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Scientific articles

Avances de sensores de movimiento para diagnóstico y seguimiento del Parkinson: revisión sistemática

Advances in motion sensors for diagnosis and monitoring Parkinson's: Systematic review

Avanços em sensores de movimento para diagnóstico e monitoramento do Parkinson: revisão sistemática

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Resumen

El Parkinson es una enfermedad neurodegenerativa que afecta a aproximadamente a cuatro o cinco millones de personas en el mundo. En México, el Instituto Nacional de Neurología y Neurocirugía reporta una incidencia anual de 50 nuevos casos por cada 100,000 habitantes. Se realizó una revisión sistemática en revistas científicas publicadas en los últimos cinco años, utilizando el método PRISMA para desarrollar un meta-análisis. El objetivo fue identificar avances en el uso de herramientas tecnológicas con sensores de registro de movimiento, empleadas para apoyar el diagnóstico clínico y el seguimiento de la enfermedad. Se analizaron 1,064 documentos obtenidos de bases de datos científicas: PubMed (645 artículos), Scopus (285 artículos) y Redalyc (134 artículos), todas enfocadas en áreas médicas, salud e ingeniería.

Los resultados subrayan la importancia de combinar evaluaciones clínicas tradicionales con tecnologías de monitoreo basadas en sensores de movimiento, las cuales han demostrado ser útiles en el diagnóstico y manejo de la enfermedad de Parkinson. Aunque estos avances tecnológicos ofrecen soluciones para el control y seguimiento de síntomas, la enfermedad permanece incurable. Sin embargo, las revisiones sistemáticas y los meta-análisis aportan evidencias valiosas que respaldan la toma de decisiones clínicas, optimizando los tratamientos y mejorando la calidad de vida de los pacientes. Este estudio enfatiza la necesidad de continuar investigando herramientas innovadoras que permitan un abordaje más eficaz de esta compleja enfermedad.

Palabras claves: enfermedad de Parkinson, evaluación clínica, evaluación por sensores, dispositivos móviles.

Abstract

Parkinson's is a neurodegenerative disease that is estimated to approximately four to five million people worldwide. In Mexico, the National Institute of Neurology and Neurosurgery estimates 50 new cases per 100 thousand inhabitants per year. Due to its epidemiological importance, the present study used a systematic review of scientific journals published in the last five years, and with the data obtained, a meta-analysis was elaborated under the PRISMA Method, achieving the objective, which was the estimation of the advances published with the use of technological tools that use movement recording sensors to support clinical diagnosis and follow-up of Parkinson's disease. The material consisted of scientific journals published in databases with medical and general orientation (PubMed, Scopus and Redalyc) on clinical evaluation and technological tools with sensors for recording body movement in Parkinson's disease. We analyzed 1,064 documents obtained from scientific databases were analyzed: PubMed (645 articles), Scopus (285 articles), and Redalyc (134 articles), all focused on medical, health, and engineering areas.

The results underscore the importance of combining traditional clinical assessments with motion sensor-based monitoring technologies, which have been shown to be useful in the diagnosis and management of Parkinson's disease. Although these technological advances offer solutions for controlling and monitoring symptoms, the disease remains incurable. However, systematic reviews and meta-analyses provide valuable evidence that supports clinical decision-making, optimizing treatments and improving patients' quality of life. This study emphasizes the need to continue researching innovative tools that allow a more effective approach to this complex disease.

Keywords: Parkinson's disease, clinical assessment, sensor evaluation, mobile devices.

Resumo

O Parkinson é uma doença neurodegenerativa que afeta aproximadamente quatro a cinco milhões de pessoas no mundo. No México, o Instituto Nacional de Neurologia e Neurocirurgia relata uma incidência anual de 50 novos casos por 100.000 habitantes. Foi realizada uma revisão sistemática em revistas científicas publicadas nos últimos cinco anos, utilizando o método PRISMA para desenvolver uma meta-análise. O objetivo foi identificar avanços no uso de ferramentas tecnológicas com sensores de registro de movimento, utilizadas para apoio ao diagnóstico clínico e monitoramento da doença. Foram analisados

1.064 documentos obtidos em bases de dados científicas: PubMed (645 artigos), Scopus (285 artigos) e Redalyc (134 artigos), todos voltados às áreas médica, saúde e engenharia.

Os resultados sublinham a importância de combinar avaliações clínicas tradicionais com tecnologias de monitorização baseadas em sensores de movimento, que têm demonstrado ser úteis no diagnóstico e tratamento da doença de Parkinson. Embora estes avanços tecnológicos ofereçam soluções para controlar e monitorizar os sintomas, a doença continua incurável. No entanto, revisões sistemáticas e meta-análises fornecem evidências valiosas que apoiam a tomada de decisões clínicas, otimizando tratamentos e melhorando a qualidade de vida dos pacientes. Este estudo enfatiza a necessidade de continuar a pesquisar ferramentas inovadoras que permitam uma abordagem mais eficaz a esta doença complexa.

