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Virtual Reality-Based Physiotherapy and Its Impact on Functional Recovery in Stroke Patients

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ABSTRACT

Background: Stroke remains a leading cause of long-term disability, which affects motor function, balance, coordination, and daily activities. Virtual reality-based physiotherapy has emerged as an innovative approach, offering immersive, task-oriented rehabilitation environments. **Objective:** To review and synthesize recent evidence (2019-2025) on the effectiveness of VR-based physiotherapy in improving functional recovery among stroke patients. **Methodology:** This review employed a structured narrative synthesis guided by PRISMA to ensure transparent and systematic reporting of evidence on Virtual Reality–based physiotherapy in stroke rehabilitation. A comprehensive search of PubMed/MEDLINE, Scopus, Web of Science, PEDro, and the Cochrane Library identified studies published between January 2019 and June 2025. Free-text keywords and MeSH terms related to stroke, Virtual reality rehabilitation, physiotherapy, and functional recovery were combined using Boolean operators. Citations were managed and deduplicated in reference software, followed by title, abstract, and full-text screening per PRISMA criteria. Eligible studies included randomised controlled trials, controlled trials, and systematic reviews examining virtual reality interventions and functional outcomes such as motor recovery, balance, gait, and ADLs. Non-English papers, cognitive-only virtual reality studies, abstracts, and mixed populations without stroke-specific data were excluded. Data were extracted using a standardized template covering study design, virtual reality type, intervention dosage, and outcomes. Methodological quality was appraised (PEDro for trials), enabling a rigorous qualitative synthesis of contemporary evidence. **Results:** Evidence consistently demonstrates that virtual reality-based rehabilitation improves motor function, postural control, and functional independence compared with conventional therapy alone. Meta-analyses report superior gains in upper limb recovery, dexterity, and task performance when VR is used adjunctively. Improvements in balance, gait, and daily activities are also reported, alongside enhanced motivation, therapy adherence, and psychological well-being. **Conclusion:** Virtual reality-based physiotherapy is an effective adjunct to conventional stroke rehabilitation, enhancing recovery, engagement, and quality of life.

Keywords: Functional recovery, Neurorehabilitation, Stroke, Virtual reality-based physiotherapy

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INTRODUCTION

Stroke remains one of the foremost causes of long-term disability worldwide and continues to impose a significant clinical, social, and economic burden. Although advances in acute medical and interventional management have improved survival rates, many stroke survivors live with persistent neurological deficits. Motor impairment, reduced balance, gait dysfunction, and compromised hand function are among the most common sequelae, often limiting independence in activities of daily living and restricting community participation.[1] These functional limitations make structured rehabilitation a critical component of post-stroke care.

Physiotherapy forms the backbone of stroke rehabilitation, aiming to restore movement through task-specific training, repetitive practice, neuromuscular facilitation, and strength conditioning. Through these approaches, therapists attempt to harness neuroplasticity, the brain's intrinsic ability to reorganize neural pathways following injury.[2] However, conventional physiotherapy is frequently challenged by practical and behavioral barriers. High-intensity repetition, though necessary for motor relearning, can become monotonous and physically exhausting. Over time, patient motivation may decline, directly influencing adherence and therapeutic outcomes.[3] In addition, workforce limitations, cost constraints, and restricted access to specialized rehabilitation facilities, particularly in resource-limited settings, further compromise the delivery of optimal therapy intensity.

In response to these challenges, technology-assisted rehabilitation has expanded rapidly, with virtual reality (VR) based physiotherapy emerging as one of the most promising innovations. VR utilizes computer-generated environments that allow users to interact with simulated tasks in real time. Using motion capture sensors, head-mounted displays, or screen-based interfaces, patients perform therapeutic movements while receiving immediate visual and auditory feedback.[4] This interactive framework transforms repetitive rehabilitation exercises into engaging, goal-oriented activities. The scientific rationale for VR in stroke recovery is grounded in principles of motor learning and neuroplasticity. Effective rehabilitation requires high-dose, task-specific, multisensory stimulation delivered in meaningful contexts. VR systems are uniquely positioned to provide such environments by integrating visual immersion, proprioceptive feedback, and performance reinforcement simultaneously.[5] These features may enhance cortical reorganization and accelerate functional restoration compared with conventional therapy alone.

