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Review Article

The Use of Bioimpedance in Renal Problems and Monitoring for Volume Analysis: A Literature Review

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Abstract *- Chronic Kidney Disease (CKD) constitutes a significant public health challenge due to its high prevalence and serious implications for patients' health. In this context, bioimpedance stands out as an emerging tool with great potential for early detection and continuous monitoring of CKD. Through a systematic review based on the Scopus database and following a methodology adapted from PRISMA, this analysis delves into the use of BIA to assess hydration status in individuals affected by CKD. The meticulous search resulted in the identification of 458 relevant publications, including 23 reviews, 22 conference papers, and 1 editorial letter, highlighting a predominance of observational studies (85%) compared to randomized controlled clinical trials (15%). This research highlights a notable increase in interest and research into bioimpedance and CKD, particularly evident since 2019. Bioimpedance is validated as well as a valuable tool for accurate assessment of hydration in CKD patients, calling attention to the imperative for further research to consolidate its utility in early detection and effective monitoring of this critical condition.*

Keywords *- Chronic Kidney Disease, Extracellular Resistance, PRISMA, Cellular bioimpedance model, Capacitance.*

1. Introduction

Chronic Kidney Disease (CKD) affects 13.4% (11.7-15.1%) of the world's population. An estimated 4.90 to 7.08 million patients require Renal Replacement Therapy (RRT) [1]. According to the International Society of Nephrology's 2021 Global Kidney Health Atlas, the average prevalence rate of CKD in Latin America was reported to be 9.9% (with a 95% confidence interval between 8.75% and 11.1%) [2]. The prevalence of CKD in Ecuador is estimated to be 11% for adults. There is a cardio-renal-metabolic connection, with type 2 diabetes mellitus (T2DM), heart failure and chronic kidney disease being the major pandemics of the 21st century. Taken individually, each of these three conditions is associated with relevant morbidity and mortality, but it is widely acknowledged that they often coincide: patients with HF have a four-fold higher prevalence of T2DM (20%) than patients without heart failure (4-6%), and T2DM is associated with a two- to four-fold higher risk of developing Cardiovascular Disease (CVD) [3]. Identifying and treating CKD in its early stages is imperative for equity. Implementing strategies for early detection, risk stratification, and treatment of CKD is key for the health system, and this should occur in primary or community care (PHC) [4].

A family history of kidney disease significantly increases the risk of developing CKD. Patients with CKD are at increased risk of cardiovascular complications, infections, and metabolic imbalances. Progression to end-stage renal disease requires costly interventions such as dialysis or kidney transplantation, which represents a considerable economic challenge for health systems, especially in low- and middle-income countries [5]. Body composition analysis through electrical bioimpedance (BIA) is a non-invasive technique widely used for the assessment of body composition and hydration status, which is crucial in nephrological practice. Bioimpedance (Z) is the opposition of biological cells and tissues to the passage of an alternating current. It is composed of two elements (vectors) whose units are in ohms: Resistance (R) and Reactance (Xc).

In the cellular Bioimpedance model, we can consider that there are three components of resistance to the passage of current: Extracellular Resistance (Re), Intracellular Resistance (Ri) and Cell Membrane Resistance (Rm), through which we can pass an electric current and have a certain metric. (Fornasari et al.). Electrical resistance is defined as the opposition to the flow of electric current through a conductor. In the case of the cellular model, it is the opposition of the extracellular and intracellular body mass and the biological membranes to the flow of the current; therefore, its metric determines the hydration state of the tissues.

In CKD, there is a tipping point below which the water balance is upset, and both the extracellular and intracellular compartments and the biological membranes enter a state of overhydration that does not necessarily cause edema. In this way, the electric current can pass through these imbalanced compartments and generate a measurement that gives us an idea of the magnitude of the problem.

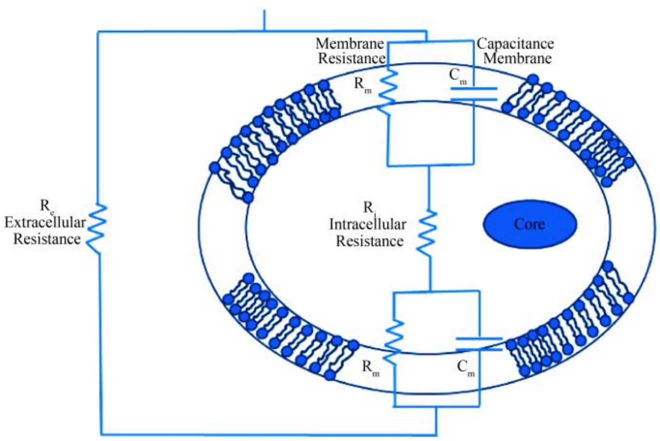

Fig. 1 Bioimpedance cellular model. Cellular components and their functioning determine an electrical circuit where the electrical resistance is given by 3 components: Extracellular Resistance (Re), Intracellular Resistance (Ri) and Cell Membrane Resistance (Rm)[9]

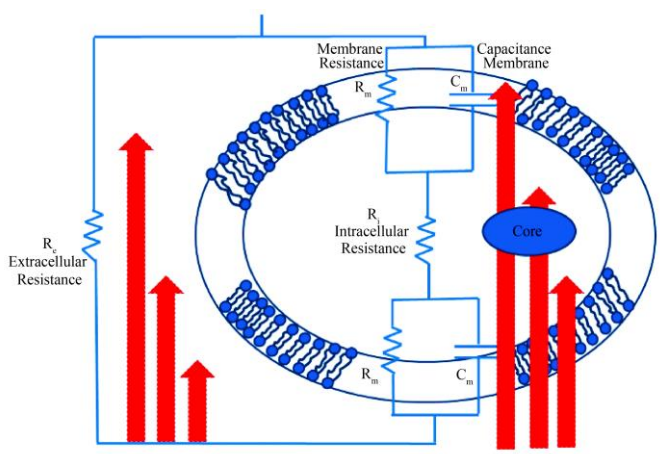

Fig. 2 Measurement of electrical resistance: by applying a low and high-frequency electrical current, we can obtain a metric of the extracellular and intracellular resistance, respectively [9].