Palavras-chave: doença de Parkinson, avaliação clínica, avaliação de sensores, dispositivos móveis.

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Introduction

Parkinson's is a neurodegenerative disease that ranks second in prevalence after Alzheimer's. Worldwide, the epidemiology of Parkinson's is estimated to affect approximately four to five million people. It occurs in around 0.3% of the population over 40 years of age and in approximately 1.3% of people over 60 years of age. In Mexico, there are no exact figures on its prevalence, although the National Institute of Neurology and Neurosurgery estimates the existence of 50 new cases per 100,000 inhabitants per year. Its origin is unknown; however, the concurrence of factors such as environmental pollution, low level of protein nutrients, sedentary lifestyle, and genetic factors has been identified, which represent around 7% of cases (Salom and Látinez, 2023).

The high prevalence of Parkinson's disease both worldwide and in Mexico was discussed in the previous paragraph, which underlines the need for epidemiological attention. The contribution of this study is to conduct a systematic review and meta-analysis to learn about the latest advances in diagnosis and monitoring of successful treatments. The information reported in scientific documents attests to the decrease in symptoms, the reduction of side effects, or the stabilization of the disease, considering that Parkinson's is a chronic and degenerative disease. It is also important to take into account the considerable physical, emotional, and economic impacts that this disease causes both to the patients and to their families, support systems, and institutions that care for them (Martínez-Fernández *et al.,* 2016).

The systematic review and meta-analysis carried out in the present research used the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) method, focusing on the diagnosis and monitoring of Parkinson's disease in the last five years. The PRISMA method is used to collect and synthesize the findings of the most recent and significant scientific studies, providing the necessary advances for the control of the disease, as reported in scientific documents (Page *et al.,* 2021).

Parkinson's disease currently has two diagnostic and monitoring methods; the main and most used is the clinical one because it evaluates physical, emotional, and social symptoms and signs, and the other is complementary to the first; it is widely used today, implemented by the use of various technological tools that help to give greater precision to the diagnosis and follow-up of treatments because they can achieve continuous monitoring with the programming of cards that record sensors and actuators by modules that can store various exact and continuous information on various symptoms or signs (Sica *et al.,* 2021).

General background

The first published reports of Parkinson's disease are presented in "Essays on the sharing palsy" published by James Parkinson in 1817, where the disease is formally described, although there are records of the disease in ancient cultures. The oldest are reported from the 1500-1200 BC centuries in Egyptian culture; for the year 1000 BC in India and for 800 BC in traditional Chinese medicine with traditional treatments (Nei-Jing) describing Parkinson's disease as head and hand tremors. In Europe, much later, Galen of Pergamon made more detailed studies and reports on the disease (Domingo, 2015).

Unfortunately, for several centuries there were no exact records of Parkinson's disease, and it was not until the 17th century that the term tremor was used to describe it by Nicolas Tulp, although it was also mentioned by figures such as Leonardo Da Vinci, Rembrandt, or Shakespeare and doctors such as Baptiste Sagar, John Hunter, or Boissier de Sauvages. By 1817 Parkinson presented more detailed data on diagnoses and their treatments; that is why it was given his name. Parkinson describes the motor symptoms of the extremities and their evolution, detailing sleep disturbances, sphincters, constipation, and sialorrhea. In the last 40 years, a higher interest in the treatment of Parkinson's disease has arisen, which has allowed the development of rational and effective treatments for the control of motor symptoms (Rosler and Young, 2011).

Physiological background of the disease

Parkinson's disease is a chronic neurodegenerative disorder caused by the destruction of 'dopaminergic' neurons, which are located in a region of the brain called the 'basal ganglia', specifically in a part of the brain stem called the 'substantia nigra'. These neurons act in the central nervous system and are used as the primary neurotransmitter of dopamine, a substance responsible for transmitting the information necessary for the correct control of movements. Without adequate levels of dopamine, tremor, rigidity, slowness of movement, and postural instability appear, among other symptoms. Parkinson's disease therefore affects those areas responsible for coordinating activity, muscle tone, and movements. Over time, it causes a progressive impairment not only of motor skills, but also, in some cases, of cognitive and autonomous function and the expression of emotions (Domingo, 2015; Martínez-Fernández *et al.,* 2016).