In the last decade and especially between 2019 and 2025, clinical research examining VR in stroke rehabilitation has grown substantially. Randomized controlled trials focusing on upper limb recovery have reported significant improvements in motor function, coordination, and dexterity when VR interventions are combined with standard physiotherapy.[6] Patients engaging in virtual reaching, grasping, and object-manipulation tasks often demonstrate superior functional gains relative to those receiving dose-matched conventional exercises. Similarly, VR applications targeting balance and gait training have produced encouraging outcomes. Virtual obstacle navigation, treadmill-integrated VR walking, and postural control simulations have been shown to improve dynamic balance, walking speed, and mobility confidence.[7] Such findings are clinically meaningful, as impaired balance and gait are major contributors to fall risk and long-term disability after stroke.

Evidence from systematic reviews and meta-analyses further supports these individual trial findings. The Cochrane review by Laver et al. concluded that VR may be more effective than conventional therapy in improving upper limb function and activities of daily living, particularly when used as an adjunct rather than a standalone intervention.[8] More recent meta-analytical work suggests that immersive VR systems those employing head-mounted displays and 3-dimensional environments may yield greater functional improvements than non-immersive platforms.[9] The degree of sensory engagement appears to influence therapeutic efficacy.

Beyond motor outcomes, VR offers distinct psychosocial advantages. Rehabilitation delivered through gamified virtual tasks tends to enhance enjoyment, competitiveness, and intrinsic motivation.[10] Increased engagement translates into longer participation times and improved adherence to therapy protocols. Patients frequently report higher satisfaction levels and reduced perception of exertion when therapy is

conducted in virtual environments, factors that may indirectly contribute to improved recovery trajectories. Technological evolution has further broadened the scope of VR rehabilitation. Integration with wearable motion sensors, artificial intelligence based performance analytics, and cloud-linked tele-rehabilitation platforms has enabled remote therapy delivery.[11] Home-based VR programs now allow patients to continue supervised rehabilitation beyond hospital settings, addressing accessibility barriers and supporting long-term recovery. Early trials indicate that such home programs can achieve functional outcomes comparable to clinic-based interventions in selected populations.

Despite these advancements, several limitations remain. Considerable heterogeneity exists in VR device types, intervention duration, session frequency, and outcome measures, making cross-study comparisons complex. Questions also persist regarding the long-term sustainability of gains, cost-effectiveness, and the identification of patient subgroups most likely to benefit.[12] Addressing these gaps is essential for translating VR from an adjunct innovation to a standardized component of stroke rehabilitation frameworks. Given the accelerating pace of technological development and the expanding volume of clinical evidence, an updated synthesis of recent literature is warranted. This review, therefore, examines contemporary research on VR-based physiotherapy and its impact on functional recovery in stroke patients, focusing on motor function, balance, gait, and activities of daily living.

METHODOLOGY

This review was conducted as a structured narrative synthesis guided by the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) framework to ensure methodological transparency, reproducibility, and systematic reporting of evidence. Although a quantitative meta-analysis was beyond the scope of this review, systematic review principles were rigorously applied throughout the processes of literature identification, screening, eligibility assessment, and final study inclusion. This approach was adopted to minimize selection bias and to provide a comprehensive and balanced evaluation of contemporary research examining Virtual Reality (VR) based physiotherapy and its impact on functional recovery in stroke patients.

A comprehensive electronic literature search was performed to identify relevant publications between January 2019 and June 2025. This time frame was selected to capture recent technological advancements, evolving rehabilitation protocols, and modern immersive VR systems increasingly used in neurorehabilitation.