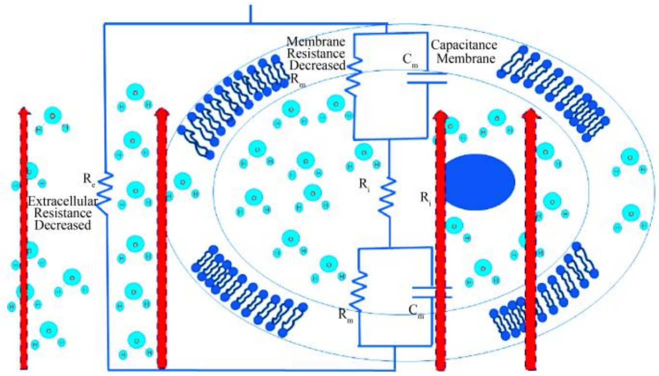

Fig. 3 Cellular Bioimpedance Model in Overhydration due to CKD: water is a good conductor, so when applying electric current, the cellular components will not offer resistance in the metric, and this will be low; in this way, the states of overhydration can be determined by electrical bioimpedance [9].

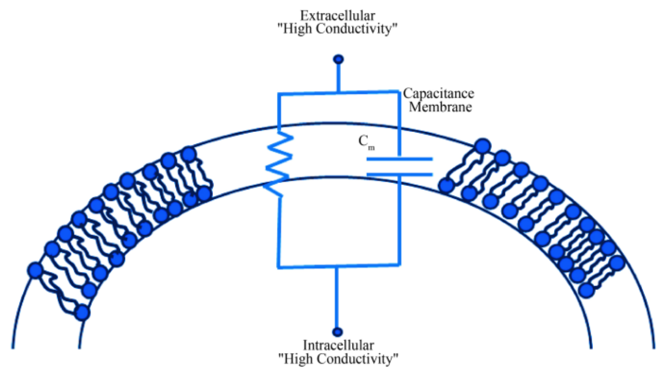

Fig. 4 Membrane capacitance (Cm). The electrical capacity of the cell membrane, which has low conductivity, is given by the difference in electrical potential between intracellular water and extracellular water.

Within the same model of cellular bioimpedance, we have a component of key importance, which is the capacitance of the membrane (Cm). Capacitance (or electrical capacity) is the property that bodies have to maintain an electrical charge and is a measure of the amount of electrical energy stored for a given electric potential difference. In the human body, capacitance occurs when regions of high conductivity (for example, intracellular water and extracellular water) are separated by those of low conductivity (for example, cell membranes).

In electronics, the most common device that stores energy by potential difference is the capacitor. Capacitors are composed of two conductors (plates) separated by an insulating material. That is why the electric circuit model can be applied to biological tissues or to the human body, where the capacitance of the membrane is similar to a capacitor. In this way, Ohm's law is followed, where a Voltage (V) is generated from the capacitor that passes through the compartments and the cell membrane, which offer resistance to the passage of current and finally an Intensity (I) of the passage of said current is determined, which can be measured.

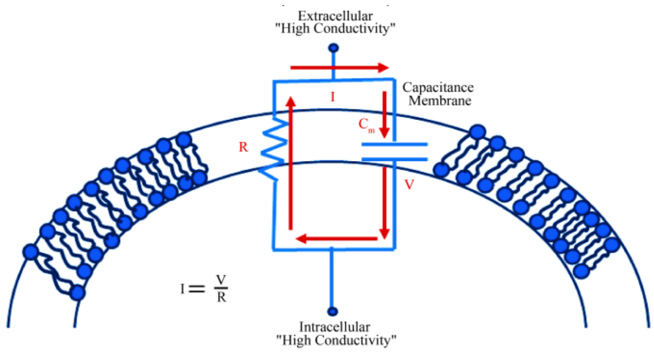

Fig. 5 Ohm's law applied to the cell membrane: the energy stored in the cell membrane generates a voltage (V), which attempts to overcome the electrical resistance (R) to generate a current intensity (I) and obtain a certain metric. In this way, an electrical circuit is obtained in the cellular bioimpedance model.

The third concept to consider is Capacitive Reactance (Xc), which is the additional opposition presented to the passage of alternating current and the inverse of capacitance. This reflects the permeability of cell membranes and is related to extracellular and intracellular water balance.

$$Xc = \frac{1}{2\pi f C}$$

If we use an electric current of 100 microamps as a marker, the ability to pass through the compartments will depend on the frequency of said current. At low frequencies, the resistance of the cell membrane is very high (low denominator value). Therefore, it is easier for the electric current to pass outside the cell and measure the extracellular. At higher frequencies, the cell membrane is permeable to the electric current.

In this way and taking into account the electrical components of the cellular circuit, the electrical bioimpedance is considered as the sum of the resistance and the reactance, which make up vectors that ultimately determine the Phase Angle (ɵ), which accurately marks the health prognosis of the human being.

$$Z = R + Xc$$

CKD is a clinical entity that causes loss of cell membrane integrity, leading to Compartmental Balance Disorder in CKD (CBD-CKD). In this situation, there is an abnormal passage of fluids and osmoles between the intracellular and extracellular compartments, which generates an imbalance in cellular function[12]. In CKD, there is a 20% increase in the measurement of plasma sodium (Nap) measured by Magnetic Resonance Imaging labeled with Sodium 23 (23Na-MRI), which is why, in the measurement by Bioimpedance Spectroscopic (BIS), the measurement of extracellular water (ECW) is overestimated by 1.2 and 2.4 L due to lower extracellular resistance, (Ref. in red below). Cellular edema, in edematous states, is the most common situation in CBD-E[13].