Initially, the disease was diagnosed using phenomenological methods where the study design was descriptive, exploratory, or interpretive, depending on the symptoms expressed by the patient to detect the evolution of the disease and the effects of the treatments applied. The research questions were related to the progression of the disease. Classified into three stages: 1) Early stage or initial stage expressed by symptoms that may be subtle in upper limbs unilaterally showing mild tremor or rigidity. 2) Intermediate or measured stage where motor symptoms become more pronounced. Tremor, rigidity, and bradykinesia (slow movements) can affect both upper limbs. 3) Advanced stage manifests itself in motor symptoms mainly impacting the upper limbs. Muscle rigidity may be more intense, and bradykinesia can greatly hinder hand and finger movements, showing fine coordination problems and difficulties in gripping and manipulating objects (Martínez-Fernández *et al.,* 2016; Moreno *et al.,* 2019).

There are tools for clinical diagnosis; two of them are widely used today due to their accuracy in diagnosing and recording the progress of the disease, which are: 1) The Hoehn and Yahr Scale, developed by doctors Hoehn and Yahr (1967) and referred to by (Clerici *et al.,* 2019) that classifies and measures the stages of Parkinson's disease based on the progression of motor symptoms, being considered the most commonly used scales in the clinical evaluation of Parkinson's disease, because it has a level of reliability between observers (ICC = 0.98), intra-observer (ICC = 0.98), and internal reliability (Cronbach's alpha = 0.96), and 2). As the Unified Parkinson's Disease Rating Scale in English is known as Unified Parkinson's Disease Rating Scale (UPDRS), created by the Unified Parkinson's Disease Rating Scale Committee, being developed in 1980 and is referred to by Anagani and Oroszi (2022) being considered a more complete and precise scale because it numerically evaluates three very important aspects of the evolution of the disease divided into: Part I evaluates the symptoms of mood, cognition, thinking ability, and behavior; Part II evaluates daily activities, such as dressing, eating, bathing, walking, and talking by the degree of disability, and dependency and; Part III evaluates motor symptoms, muscle rigidity, bradykinesia (slow movements), tremor, and posture, both at rest and during movement.

Background of electronic sensors

Inertial sensors, such as accelerometers and gyroscopes, are widely used to measure vibrations and movement in different parts of the body, including the upper limb. These sensors are small, portable, and can be integrated into monitoring devices that patients can wear throughout the day.

A study published by Sica *et al.* (2021) in the journal *PLoS One* described the development of a Parkinson’s disease assessment system based on an inertial sensor. The system used an accelerometer to measure vibrations in the hand and arm during different motor tasks. The collected data was processed and analyzed using specific algorithms to identify characteristics associated with Parkinson’s disease.

Another advance in this field is found in the use of programmable cards or microcontrollers for data processing and real-time analysis of the vibrations measured by the sensors. These devices are capable of acquiring data from the sensors and executing signal processing algorithms to extract relevant features. In addition, they allow wireless communication to transmit the data to a display unit or a medical device for synchronous or asynchronous analysis (Rodríguez-Molinero, 2022) .

In a study published by Tello and Concepción (2021) in the Journal of Systems and Informatics Research, a mobile app was used that controls the monitoring and detection of occurrences of Parkinson's tremor. The system was able to record and analyze upper limb vibrations in real time, providing objective information on muscle movement and stiffness.

These advances in sensors and programmable cards for recording upper limb vibrations in the diagnosis and monitoring of Parkinson's have the potential to improve early detection of the disease, monitoring of progression, and evaluating the efficacy of treatments. However, it is important to note that the clinical implementation of these devices is still under development, and further research is needed to validate their accuracy and utility in real clinical scenarios (Pérez-López *et al.,* 2022).

The development of the most precise and easy-to-use technological tools for doctors and patients has had greater evolution in 2021. This scientific advance is found in *the sensors and programmable cards for recording and measuring vibrations in the upper limbs,* which is where Parkinson's symptoms are most frequently expressed. However, it is important to keep in mind that scientific research is constantly advancing, so it is necessary to be at the forefront of recent developments (Rodríguez-Molinero *et al.,* 2022; Pérez-López *et al.,* 2022).

Research question

Which motion sensors have been registered in scientific journals over the past five years as a diagnostic and treatment aid for Parkinson's disease in patients between 40 and 80 years of age and of both genders?

Aim

The aim is to conduct a systematic investigation of the past five years of technological tools that use motion-recording sensors to support clinical diagnoses and monitoring of Parkinson's disease.

Specific objectives

1. To gather information from recent scientific journals on motion sensor technology tools applied to support clinical diagnosis and monitoring of Parkinson's disease.
2. Conduct a meta-analysis of the information collected on motion sensors used to support clinical diagnosis and monitoring of Parkinson's disease.