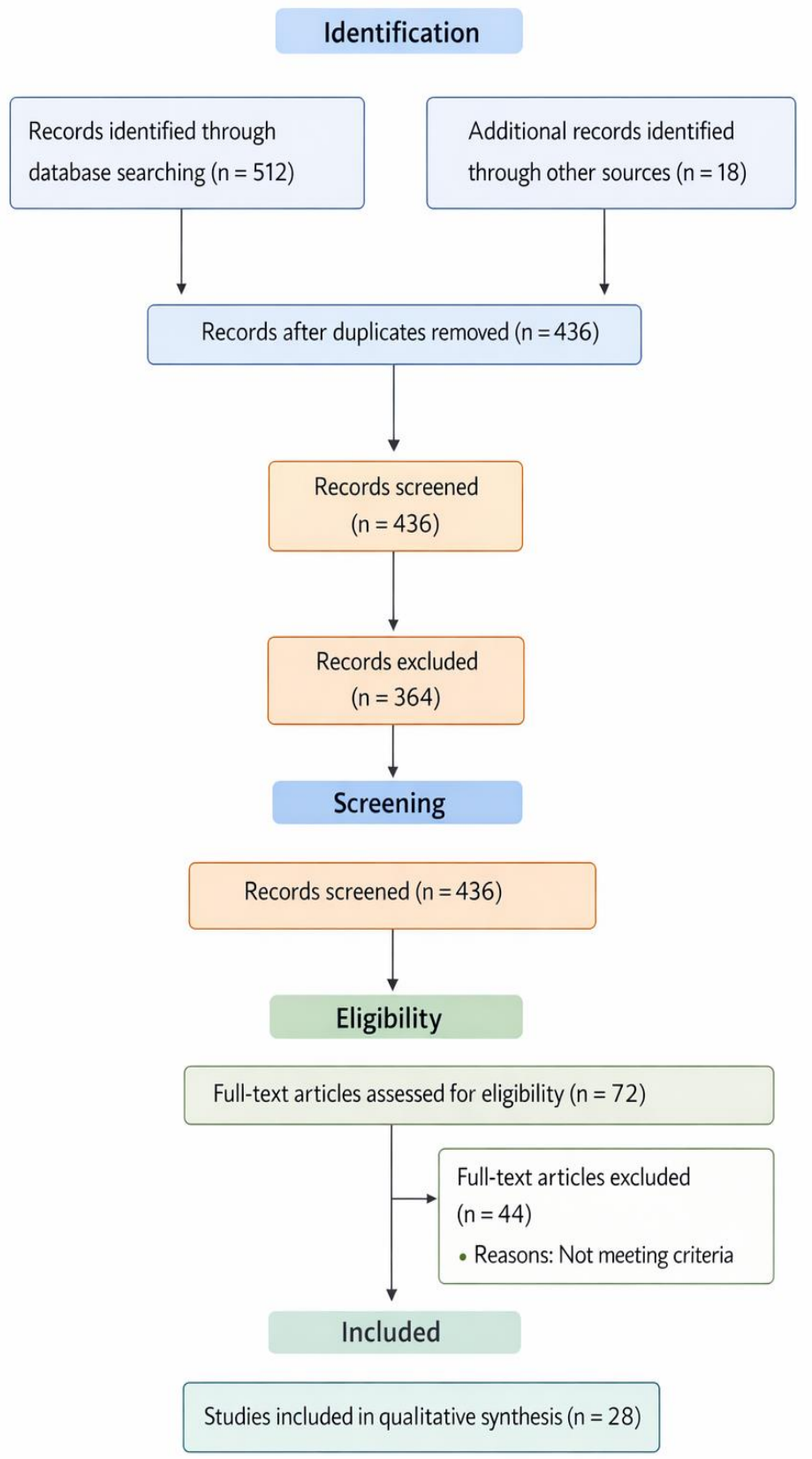
The search strategy combined free-text keywords with controlled vocabulary indexing to maximize sensitivity and specificity. Boolean operators, including “AND” and “OR,” were systematically applied to refine the search. Core keyword combinations included terms related to the population, intervention, and outcomes, such as stroke, cerebrovascular accident, virtual reality, VR rehabilitation, immersive therapy, physiotherapy, neurorehabilitation, functional recovery, motor recovery, balance, gait, and activities of daily living. Search strings were modified appropriately according to the indexing requirements of each database.