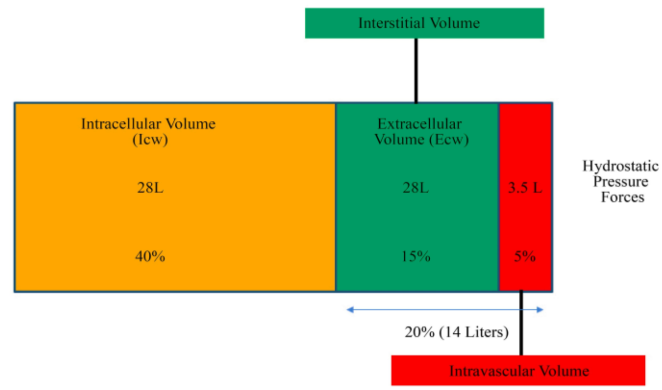

Fig. 6 Anatomy of body fluids and the importance of their compartment distribution in kidney diseases. In a 70 kg person, Total Body Water is approximately 60%, depending on sex and age.

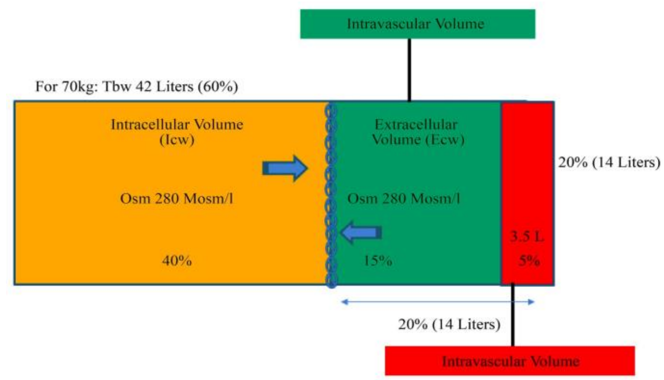

Fig. 7 Compartment Balance Disorder in CKD (CBD-CKD): The loss of cell membrane integrity generates an abnormal passage of fluids and osmoles from the intracellular to the extracellular compartment and vice versa. In this way, intracellular edema is present in edematous states.[13], [14]

In CKD, there is often a loss of capillary endothelial integrity, generating an imbalance between the interstitial and intravascular compartments. Cardiorenal syndrome in its different types, glomerulopathies, hyperfiltration states, vasculitis and autoimmune diseases are some of the causes of this imbalance[14].

It is important to highlight the clinical situations and environments that can lead to a Compartment Balance Disorder (CBD) and that are managed by the nephrologist. The first one is called Compartment Balance Disorder in Obesity (CBD-O), where the excess of Fat Mass (FM) generates a decrease in the Fat-Free Mass (FFM) and, therefore, affects the functioning of the aqueous compartment, muscle mass, tissues and bones. The second situation is the edematous states generated by water overload in intensive care units, which we will call Compartment Balance Disorder in Intensive Care Units (CBD-ICU), where the large water supply generates an increase in the aqueous compartment (intracellular, interstitial and intravascular) that leads to an abnormal increase in the Fat-Free Mass (FFM) and therefore to a dysfunction of the biological membranes [15].

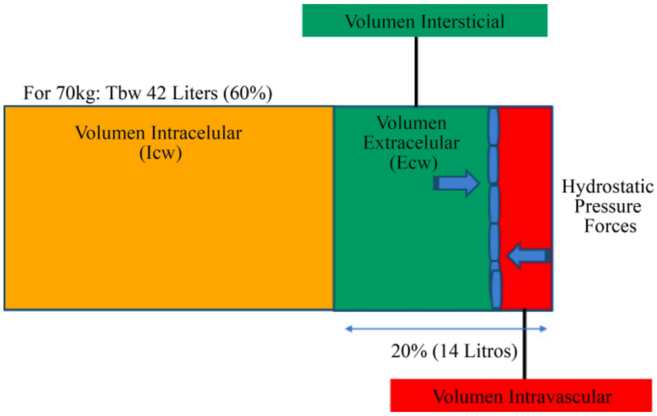

Fig. 8 Compartment Balance Disorder in CKD (CBD-CKD): The loss of capillary endothelial integrity generates an abnormal passage of fluids and osmoles from the intravascular volume to the interticial volume and vice versa. In this way, for example, there may be an increase in the volume of extracellular water with an increase in interticial volume but with depletion of intravascular volume, which occurs in cardiorenal syndrome.

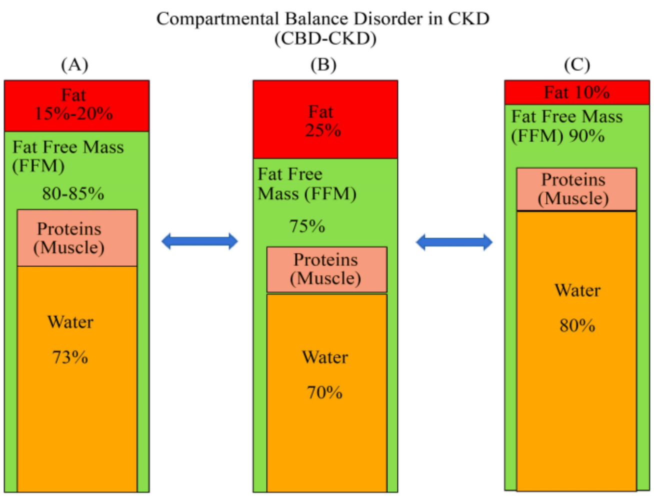

Fig. 9 Compartmental Balance Disorder in Intensive Care Unit (CBD-ICU) and Compartmental Balance Disorder in Obesity (CBD-O):

(A) Bicompartmental Model in Balance: Fat constitutes approximately 15 to 20% of body weight, and Fat-Free Mass (FFM) constitutes 80-85% of it. The aqueous compartment has a fixed value of 73% of FFM.

(B) Compartmental Balance Disorder in Intensive Care Unit (CBD-ICU): Excess water at 85%, for example, generates an increase in Fat-Free Mass, which generates an organic dysfunction in all its components: muscles, tissues and bones.

(C) Compartmental Balance Disorder in Obesity (CBD-O): The increase in Fat Mass (FM), for example, to 40% of body weight, generates an imbalance of such magnitude that it induces dysfunction of all the components of the MLG in addition to the already known inflammatory state.

All the situations mentioned above are subject to measurement by electrical bioimpedance, so it is important to know the physical principles and their validity in various clinical environments.