Materials and methods

A systematic review will be conducted through the use of the PRISMA method to collect and synthesize the findings of studies that address a clearly formulated question (Higgins *et al.,* 2019; Page *et al.,* 2021).

The systematic review was carried out in scientific articles from medical and general databases (*PubMed, Scopus, and Redalyc*) on the topic of clinical evaluation and technological tools with sensors for recording body movements in Parkinson's disease.

Participants diagnosed with Parkinson's disease between 40 and 80 years of age.

Material

A review of scientific journals from databases such as PubMed and Medline, Scopus and Redalyc was used (Table 1).

PubMed is a bibliographic and scientific database, and searches are carried out in English on medicine, being free and coming from the National Library of Medicine.

Scopus is a bibliographic and citation database published by Elsevier, a publishing house located in the Netherlands, specializing in scientific, technical, and medical subjects. It contains the ScienceDirect collection of electronic journals, some of which are free to consult.

Redalyc is a platform that contains data from scientific journals of the Network of Scientific Journals of Latin America and the Caribbean, Spain, and Portugal, managed by the Autonomous University of the State of Mexico. It contains various fields of knowledge (health sciences and engineering), the subject of our research, whose consultation is free. Its main objective is to promote the dissemination and visibility of research carried out in Latin America, the Caribbean, Spain and Portugal.

Criteria for the selection of scientific journals

Inclusion criteria

1- Study with participants between 40 and 80 years of both genders with Parkinson's disease.

2- Non-probabilistic clinical studies by diagnosis and randomized.

3- Longitudinal studies

4- Study published between 2017-2022.

5- Study using technological tools for motion sensors.

Exclusion criteria

1- Study not focused on Parkinson's disease.

2- The non-use of clinical assessment and technological tools of motion sensors to diagnose Parkinson's disease

Procedure

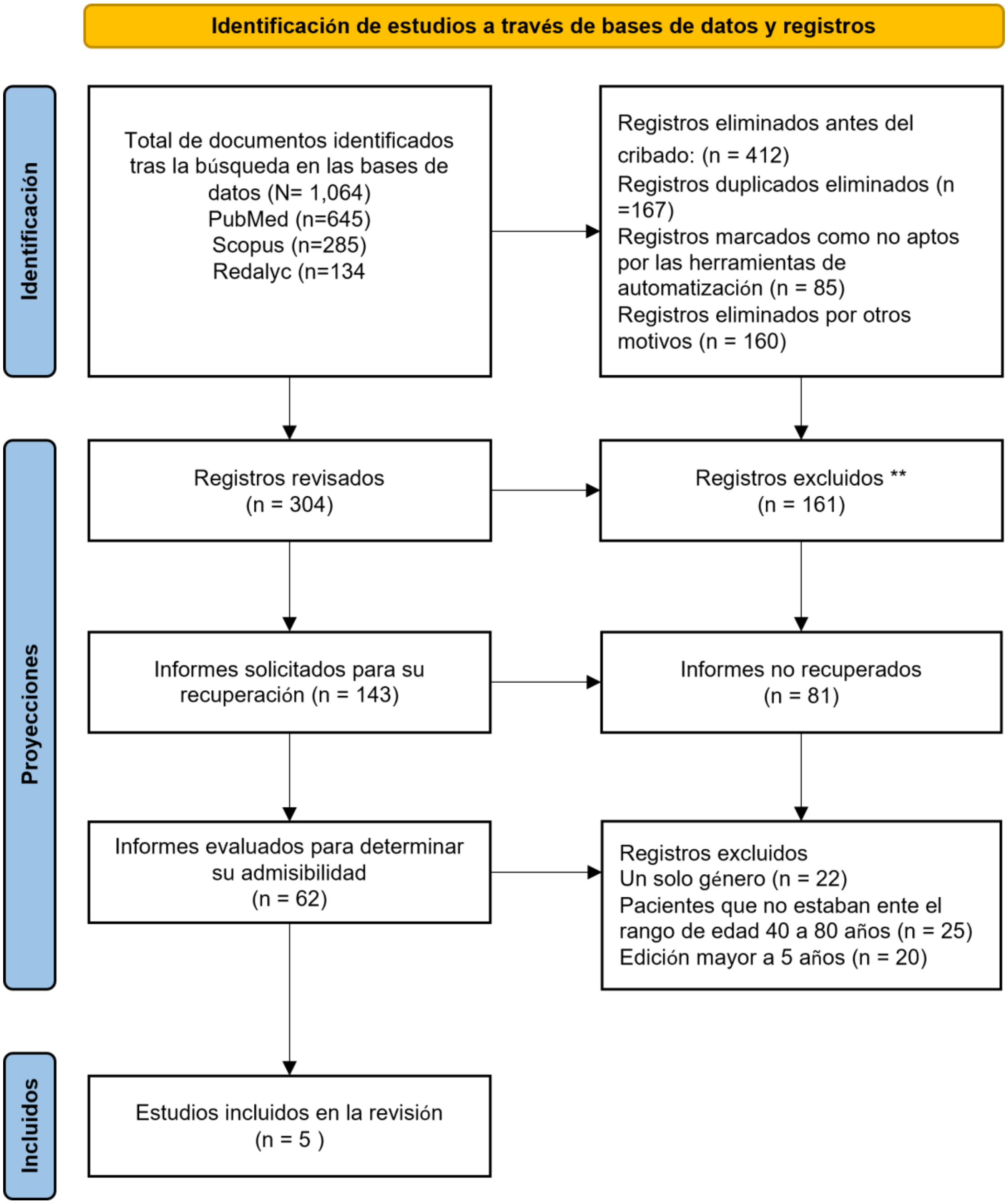
Table 1. Procedure for identifying studies

