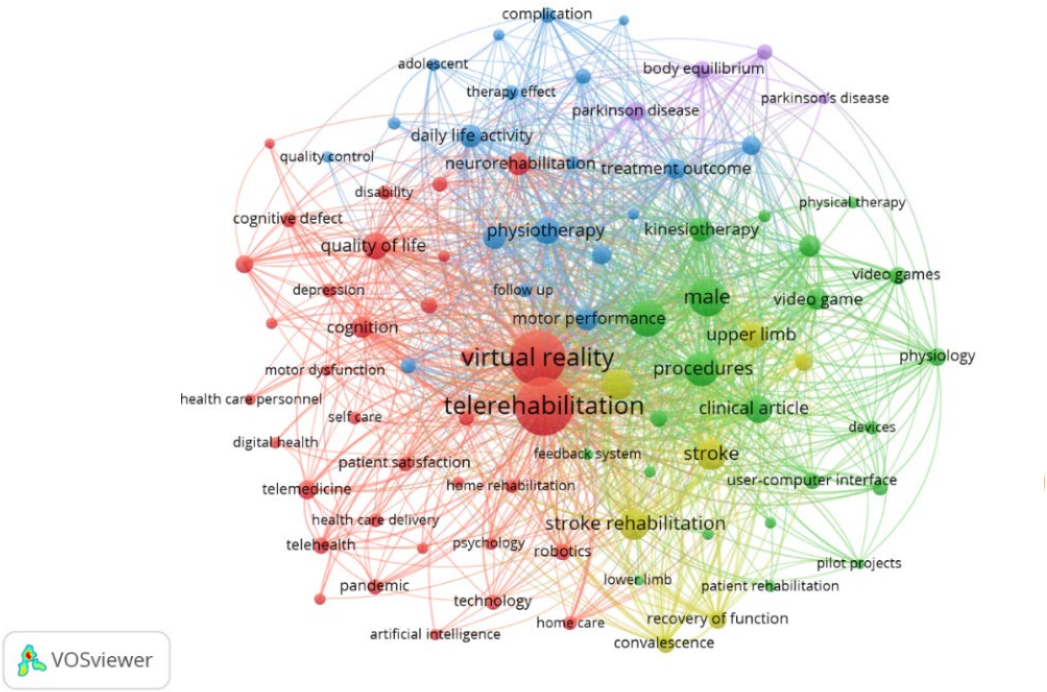


Figure 4. Telerehabilitation and Virtual Reality Research Trends, (2015-2024)

Figure 4 shows a visualization of the keyword co-occurrence network from literature related to VR-based telerehabilitation over the past decade (2015–2024), analyzed using the VOSviewer tool. Each color in this map represents interrelated thematic clusters, illustrating the main research focuses in this field. The larger the font size of a keyword, the more frequently that term appears in the analyzed literature. This finding reveals that “virtual reality” and “telerehabilitation” are the two most dominant keywords and serve as the central hubs of various cross-thematic connections. This underscores that VR and telerehabilitation are not only primary topics but also act as bridges for various therapeutic approaches, particularly in the fields of neurology and motor rehabilitation.

The red cluster shows a focus on patient aspects, quality of life, technology, and pandemic conditions, including the emergence of terms such as patient satisfaction, quality of life, digital health, and pandemic. This reflects how VR in telerehabilitation responds to patients' personal needs, especially during the COVID-19 pandemic. The dominance of this color also indicates that service personalization and patient perception are the center of attention in current literature. Meanwhile, the green cluster groups keywords such as stroke, upper limb, clinical article, procedures, and recovery of function, highlighting a major focus on post-stroke recovery, particularly functional rehabilitation of the upper limbs. This underscores the importance of VR as a therapeutic exercise medium in the context of neurological rehabilitation.

The blue and purple clusters indicate a more clinical and physiological approach, with the emergence of words such as daily life activity, therapy effect, Parkinson's disease, motor performance, and neurorehabilitation. The blue color on the outer part indicates that this theme was studied earlier (around 2014–2017), showing that the initial development of VR telerehabilitation was rooted in the therapeutic needs of neurodegenerative diseases such as Parkinson’s. The yellow cluster represents a new direction that has gained popularity in recent years, with terms like “video games,” “pilot project,” and “user interface.” This indicates a shift toward the use of interactive and game-based VR technology to enhance patient participation and support the development of prototypes and feasibility studies.

Interestingly, a number of keywords, such as AI, convalescence, and technology, are strategically positioned to connect several clusters, indicating that interdisciplinarity—including the integration of artificial intelligence and digital innovation—is beginning to play an important role in this literature (228–232) These findings collectively indicate that VR-based telerehabilitation research has undergone a thematic evolution from pure motor rehabilitation toward a more holistic, patient-centered approach. This encompasses functional, emotional, and technological aspects—suggesting

that future development of digital health policies and practices must comprehensively consider the interconnectedness of these themes.