Among the clinical applications of BIA, we have

- Body Composition Assessment - BIA is used to determine lean mass, fat mass, and total body water. These measurements are vital in a variety of clinical applications, such as nutritional assessment, sports medicine, and chronic disease management [6].
- Hydration Status - BIA is particularly useful for assessing hydration status, a crucial factor in the management of patients with chronic kidney disease and on dialysis. The accuracy of BIA in assessing fluid volume allows for more precise adjustments in dialysis treatments [7].
- Monitoring Renal Patients - In nephrology, BIA is used to monitor patients with chronic kidney disease, allowing early detection of fluid imbalances and optimization of dialysis therapy. This is essential to prevent cardiovascular complications and improve the quality of life of patients [8].

The advantages of using BIA include that it is non-invasive, making it a safe and comfortable technique for patients; it is fast and easy to use, meaning the measurements are quick and can be performed in just a few minutes; and it is cost-effective because it is a relatively inexpensive technique compared to other methods of assessing body composition.

Among the limitations of this methodology is the precision of the BIA that can be affected by the patient's hydration status, body position and ambient temperature and the variability given because different BIA devices and methodologies can give variable results, which require standardization and calibration [9].

Electrical bioimpedance is a valuable tool in the assessment of body composition and hydration status, particularly in the field of nephrology. Its application in the management of patients with renal diseases provides crucial information for treatment and monitoring. However, it is essential to consider its limitations and use it in combination with other clinical assessments to obtain a complete picture of the patient's health status.

In this context, bioimpedance emerges as a promising and accessible tool to identify individuals at risk of developing CKD by offering a non-invasive and inexpensive assessment of body composition, including hydration and the presence of edema or dehydration, crucial aspects of this disease.

This study aims to address the use of bioimpedance in monitoring patients with kidney problems by conducting a bibliographic review of new scientific findings for the treatment and monitoring of chronic kidney diseases using bioimpedancemetry (BIA) techniques, using Scopus as a database. In this research, the review will focus on identifying studies that investigate the use of bioimpedancemeters to assess hydration in patients with chronic kidney disease and how these devices can contribute to their treatment.

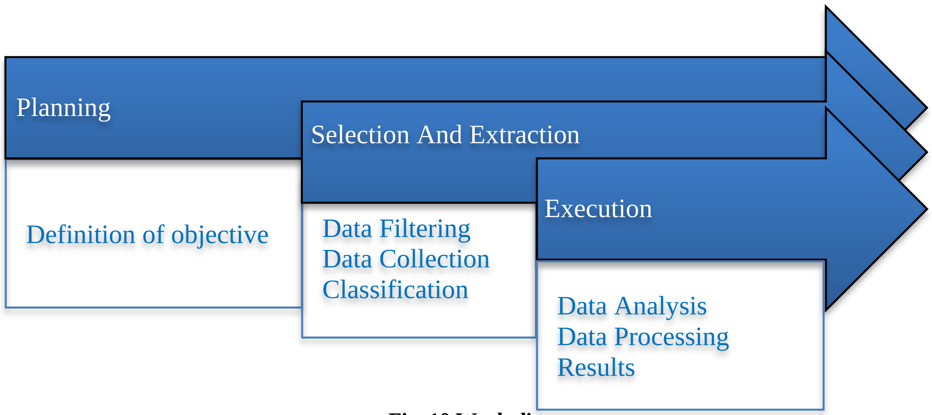

Fig. 10 Work diagram

This paper is structured as follows. Section II provides a detailed description of the methodology used to develop the systematic search. Section III then presents the results obtained, and finally, in Section IV, the results and conclusions of the project are discussed.

2. Materials and Methods

The analysis is based on the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) methodology, which aims to conduct a detailed review of algorithmic search models. This methodology, recognized for its rigor and clarity in the presentation of results, will allow a detailed and systematic collection of relevant information, thus ensuring the exhaustiveness and quality of the analysis carried out on the different algorithmic search models.

2.1. Flowchart

To facilitate understanding of the tasks assigned and the decisions made during the process, this research will use a sequential flowchart. This diagram, developed following PRISMA guidelines and our specific adaptation for systematic review, will offer a clear and orderly visual representation of each stage of the study. In this way, readers will be able to accurately follow the development of the research and intuitively understand the workflow and decisions made at each stage of the review process.

The structure of the research has followed the flow chart described in Figure 10. This begins by emphasizing the importance of defining a relevant and clear objective that allows concise outlining of the information selection process from the database through the use of keywords, which indicate the selection parameters for the best quality of the results obtained. The selection will be carried out in the Scopus interface, which performs the selection effectively through boolean logic.

2.2. Planning

In the Planning section, the information management process using Scopus's Boolean search capabilities is detailed. At this stage, data is filtered based on document type and year of publication and then organized into .CSV files for further analysis. This procedure converts raw data into a more accessible format, presenting it in tables and graphs. These visual representations are designed to highlight key features, such as novelty, number of citations, year of publication, and overall impact, facilitating a thorough evaluation of research findings. When searching for data in the Scopus database, it is crucial to focus on trends related to chronic kidney diseases, specifically using bioimpedancemetry (BIA). Importantly, this search should not be limited to a single discipline but should encompass diverse areas such as medical sciences, signal processing, and bioengineering, which will allow for a more complete and multifaceted understanding of the topic in question.

2.3. Selection and Extraction

The second section of the study will focus in detail on information processing, starting with the precise configuration of specialized Boolean searches in Scopus. This process will specifically aim to research chronic kidney diseases through the use of Bioimpedance Analysis (BIA) techniques. During this crucial phase, relevant information will be collected according to previously established filters. However, a rigorous manual selection of documents that meet the desired parameters will be necessary, discarding those that do not align with the main objectives of the project.

The documents selected at this stage will include a variety of types, all focused on chronic kidney diseases, presenting innovative solutions and advanced methods for their diagnosis. It should be noted that the search will not be restricted by language, allowing the inclusion of documents from different fields of study and disciplines as long as they offer solutions and diagnostic methods for chronic kidney diseases.