PubMed	The search was with keywords “Parkinson's disease” “diagnosis” “clinical evaluation” “Motion Evaluator Sensors”. Operators such as “AND”, “OR”, and “NOT” can be used. Only the “AND” operator was used, entries “Parkinson's disease AND diagnosis AND clinical evaluation AND body movement evaluator sensors
Scopus	The search was with keywords “Parkinson's disease” “diagnosis” “clinical evaluation” “Motion Evaluator Sensors”. Only the “AND” operator was used with entries “Parkinson's disease AND diagnosis AND clinical evaluation AND body movement evaluator sensors
Redalyc	The search terms “Parkinson’s disease”, “diagnosis”, “clinical assessment”, and “body movement assessment sensors” were used.

Source: Own elaboration

Results

Figure 1. Selection of studies with Prisma 2020 flowchart



Source: Prepared by the authors with information from the Page *et al.* format . (2021).

Table 2. Systematic review of wearable sensors and technologies to assist in the diagnosis and monitoring of treatment of Parkinson's disease

Topic 1		List of items	Reported YES/NO
Title and author	New Sensor and Wearable Technologies to Aid in the Diagnosis and Treatment Monitoring of Parkinson's Diseases (Monje *et al.*, 2019).		YEAH
Qualification	1	Identify the report as a systematic review.	NO
BACKGROUND			
Aim	2	Provide an explicit statement of the main objectives or research questions.	YEAH
METHOD			
Eligibility criteria	3	Specify the inclusion and exclusion criteria for participants.	YEAH
Resource Information	4	Specify the sources of information (databases and registries) used to identify the studies.	YEAH
Basic risks	5	Specify the methods used to evaluate the included studies.	YEAH
Summary of results	6	Specify the methods used to present and synthesize the results.	YEAH
RESULTS			
Studies included	7	State the total number of included studies and participants and summarise relevant study characteristics.	YEAH
Summary of results	8	Present the results main studies, preferably indicating the number of included studies and participants for each. If a meta-analysis was performed, report the summary estimate and confidence interval/credibility. If comparing groups, indicate the direction of the effect (i.e. which group is favoured).	YEAH
DISCUSSION			
Limitations of the evidence	9	Provide a brief summary of the limitations of the evidence included in the review (e.g. risk of study bias, inconsistency and imprecision).	YEAH
Interpretation	10	Provide a general interpretation of the results and important implications.	YEAH
OTHER			
Financing.	11	Please specify the primary source of funding for the review.	NO
Record	12	Please provide name and registration number.	YEAH

Source: Own elaboration based on the format of Page et al. (2020b). The PRISMA 2020 statement: an updated guideline for reporting systematic reviews.

Table 3. Monitoring bradykinesia in Parkinson's disease using a wrist accelerometer