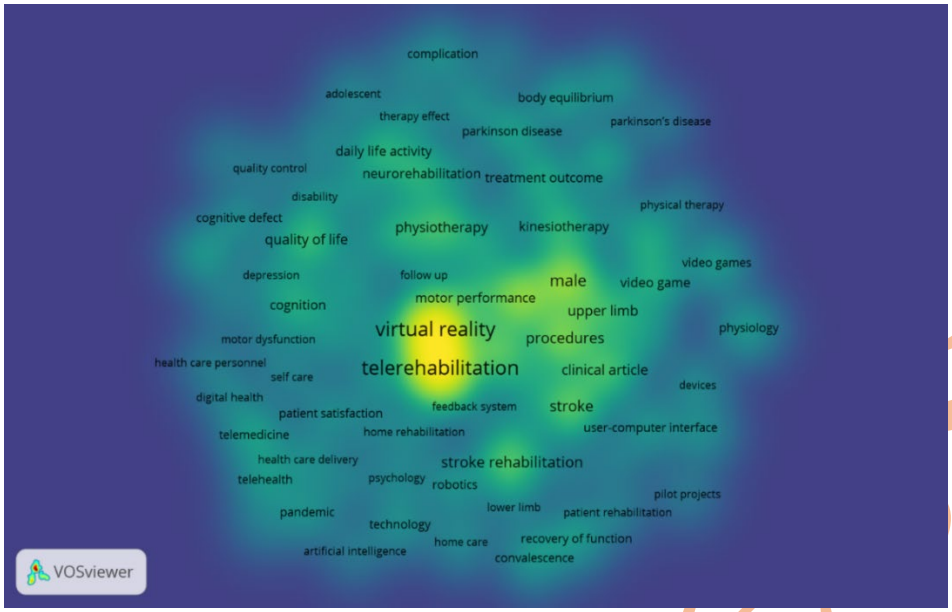

Figure 5. Conceptual Map of Bibliometric Analysis: Focus and Research Opportunities in Virtual Reality-Based Telerehabilitation

Based on the keyword visualization presented, it can be analyzed that topics such as "virtual reality procedures physiology," "neurorehabilitation treatment outcome," and "stroke rehabilitation" appear as the densest keywords (marked in dark yellow), indicating that these aspects have been extensively researched in the context of telerehabilitation. From a bioethical perspective, these findings raise questions regarding the impact of VR procedures on patient autonomy, particularly in terms of adequate informed consent for technology-based therapy. Additionally, the focus on treatment outcomes and physiology necessitates ethical considerations regarding equitable access, as VR technology may not yet be widely available. Meanwhile, keywords such as "quality of life," "patient satisfaction," and "self-care," which are also quite prominent, highlight the importance of the principles of beneficence and non-maleficence in ensuring that telerehabilitation interventions genuinely improve patient well-being without causing psychological or physical harm. On the other hand, keywords such as “digital health,” “telehealth,” and “home rehabilitation,” which are less prominent (light yellow), open up new research opportunities in bioethical reviews, particularly regarding patient data privacy, digital system security, and the challenges of implementing technology in home environments that may be less supervised (233–236). Thus, this study can fill a gap in the literature by comprehensively examining the ethical aspects of VR-based telerehabilitation, from patient rights to the responsibilities of healthcare providers in the digital age (237–240).

## DISCUSSION

### Virtual Reality-Based Telerehabilitation from a Bioethical Perspective

The integration of virtual reality (VR) into telerehabilitation practices has brought about a significant revolution in the field of digital health over the past decade (345). Based on a bibliometric analysis of 323 scientific publications from 2015 to 2024, it is clear that research in this field is still heavily dominated by studies on clinical effectiveness and technical aspects of implementation (346). Our findings indicate that terms such as “neuro-rehabilitation outcomes,” “therapeutic effectiveness,” and “cost efficiency” emerge as the most dominant keywords (Figure 5), while bioethical concepts such as “informed consent,” “data privacy,” and “equitable access” are scarcely discussed. This situation reflects a serious imbalance between technological advancements and ethical considerations in the development of VR-based telerehabilitation (347).

### The Dominance of Technocratic Approaches and the Neglect of Ethical Aspects

Keyword network mapping using VOSviewer (Figure 4) reveals a rather concerning pattern. The dense and interconnected research clusters are almost entirely focused on technical and clinical aspects, such as “upper extremity rehabilitation,” “motor performance,” and “post-stroke recovery.” Meanwhile, ethical issues emerge as isolated nodes that are not well integrated into the main research network. As highlighted by Gopal et al., (2019) in their bioethical principles, the four main pillars of medical ethics (autonomy, justice, beneficence, and non-maleficence) should serve as the foundation for any development of health technology (348). An analysis of the most frequently cited studies (Table 1) further reinforces this finding. For example, the study by Dobkin, (2017), which is the most influential article with 234 citations, although it successfully demonstrated the equivalence of VR effectiveness with conventional therapy, completely overlooked the aspect of patients' understanding of the technology being used (349). However, according to the theory of informed consent developed by Lindberg et al., (2024), a comprehensive understanding of the risks and benefits of a medical intervention is an absolute requirement for patient autonomy (350). A similar phenomenon is observed in the study Pot-Kolder et al., (2010), which focuses on cost savings but overlooks the evaluation of the psychological impact of long-term VR use (351). This is in line with the sharp criticism by Rubeis et al., (2022) in his book “Deep Medicine” about the tendency of “solutionism” in digital health, where technical solutions are often considered to be the answer to all problems without considering the ethical complexities that come with them (352). For example, VR systems that use machine learning algorithms to customize therapies automatically could potentially contain hidden biases against certain patient groups, as cautioned by Gianfrancesco et al., (2018) in their study on algorithmic bias in health prediction tools (353).