The time period considered for this analysis will span from 1989 to February 2024. During this interval, the volume of documents generated annually will be analyzed, in addition to examining key data such as the most cited authors, the countries with the greatest research activity in the field, the number of documents produced by country or territory, the publications attributed to each author, the scientific journals with the greatest number of publications on the subject, and the temporal distribution of said publications.

In the event that the results obtained in Scopus are not complete, the Boolean formula will be fine-tuned, modifying it to include or exclude criteria as necessary. In addition, in order not to omit relevant information, some research will be saved manually. As a final stage, the extraction and classification of the .CSV and .BIB files will be carried out, organizing them according to priority criteria, year of publication, journal, number of citations and other relevant data for later analysis.

2.4. Execution

Data processing for this research will be performed using Python through Anaconda, with a special focus on the use of VOSviewer for bibliometric analysis and data visualization. This strategy is based on leveraging advanced tools for analysis and graphical representation using the capabilities of Python and its specialized libraries.

VOSviewer will continue to be the primary tool for bibliometric visualization and analysis, allowing us to explore the complex interrelationships between research, authors and topics in areas such as chronic kidney disease. By analyzing data from bibliographic databases such as Scopus, VOSviewer facilitates the creation of co-authorship maps, co-citations and keywords, providing deep insight into the development and dynamics of the field of study.

Python will be used via Anaconda for data processing due to its ability to efficiently manage packages and virtual environments, which is essential for running data analysis scripts. Dask will be a valuable tool for manipulating large data sets, allowing parallel processing and handling data that does not fit in memory. For graph generation, Seaborn will be the recommended choice thanks to its high-level interface for creating attractive and informative statistical visualizations, facilitating the creation of complex graphical representations with less code.

The combination of VOSviewer for bibliometric analysis, together with Python capabilities using libraries such as Dask and Seaborn, executed through Anaconda, will allow for a detailed exploration of the SCOPUS database. This efficient approach will facilitate the selection and extraction of relevant information, improving the analysis of scientific production, authors and journals within the selected period. The results will be presented in visual formats.SVG files, enriching the research findings.

This integrated approach, combining advanced tools such as VOSviewer with the capabilities of Python, Dask and Seaborn through Anaconda, offers a robust methodology for analyzing and visualizing trends in chronic kidney diseases, providing a broad and detailed perspective of the field of study.

3. Results

3.1. Selection and Extraction

Boolean algebra algorithms achieve the appropriate integration of the content, which pursues the fulfillment of the objective of this study following the PRISMA methodology. In addition, the latest technologies have been incorporated, such as machine learning, artificial intelligence, and a wide range of advanced data processing techniques, which are in line with current demands and advances in the field.

(TITLE-ABS-KEY (bia) AND TITLE-ABS-KEY (renal) OR KEY (kidney) OR KEY (impedance) OR KEY (erc) OR KEY (bia) OR KEY (bis) OR KEY (tbw) OR KEY (icw) OR KEY (ecw) OR KEY (fiv) AND ABS (bioimpedance) OR TITLE-ABS-KEY (ia) OR TITLE-ABS-KEY (machine AND learnign) OR TITLE-ABS-KEY (machine AND intelligent) OR TITLE-ABS-KEY (neuronal AND network) OR TITLE-ABS-KEY (supervised AND learning) OR TITLE-ABS-KEY (deep AND network) OR TITLE-ABS-KEY (network AND model) OR TITLE-ABS-KEY (convolution AND automat) OR TITLE-ABS-KEY (unsupervised AND clustering) OR TITLE-ABS-KEY (big AND data) OR TITLE-ABS-KEY (natural AND speech AND process) OR TITLE-ABS-KEY (expert AND sistem) OR TITLE-ABS-KEY (hibrid AND intelligent AND system) OR TITLE-ABS-KEY (diffuse AND logic) OR TITLE-ABS-KEY (random AND forest) OR TITLE-ABS-KEY (decision AND making AND tree) OR TITLE-ABS-KEY (bayes) OR TITLE-ABS-KEY (artificial AND intenlligence) OR TITLE-ABS-KEY (thinking AND computer AND system) OR TITLE-ABS-KEY (recursive AND learning)) AND PUBYEAR > 1988 AND PUBYEAR < 2025 AND PUBYEAR > 1999 AND PUBYEAR < 2025 AND (LIMIT-TO (SUBJAREA , “MEDI”) OR LIMIT-TO (SUBJAREA , “NURS”) OR LIMIT-TO (SUBJAREA , “BIOC”) OR EXCLUDE (SUBJAREA , “ARTS”) OR EXCLUDE (SUBJAREA , “AGRI”) OR EXCLUDE (SUBJAREA , “NEUR”) OR EXCLUDE (SUBJAREA , “SOCI”)) AND (LIMIT-TO (DOCTYPE , “ar”) OR LIMIT-TO (DOCTYPE , “re”) OR LIMIT-TO (DOCTYPE , “cp”) OR LIMIT-TO (DOCTYPE , “le”))