Topic 4		List of items	Reported YES/NO
Title and author	Rapid Dynamic Naturalistic Monitoring of Bradykinesia in Parkinson's Disease Using a Wrist-Worn Accelerometer. (Habets *et al.*, 2021)		YEAH
Qualification	1	Identify the report as a systematic review.	NO
BACKGROUND			
Aim	2	Provide an explicit statement of the main objectives or research questions.	YEAH
METHOD			
Eligibility criteria	3	Specify the inclusion and exclusion criteria for participants and medical procedures and technological tools.	YEAH
Resource Information	4	Specify the sources of information, databases and registries used to identify the studies.	YEAH
Basic risks	5	Specify the methods used to evaluate procedures with included sensors.	YEAH
Summary of results	6	Specify the methods used to present and synthesize the results.	YEAH
RESULTS			
Studies included	7	Please state the total number of studies and participants included and summarise relevant characteristics of studies involving drugs or technology tools.	YEAH
Summary of results	8	Present the results main studies, preferably indicating the number of included studies and participants for each. If a meta-analysis was performed, report the summary estimate and confidence interval/credibility. If comparing groups, indicate the direction of the effect of the groups.	YEAH
DISCUSSION			
Limitations of the evidence	9	Provide a brief summary of the limitations of the evidence included in the review: risk of study bias, inconsistency by treatments.	YEAH
Interpretation	10	Provide a general interpretation of the results and important implications.	YEAH
OTHER			
Financing.	11	Please specify the main source of funding for the review.	YEAH
Record	12	Please provide name and registration number.	YEAH

Source: Prepared by the authors using information from the Page *et al* . (2021) format.

Table 4. Applied science in single wearable sensor for gait analysis in Parkinson's disease: a preliminary study.

Topic 5		List of items	Reported YES/NO
Title and author	Single Wearable Sensor for Gait Analysis in Parkinson's Disease: A Preliminary Study. Applied Sciences. (Pierleoni et al., 2022).		YEAH
Qualification	1	Identify the report as a systematic review.	NO
BACKGROUND			
Aim	2	Provide an explicit statement of the main objectives or research questions.	YEAH
METHOD			
Eligibility criteria	3	Specify participant inclusion and exclusion criteria and electronic registration methods.	YEAH
Resource Information	4	Specify the sources of information, databases and registries used to identify the studies.	YEAH
Basic risks	5	Specify the methods used to evaluate the included studies of medications and movements recorded in upper extremities.	YEAH
Summary of results	6	Specify the methods used to present and synthesize the results.	YEAH
RESULTS			
Studies included	7	State the total number of included studies and participants and summarise relevant study characteristics.	YEAH
Summary of results	8	Present the main results, preferably indicating the number of included studies and participants for each. If a meta-analysis was performed, report the summary estimate and confidence interval/credibility. If comparing groups and part of the Parkinson@Home study protocol	YEAH
DISCUSSION			
Limitations of the evidence	9	Provide a brief summary of the limitations of the evidence included in the review of electronic tools used and its project progress.	YEAH
Interpretation	10	Provide a general interpretation of the results and important implications.	YEAH
OTHER			
Financing.	11	Please specify the primary source of funding for the review.	YEAH
Record	12	Please provide name and registration number.	YEAH

Source: Prepared by the authors using information from the Page *et al* . (2021) format.

Table 5. Applied science in mobile with machine learning techniques in inertial sensor data for monitoring and identifying occurrences of Parkinson's tremor

Topic 4		List of items	Reported YES/NO
Title and author	A mobile application with machine learning techniques from inertial sensor data for monitoring and identifying occurrences of Parkinson's tremor (Tello and Concepción, 2021)		YEAH
Qualification	1	Identify the report as a systematic review.	NO
BACKGROUND			
Aim	2	Provide an explicit statement of the main objectives or research questions.	YEAH
METHOD			
Eligibility criteria	3	Specify the inclusion and exclusion criteria for participants.	YEAH
Resource Information	4	Please specify the sources of information, databases and records used in the mobile app that controls the monitoring and detection of Parkinson's tremor occurrences.	YEAH
Basic risks	5	Specify the methods used to evaluate the included studies.	YEAH
Summary of results	6	Specify the methods used to present and synthesize the results with app is based on the Ionic framework and uses linear regression techniques for early identification from inertial sensor data.	YEAH
RESULTS			
Studies included	7	Please indicate the total number of studies and participants included and summarize the relevant features of the mobile app.	YEAH
Summary of results	8	Present the main results, preferably indicating the number of included studies and participants for each. If a meta-analysis was performed, report the summary estimate and confidence/credibility interval.	YEAH
DISCUSSION			
Limitations of the evidence	9	Provide a brief summary of the limitations of the evidence included in the review with other technologies used.	YEAH
Interpretation	10	Provide a general interpretation of the results and important implications considering the variables, specifications, models, architecture, and use cases that enable the optimum.	YEAH

Source: Prepared by the authors using information from the Page *et al* . (2021) format.