**Digital Divide and Global Injustice**

The geographical distribution of research output (Figure 3) shows a very strong dominance of developed countries, with the United States and Italy alone accounting for 44% of all publications. This reflects greater inequality in actual access to VR-based telerehabilitation technologies (343,344). According to some reports, around 74% of rehabilitation facilities in low- and middle-income countries do not yet have access to basic VR devices, let alone advanced systems such as those used in key studies (356,357). This problem is exacerbated by supporting infrastructure factors. As revealed by Bhuiyan, (2020) in their systematic review, even “low-cost” VR solutions still require stable internet connectivity and adequate supporting devices - requirements that are often difficult to fulfill in rural or remote areas (358). This creates what Shaban, (2025) calls a "second-order digital divide," where inequality exists not only in access to technology but also in the ability to utilize it optimally (359). The cultural aspect is also a serious challenge that is often overlooked. Most VR systems are designed with the cultural assumptions and digital literacy of Western society, as seen in the interface design of existing RIoT (Rehabilitation Internet of Things) systems (360). In fact, as reminded by Moor, (2005) in their cultural dimension theory, the effectiveness of a health intervention is strongly influenced by its compatibility with local cultural values (361). Brazil's experience with the Telehealth SUS program Naderbagi et al., (2024) shows that cultural adaptation to digital health technologies can significantly improve patient acceptance and adherence (362).

**The Dilemma of Humanism in the Era of Health Digitization**

Recent trends in VR telerehabilitation research, as seen from the emergence of the keyword clusters "patient satisfaction" and "video games" (Figure 4), point to efforts to make therapy more engaging and interactive. However, this approach carries the risk of reducing the supposedly holistic rehabilitation process to mere fragmented "technical solutions" (363). According to Lewkowicz et al., (2021), the importance of the human connection between patient and therapist in chronic back pain rehabilitation is a reminder that technology should not replace essential therapeutic interactions altogether (364). In the context of VR telerehabilitation, as expressed by Manseau, (2025), there is a great risk of dehumanizing healthcare when digital interfaces completely replace human interaction (365). In fact, as shown by the research of Drossman & Ruddy, (2020), the quality of communication between healthcare providers and patients contributes significantly to clinical outcomes (366).

Based on the above findings, we offer several strategic recommendations to address the gap between technological innovation and ethical considerations (367). First, it is necessary to develop an "ethics-by-design" framework in the development of VR systems for telerehabilitation. This concept, adapted from the privacy-by-design principle Spindler et al., (2020), emphasizes the need for the integration of ethical considerations from the early stages of technology design (368). For

example, VR systems should have specialized modules that ensure patient understanding before giving consent, using adaptive methods according to the user's digital literacy level (369). Second, a more inclusive financing model is needed to address the global gap. Cross-subsidization and differential pricing schemes based on the country's economic capabilities can be a solution (370). India's experience in developing a low-cost telemedicine system can be a reference for the development of more affordable VR (371). Third, it is important to develop a hybrid model that blends technological advantages with a humanistic touch; the optimal ratio might be 70% VR sessions balanced with 30% face-to-face interaction (either in person or via teleconference) to maintain the therapeutic relationship (372,373).

**CONCLUSION**

This research reveals that the development of virtual reality (VR)--based telerehabilitation in the past decade has been dominated by technical and clinical studies. At the same time, ethical aspects such as patient consent, fairness of access, and data privacy protection have not received adequate attention. This imbalance is evident from the dominance of research by developed countries, reflecting the global gap in the utilization of cutting-edge rehabilitation technologies. The main findings of the study point to three critical challenges: (1) the dominance of technocratic approaches that ignore ethical dimensions, (2) the digital divide between developed and developing countries, and (3) the risk of reducing humanism in rehabilitation practices. Overcoming these challenges requires an integrated approach that combines technological excellence with in-depth ethical considerations.

Key recommendations include the development of ethical frameworks from the technology design stage, hybrid models that maintain human interaction, and inclusive financing schemes to reach marginalized populations. In the future, research needs to focus more on patient experience, evaluation of technological bias, and development of regulations that protect user rights. Overall, the VR-based telerehabilitation revolution will only be meaningful when it is able to harmonize technological sophistication with fundamental human values. The integration of technical innovation and ethical wisdom is the key to realizing rehabilitation services that are not only effective but also fair and humane for all members of society. Integrating ethical wisdom into innovation is no longer an option but a necessity in ensuring inclusive and humane healthcare in the digital age.