3.2. Execution

Table 1. Documents in Scopus

Document Type	Amount
Article	458
Revision	23
Conference presentation	22
Letter	1

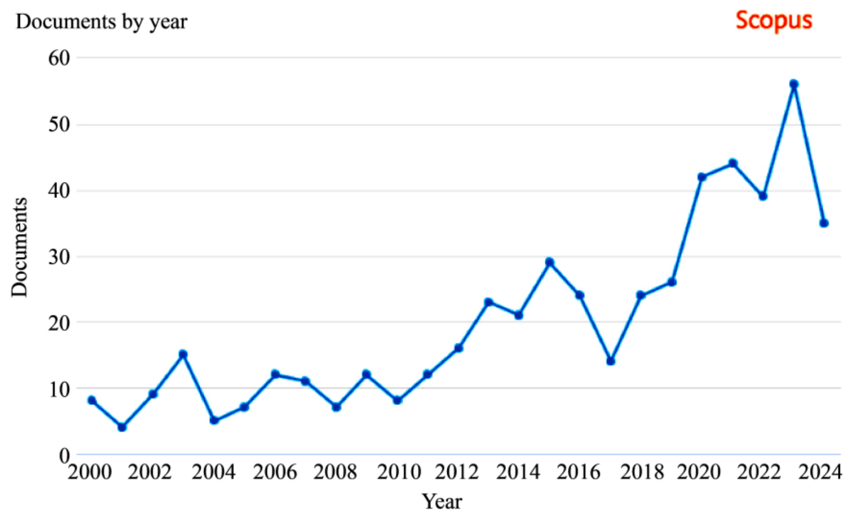

Fig. 11 Documents by Year

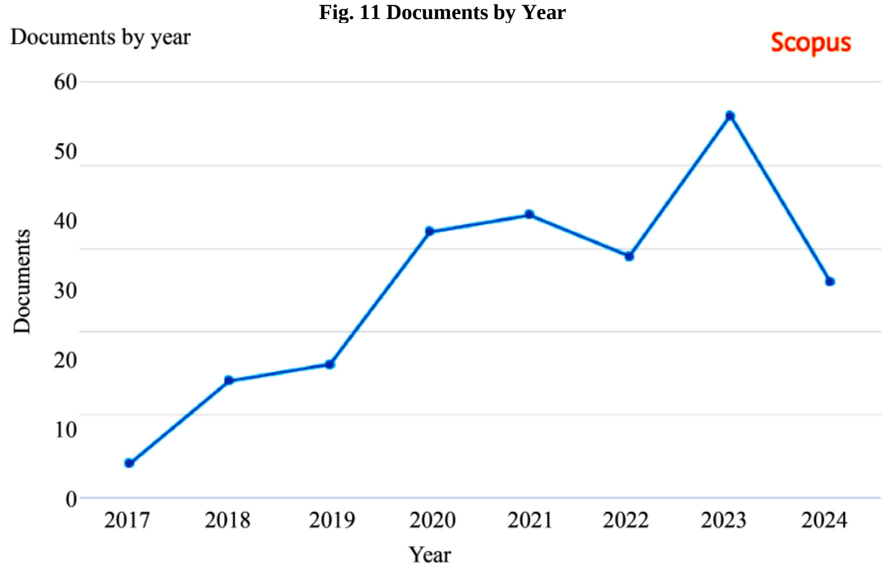

Fig. 12 Documents by Year from 2017 to 2024

The Scopus database offers a wide range of scientific documents collected from various sources, ensuring comprehensive coverage of the academic literature. Table 1 shows that articles, reviews, papers and letters will be specifically chosen since these types of documents contain crucial information for the searches and the improvement of the graphs to be processed.

In addition, the “bronze” and “gold” criteria will be applied for the selection of articles and scientific documentation, which will significantly enrich the results obtained. Likewise, the use of the Scopus interface is highlighted, making the most of its tools and functionalities to optimize these searches and guarantee the quality of the data collected.

The diagram in Figure 11 shows the evolution of the number of documents published in five-year intervals from 2000 to the projection for 2024, focusing on the systematic review of the use of bioimpedance analyzers (BIA) in the context of chronic kidney disease and volumetric analysis.

The graphical representation reveals a gradual increase in the number of publications over time, starting from 8 documents in 2000 and advancing in 2024 with a total of 36 documents. The years with the highest number of publications are 2023, with 56 publications, and 2021, with 44 publications.

This graph shows a growing interest in the application of bioimpedance meters in the field of chronic kidney disease and volumetric analysis, highlighting the importance of conducting a systematic review on this topic.

Such a review could provide a comprehensive and up-to-date overview of trends and advances in this field, providing researchers and healthcare professionals with the necessary information to make informed decisions.