Table 6. Meta -Analysis of Systematic Review of Wearables Use in Bradykinesia and Rigidity in Patients with Parkinson's Disease

Topic 5		List of items	Reported YES/NO
Title and author	Using wearables to assess bradykinesia and rigidity in patients with Parkinson's disease: a focused, narrative review of the literature. (Teshuva *et al.,* 2019)		YEAH
Qualification	1	Identify the report as a systematic review.	YEAH
BACKGROUND			
Aim	2	Provide an explicit statement of the main objectives or research questions.	YEAH
METHOD			
Eligibility criteria	3	Specify the inclusion and exclusion criteria for participants.	YEAH
Resource Information	4	Specify the sources of information (databases and registries) used to identify the studies.	YEAH
Basic risks	5	Specify the methods used to evaluate the included studies.	YEAH
Summary of results	6	Specify the methods used to present and synthesize the results.	YEAH
RESULTS			
Studies included	7	State the total number of included studies and participants and summarise relevant study characteristics.	YEAH
Summary of results	8	Present the results main studies, preferably indicating the number of included studies and participants for each. If a meta-analysis was performed, report the summary estimate and confidence interval/credibility. If comparing groups, indicate the direction of the effect (i.e. which group is favoured).	YEAH
DISCUSSION			
Limitations of the evidence	9	Provide a brief summary of the limitations of the evidence included in the review (e.g. risk of study bias, inconsistency and imprecision).	YEAH
Interpretation	10	Provide a general interpretation of the results and important implications.	YEAH
OTHER			
Financing.	11	Please specify the primary source of funding for the review.	YEAH
Record	12	Please provide name and registration number.	YEAH

Source: Prepared by the authors using information from the Page *et al* . (2021) format.

Discussion

Parkinson's is a chronic neurodegenerative disease, and its epidemiology is estimated to affect approximately four to five million people worldwide, and its origin is unknown (Salom and Látinez, 2023). Due to its importance, it requires scientific attention where recent findings can be analyzed with a systematic review and meta-analysis of the last five years to make known the diagnoses and follow-up of treatments (Lidstone *et al*., 2020).

The systematic review was conducted using the PRISMA research method to collect and synthesize the findings of scientific studies (Page *et al.,* 2021) on the electronic platforms of PubMed, Focus, and Redalyc. The search focused on diagnoses and follow-up of treatments for Parkinson's disease where clinical methods and technological tools were used for continuous monitoring of signs and/or symptoms of patients between 40 and 80 years of age of both genders (Sica *et al.,* 2021).

The total number of documents identified was 1,064, which were divided as follows: 1) PubMed (National Library of Medicine) with 645 scientific journals on the platform, which demonstrated greater reach due to its dedication to the medical field; 2) Scopus (Elsevier publishing house) with 285 scientific journals on the platform, specialized in medicine and electronic journals; and 3) Redalyc (based at the Autonomous University of the State of Mexico) with 134 scientific journals on the platform, extracted from the Latin American, Caribbean, Spanish, and Portuguese Network, specialized in health sciences and engineering. The first two platforms are in English, using only the "AND" operator with the entries "Parkinson's disease", "diagnosis", "clinical evaluation", and "body movement evaluator sensors". In the last platform, in Spanish, the entries used were "Parkinson's disease", "diagnosis", "clinical evaluation" and "sensors to evaluate body movements". The operators used were selected according to inclusion criteria, and other exclusion filters such as age, gender and age of publication were subsequently used. Finally, only five articles were included in the meta-analysis (Figure 1).

The meta-analysis included four articles in English and one in Spanish, which have several strengths, since all of them contain the variables to be evaluated and allow estimating the benefits of the association between the variables of the clinical diagnosis and the use of technological sensor tools that measure body movement constantly and accurately in Parkinson's disease (Page *et al.,* 2021). The five articles included present Parkinson's disease in different scenarios and under different treatment effects, providing diagnostic estimates and treatment monitoring in a precise and real way. It is very useful to have more precise markers for diagnosis and symptom monitoring (Di Biase *et al.,* 2022).

The topic under investigation also has its limitations, since there are care and research centers that carry out partial diagnoses and treatments without carrying out an exhaustive control of the disease, using only neurological scales. This is problematic, since Parkinson's disease is multifactorial, and apathy towards its measurement with neuropsychiatric scales, general clinics, and monitoring sensors limits the precision of diagnoses and treatments (Custodio *et al.,* 2018).

The first article, titled "New Sensor and Wearable Technologies to Aid in the Diagnosis and Treatment Monitoring of Parkinson's Disease" (Monje *et al.,* 2019), discusses the evolution and refinement of various electronic tools with motion sensors for the detection of Parkinson's disease symptoms. The article details the more sensitive monitoring of motor and non-motor characteristics, as well as the precise adjustments in medical treatments. Although clinical assessments are still more widely used due to their traditional nature to evaluate the diverse and progressive symptoms of Parkinson's disease, this characteristic of the disease prevents the standardization of sensors. However, new devices, especially inertial measurement units, are revolutionizing diagnosis and treatment monitoring. The validity and reliability of these new devices remain questioned, limiting the generalization of these technologies in clinical practice (Table 2).