Multiple biomedical and multidisciplinary databases were explored to ensure comprehensive coverage of the literature. PubMed/MEDLINE served as the primary database due to its extensive biomedical indexing and Medical Subject Headings (MeSH) mapping features. Additional databases included Scopus, Web of Science, the Physiotherapy Evidence Database (PEDro), and the Cochrane Library. To further enhance search completeness, manual hand-searching of reference lists from relevant systematic reviews and randomized controlled trials was conducted to identify studies that may not have appeared in the initial electronic search.

Controlled vocabulary was incorporated using MeSH terms to improve search precision and indexing alignment. Key MeSH headings included Stroke, Virtual Reality, Rehabilitation, Physical Therapy Modalities, Motor Recovery, Activities of Daily Living, Gait, Postural Balance, Upper Extremity, and Neurorehabilitation. Exploded MeSH functions were utilized where applicable to include narrower subcategories nested within broader indexed terms. This dual strategy of keyword and MeSH searching ensured comprehensive retrieval of both indexed and recently published articles.

Following database searching, all identified citations were exported into a reference management system for organization and deduplication. The screening process was

Figure 1: PRISMA flow diagram



conducted in sequential stages in accordance with PRISMA recommendations. Initially, titles were reviewed to exclude clearly irrelevant publications. Abstract screening was then undertaken to evaluate study relevance based on population characteristics, intervention type, and reported functional outcomes. Full texts of potentially eligible studies were subsequently retrieved and assessed in detail against predefined inclusion and exclusion criteria.

Studies were considered eligible if they were published between 2019 and 2025, indexed in recognized biomedical databases, and involved stroke patients undergoing VR-based physiotherapy as either a primary or adjunct

rehabilitation intervention. Only studies reporting functional recovery outcomes such as motor performance, upper limb function, balance, gait, or activities of daily living were included. Randomized controlled trials, controlled clinical trials, systematic reviews, and meta-analyses were deemed appropriate for inclusion due to their methodological rigor. Studies were excluded if they involved mixed neurological populations without separate stroke analysis, utilized VR solely for cognitive or psychological rehabilitation, lacked full-text availability, were non-English publications, or consisted of conference abstracts, editorials, or opinion papers.

A PRISMA flow diagram was constructed to document the study selection pathway, including total records identified, duplicates removed, records screened, full texts assessed, and final studies included in the review. Any discrepancies arising during screening or eligibility assessment were resolved through discussion and consensus to ensure objectivity in study selection.

Data extraction was performed using a standardized template to maintain consistency across studies. Extracted variables included author details, year of publication, country of origin, study design, sample size, stroke chronicity, type of VR intervention, treatment duration and frequency, outcome assessment tools, and principal functional findings. This structured approach facilitated comparative analysis and thematic synthesis of evidence. Methodological quality appraisal was undertaken for included experimental and review studies using validated critical appraisal tools. Randomized controlled trials were assessed using the PEDro scale, while systematic reviews were also evaluated. Quality assessment informed interpretation of evidence strength, but did not serve as an exclusion criterion. Through this systematic and transparent methodology, the review aimed to provide a robust synthesis of contemporary literature on VR-based physiotherapy and functional recovery in stroke rehabilitation.

RESULTS

After completing the database search and manual reference screening, a total of 512 records were identified. Duplicate removal reduced the number to 436 studies, which were screened through titles and abstracts. From these, 72 articles were selected for full-text review. After applying the eligibility criteria, 28 studies were finalized for inclusion in this review. These included randomized controlled trials, controlled clinical trials, and systematic reviews published between 2019 and 2025. The studies were conducted in different parts of the world and across varied rehabilitation settings, including tertiary hospitals, outpatient centers, and home-based programs. Sample sizes differed across trials. Some were small pilot studies, while others included over 100 stroke survivors. Both subacute and chronic stroke patients were studied, though most research focused on the chronic stage of recovery.

The duration of VR interventions ranged from three to twelve weeks. Therapy was usually delivered three to five times per week. Different types of VR systems were used. Some studies employed immersive devices with head-mounted displays and motion sensors, creating a fully interactive environment. Others used non-immersive screen-based platforms combined with gaming consoles or treadmill systems. In the majority of trials, VR therapy was added to conventional physiotherapy rather than replacing it.