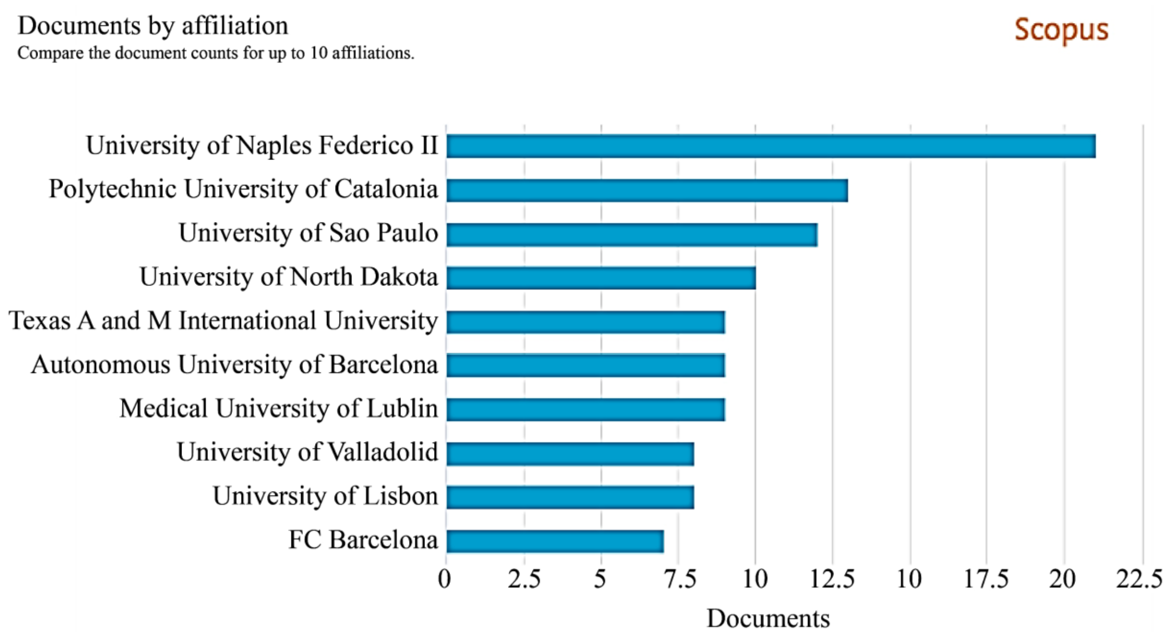

Fig. 13 Documents by affiliation

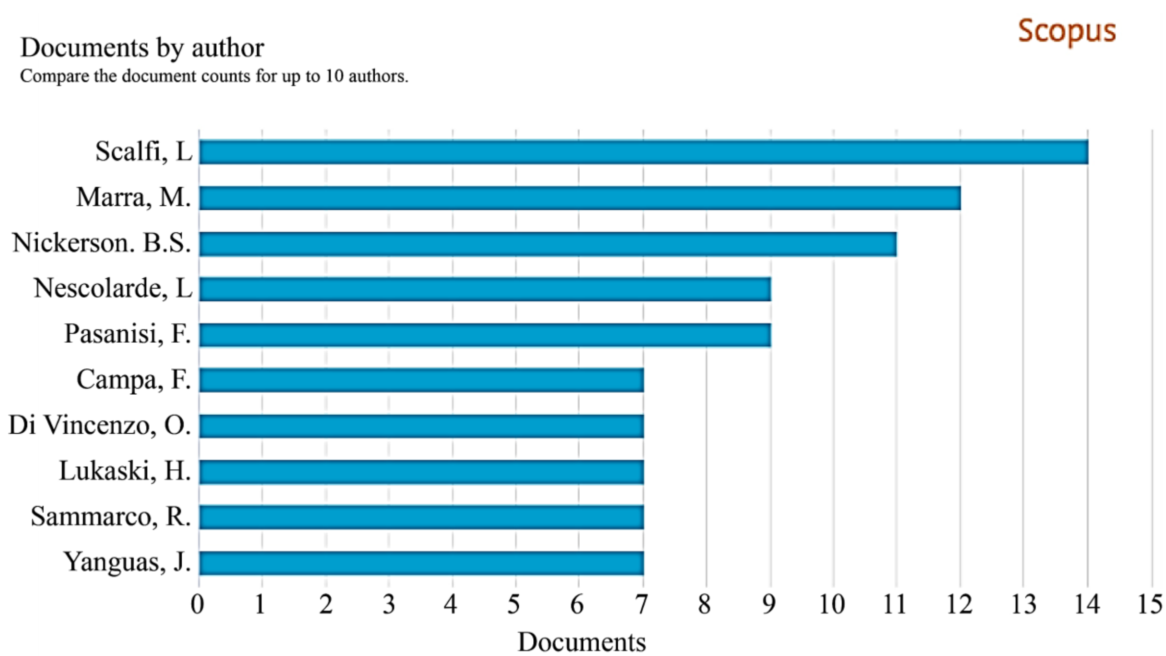

Fig. 14 Documents by author

Figure 12 shows a notable increase in the number of studies on bioimpedancemeters and volumetric analysis related to kidney problems. Starting in 2017, a significant growth in scientific production is observed, reaching its peak in 2023 with 56 publications. This progressive increase of 42 papers between 2017 and 2023 suggests a growing interest and recognition of the importance of bioimpedance techniques in the assessment of chronic kidney disease. The temporal distribution of these publications reflects sustained attention over time, with a continuous presence of studies since at least 2004. However, the rapid increase in recent years could be indicative of technological advances, greater availability of data, and growing interest in the application of bioimpedance in the renal field.

These results underline the relevance and timeliness of the research topic, highlighting the importance of continuing to explore and analyze recent scientific literature to better understand trends and advances in the use of bioimpedance meters in the context of renal diseases.

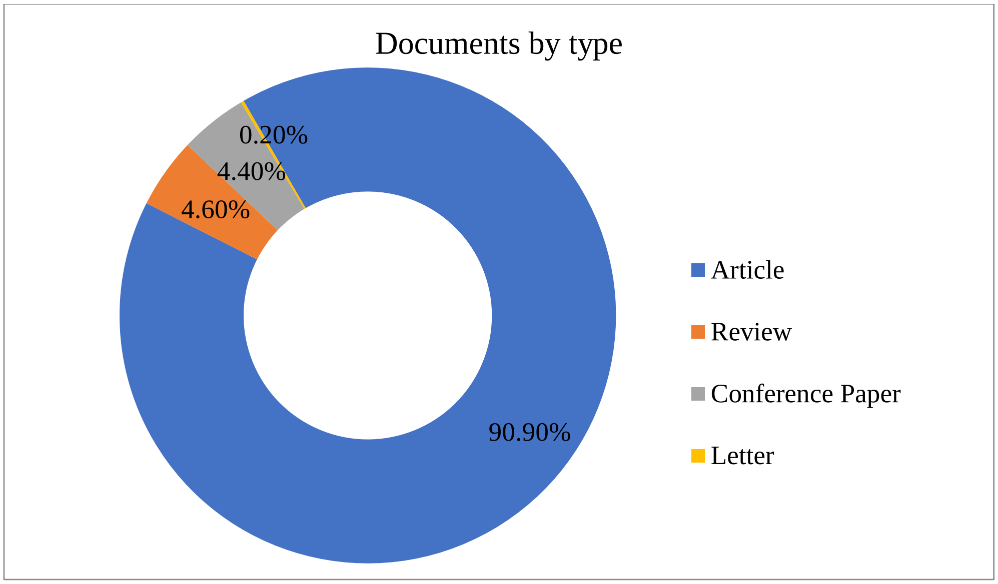

Fig. 15 Documents by type

According to the results shown in Figure 13 on the most frequent institutional affiliation in the systematic review of studies on bioimpedancemeters related to renal problems and volumetric analysis, the Universidade degli Studi di Napoli Federico II leads the list with 21 publications, followed by the Universitat Politècnica de Catalunya with 13 and the Universidade de São Paulo with 12 publications each. This pattern suggests a notable involvement of European and Latin American universities in research on bioimpedance and chronic kidney disease.

Furthermore, the collaboration of renowned institutions such as the University of North Dakota, the University of Queensland, and Texas A&M International University is highlighted, indicating global cooperation in this field. In terms of geographic distribution, the concentration of institutions in Europe and Latin America underlines the relevance of research in these regions. The inclusion of Asian universities, such as Yonsei University and Seoul National University, together with the participation of research centers in North America and Oceania, demonstrates the geographic diversity in bioimpedance and kidney disease research. These data suggest that research in this field is an international collaborative effort, with multiple institutions contributing to the understanding of chronic kidney disease trends using bioimpedance techniques.