The second article, titled "Rapid Dynamic Naturalistic Monitoring of Bradykinesia in Parkinson's Disease Using a Wrist-Worn Accelerometer" (Habets *et al.,* 2021), is part of the Parkinson@Home study protocol. This study uses a short-term wrist accelerometer to monitor naturalistic fluctuations of bradykinesia in 20 patients during their daily routines. The test was performed to detect which stage the patients were in (initial, intermediate, or advanced), since each of these manifests specific symptoms (Martínez-Fernández *et al.,* 2016; Moreno *et al.,* 2019). The patients were under treatment with medications for the control of bradykinesia, and three groups with different symptoms and treatments were compared. It was shown that bradykinesia can be classified using wrist accelerometry in just one minute. Rapid, naturalistic motor monitoring in Parkinson's disease has significant clinical potential to assess dynamic symptomatic and therapeutic fluctuations and to help tailor treatments on a rapid time scale (Table 3).

The third article, titled "Single Wearable Sensor for Gait Analysis in Parkinson's Disease: A Preliminary Study" (Pierleoni *et al.,* 2022), presents a continuous monitoring system based on a single wearable sensor placed on the lower back, coupled with an algorithm for the assessment of gait parameters. Laboratory and home scenarios were used to record and assess patients for 12 hours. The results showed good accuracy of the proposed algorithm, demonstrating a sensitivity of 99.13% and a specificity of 100%. Tracking different medications and patient activity requires adjustments of the algorithm; thus, it is considered a useful tool in both clinical and home settings for monitoring activities of daily living in subjects with Parkinson's disease (Table 4).

The fourth selected article, entitled "A mobile application using machine learning techniques from inertial sensor data for monitoring and identifying Parkinson's tremor occurrences" (Tello and Concepción, 2021), presents the development of a mobile app that controls the monitoring and detection of Parkinson's tremor occurrences. The hybrid application uses machine learning techniques and data from inertial sensors present in smartphones to record the patient's history regarding movement and stiffness, as well as the dosage of medications prescribed in the treatment. The app is based on the Ionic framework and uses linear regression techniques for the early identification of tremors from inertial sensor data, showing good results in movement monitoring and medication administration. This accurate history allows for proper Parkinson's follow-up (Table 5).

The fifth and final article, titled "Using wearables to assess bradykinesia and rigidity in patients with Parkinson's disease: a focused, narrative review of the literature" (Teshuva *et al.,* 2019), was selected for being a systematic review that includes articles published since 2000 and edited five years ago, showing advances in technological tools for the detection of movements through portable sensors of some symptoms, recorded separately. The current meta-analysis shows advances, since the sensors are increasingly specialized, and through computer cards located in a single device, various movements can be recorded spontaneously for synchronous diagnoses, or different types of movements can be stored for long periods. This allows precise monitoring of treatments with various medications. It is important to mention that the information reported by these technological tools is sensitive and accurate, but it has not been possible to standardize it because Parkinson's movements can vary widely because it is a multifactorial neurodegenerative disease. This reason makes neurologists always start from clinical diagnoses, and electronic devices are used as support in diagnoses, treatment monitoring, and individual prognoses (Table 6).

Conclusions

Diagnosis and treatment monitoring using clinical assessments and technological tools is becoming more and more precise. The diagnosis and prognosis of a chronic neurodegenerative disease such as Parkinson's is complex, as it is essential to analyze what stage it is in, stop the symptoms, stabilize the patient, and avoid episodes of crisis. Improvement or elimination of symptoms is achieved through adequate medication and continuous evaluation of all the patient's biopsychosocial spheres.

Monitoring and analysis of these areas can significantly benefit from technological tools, which record different patient activities and provide individualized databases. These data can be used by the treating physician to adjust treatment and improve disease prognosis. To date, there is no standardized technological tool for the complete recording of Parkinson's disease due to its multifactorial nature.

In this meta-analysis of scientific articles, we found the existence of specialized and precise technological tools that provide high-quality information for the diagnosis and treatment of Parkinson's disease in an efficient and timely manner. However, these tools are used on an individual basis, since neurologists treat patients with Parkinson's according to their specific conditions and clinical history.

Future Lines of Research

As is known, Parkinson's disease has different symptomatic motor manifestations that can be diagnosed and treated efficiently and effectively with clinical evaluations and with technological evaluations using motion recording sensors that are increasingly more specialized and precise. Future research will focus on refining the storage of technological evaluations from different motion sensors in a single portable, precise device that is easy to use and interpret by doctors so that it can be used on patients in different circumstances.

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