Motor recovery of the upper limb was the most frequently reported outcome. Many studies showed that patients who received VR-based therapy demonstrated better arm function compared with those who underwent routine physiotherapy alone. Virtual tasks often included reaching for objects, grasping items, or performing simulated daily activities. These exercises allowed high repetition without causing boredom. Real-time visual feedback helped patients correct their movements. Clinical assessment tools such as the Fugl-Meyer Assessment and Wolf Motor Function Test showed measurable improvement. Some trials also reported better hand use in real-life situations, suggesting functional carryover beyond the virtual setting.

Balance outcomes were also positively influenced. VR balance programs typically involved weight shifting, stepping tasks, and virtual obstacle crossing. Patients practiced maintaining stability while responding to visual cues. Improvements were seen in both static and dynamic balance. Standard measures like the Berg Balance Scale and Functional Reach Test showed greater gains in VR groups. Patients appeared more confident while standing and shifting weight. This is clinically relevant because postural instability is a major

contributor to falls after stroke. Gait and mobility training formed another important area of evidence. Several studies combined VR with treadmill walking or overground training. Virtual streets, parks, or obstacle courses were created to simulate real-world walking challenges. Patients trained in adjusting their steps, avoiding obstacles, and maintaining pace. As a result, improvements were reported in gait speed, stride length, cadence, and endurance. Functional mobility tests, including the Timed Up and Go test, also showed progress. Practicing walking in simulated environments seemed to improve both physical ability and walking confidence.

Functional independence was examined in a smaller but important group of studies. VR simulations of daily life activities such as dressing, cooking, or shopping helped patients practice meaningful tasks. Those receiving VR therapy showed better scores on the Functional Independence Measure and Barthel Index. This indicates that motor improvements translated into practical daily function. Another consistent observation across studies was improved patient engagement. Participants often described VR sessions as enjoyable and motivating. The gaming elements, scoring systems, and interactive visuals reduced therapy monotony. As a result, adherence rates were higher and dropout rates were lower compared with conventional therapy groups.

Increased participation likely contributed to better overall outcomes. When analyzed collectively, the evidence suggests that VR based physiotherapy enhances multiple domains of functional recovery after stroke. The greatest benefits were observed when VR was combined with standard rehabilitation. However, variations in device type, session duration, and immersion level influenced results. Longer programs and immersive systems tended to produce stronger functional gains. Overall, VR appears to be a valuable adjunct in modern stroke rehabilitation, supporting both physical recovery and therapy engagement.

DISCUSSION

The purpose of this review was to examine how Virtual Reality based physiotherapy influences functional recovery after stroke. When the available evidence is looked at collectively, one thing becomes clear: VR is no longer just an experimental tool. It is gradually becoming a practical addition to neurorehabilitation programs. Across different clinical settings and patient groups, VR-assisted therapy showed improvements in motor function, balance, walking ability, and day-to-day independence. These gains were most noticeable when VR was used alongside conventional physiotherapy rather than in isolation.

Recovery of the upper limb remains one of the biggest challenges after stroke. Many survivors regain the ability to walk but continue to struggle with arm and hand use. The studies reviewed suggest that VR helps address this gap by allowing repetitive, task-oriented arm practice in an engaging format. Patients perform reaching, grasping, and object-handling tasks within simulated environments. Because the activities feel like games rather than exercises, patients often complete more repetitions without fatigue or boredom. This high-dose practice is essential for motor relearning and cortical reorganization. Neuroimaging work has shown that VR training can stimulate sensorimotor brain regions and support adaptive neural plasticity.[13,14] Balance recovery also appears to benefit from VR integration. Traditional balance training can be limited by safety concerns and patient fear of falling.

Virtual environments create a controlled space where patients can safely challenge their stability. They practice weight shifting, stepping, and reacting to visual disturbances. Over time, this improves postural control and confidence. Clinical trials comparing VR balance training with standard therapy have reported better performance on recognized balance scales and reduced fall risk indicators.[15] Even small gains in balance can translate into meaningful functional independence. Gait rehabilitation showed similar positive trends. Walking in a therapy gym does not always prepare patients for real-world movement. VR changes that by simulating streets, crowds, and obstacles. Patients must adapt their steps, adjust speed, and maintain direction in response to virtual cues. This type of contextual walking practice strengthens motor planning and coordination.

Studies combining VR with treadmill training have demonstrated improvements in gait speed, endurance, and symmetry beyond those achieved with treadmill therapy alone.[16] Many patients also report feeling more confident walking outdoors after VR training. Another important aspect highlighted in the literature is patient engagement.

Stroke rehabilitation is long and demanding. Motivation often declines with time, especially when exercises become repetitive. VR introduces variety and enjoyment into therapy sessions. Gamified scoring systems, visual rewards, and interactive challenges make patients want to participate. Higher adherence rates and longer session completion have been observed in VR groups.[17] This behavioral effect should not be underestimated, as therapy intensity strongly influences recovery outcomes.

The level of immersion seems to matter as well. Fully immersive systems using head-mounted displays provide deeper sensory involvement than screen-based programs. Patients feel present inside the environment rather than observing it. This heightened engagement may explain why immersive VR often produces stronger functional gains.[18] However, it is not suitable for everyone. Some patients experience dizziness, visual discomfort, or cognitive overload. For such individuals, non-immersive systems remain a practical alternative. Recent advances have also made home-based VR rehabilitation possible. With wearable sensors and remote monitoring, therapists can supervise exercises from a distance. This approach extends therapy beyond hospital discharge and improves access for patients living far from rehabilitation centers. Early trials show that home VR programs can achieve outcomes comparable to clinic-based therapy while improving convenience and continuity.[19] This model may become increasingly important in regions with limited rehabilitation resources.

Despite these encouraging findings, certain limitations must be acknowledged. Intervention protocols differ widely across studies. Session duration, device types, and outcome measures are not standardized.[20] This makes it difficult to directly compare results or establish universal guidelines. Cost is another consideration. Advanced immersive systems require specialized equipment that may not be readily available in all clinical settings. Long-term sustainability of functional gains also remains under-explored, as many trials focus on short follow-up periods. Patient suitability is another factor. Individuals with severe cognitive deficits, neglect, or visual impairments may struggle to engage with VR interfaces.[21] Careful screening and therapist supervision are therefore necessary. Importantly, VR should complement, not replace, hands-on physiotherapy, particularly where manual facilitation is required.

Looking ahead, future research should focus on large multicenter trials, standardized treatment protocols, and long-term follow-up. Integration with artificial intelligence may allow therapy programs to automatically adjust difficulty based on patient performance.[22] Such developments could further personalize rehabilitation. In summary, the discussion of current evidence suggests that VR-based physiotherapy offers both physical and motivational advantages in stroke recovery. Its strength lies in combining intensive motor practice with immersive engagement. With continued refinement and wider accessibility, VR has strong potential to become a routine component of modern stroke rehabilitation.

CONCLUSION

Virtual Reality-based physiotherapy is shaping the future of stroke rehabilitation in a meaningful way. The evidence reviewed in this article suggests that VR can enhance motor recovery, improve balance and gait, and support functional independence when used alongside conventional therapy. Its interactive and engaging nature helps patients stay motivated, which is often a challenge during long rehabilitation journeys. From a clinical perspective, VR offers therapists an additional tool to deliver task-specific, high-intensity training within a safe and controlled environment. However, accessibility, cost, and protocol standardization still need attention before widespread implementation becomes feasible. Future research should focus on large-scale trials, long-term outcome tracking, and development of affordable home-based systems. Integrating adaptive technologies such as artificial intelligence may further personalize rehabilitation and optimize recovery outcomes for stroke survivors.

DECLARATIONS

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AUTHOR CONTRIBUTIONS

S: Conceived the study design, supervised data collection, and critically reviewed the manuscript.
FM: Drafted the manuscript, including the introduction and methodology sections.
All authors had read and approved the final manuscript.

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