The data presented in Figure 14 show the frequency with which authors are mentioned in the scientific literature related to the systematic review of bioimpedancemeters in the context of renal problems. The researchers Marra, M. and Scalfi, L. stand out with 12 and 14 mentions, respectively, which indicates their significant dedication and contribution to this field. Likewise, a diversity of authors is observed with moderate frequencies, such as Nickerson, B.S., Pasanisi, F., and Sammarco, R., which suggests an active participation of several researchers in the exploration of BIA techniques for the evaluation of renal problems.

The presence of authors such as Ward, L.C., Lukaski, H., and Nescolarde, L., each with 8 mentions, along with others with 7 mentions, reflects a continued and collaborative interest in this area of study. In addition, researchers with 6 and 5 mentions are identified, evidencing a broad network of experts contributing to this field of research. These results underline the breadth and collaboration in research on bioimpedancemeters applied to chronic renal problems, which is of great relevance to the proposed systematic review.

Figure 15 shows that in bioimpedancemeters in the context of renal problems and volumetric analysis, the overwhelming predominance of scientific articles (458) stands out, evidencing the robustness of research in this field. These studies address a wide range of aspects related to the application of bioimpedancemeters in the evaluation of chronic kidney disease, which contributes to a more complete understanding of current trends in the use of this technology.

Furthermore, the presence of reviews (23) and conference papers (22) indicates a continuing and developing interest in the topic, reflecting the ongoing evolution of research. This suggests that the exploration of bioimpedancemeters and their application in renal problems is not limited to original research alone but also includes synthesis and critical discussion of existing literature. The inclusion of a “Letter” (1) suggests that even short, specific contributions may be relevant in this context. In summary, these data underline the diversity and depth of the reviewed literature, offering a comprehensive overview of trends and advances in the application of bioimpedance meters in the assessment of renal problems.

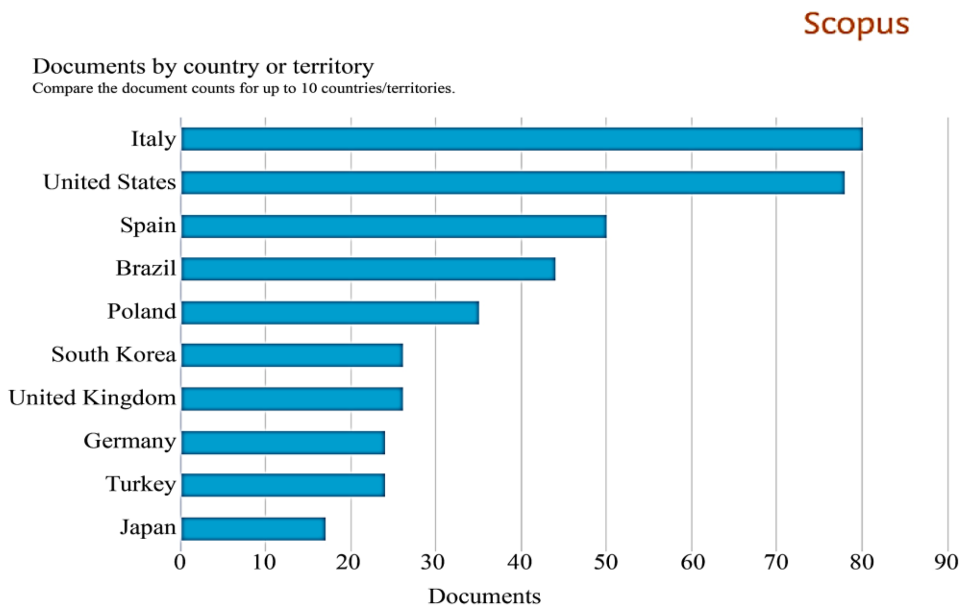

Fig. 16 Documents by country or territory

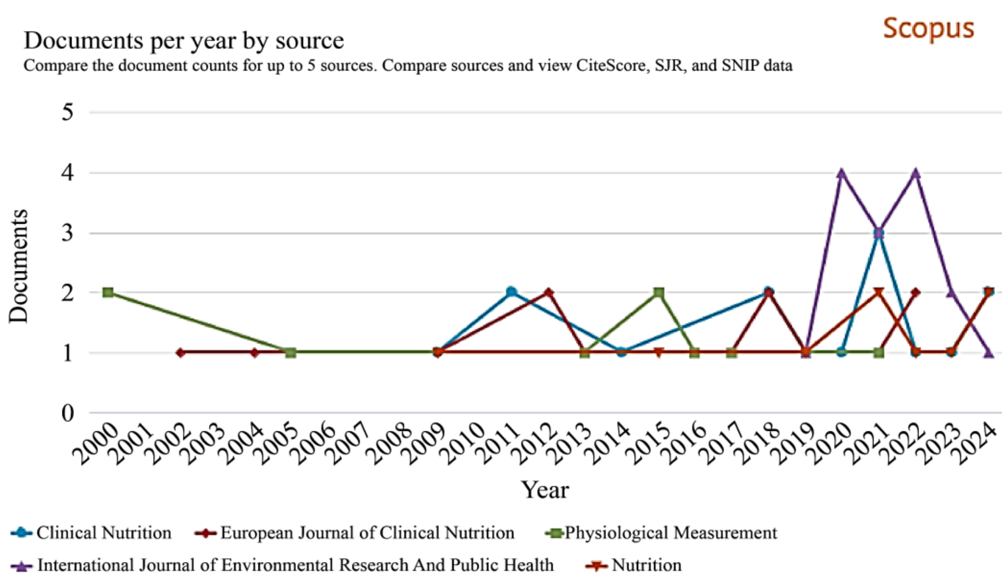

Fig. 17 Documents per year by source

Figure 16 shows that Italy leads with 80 contributions, followed by the United States (78), Spain (50) and Brazil (44), which stand out as leading research centres in the use of bioimpedancemeters to study chronic kidney diseases. The presence of nations such as Poland, the United Kingdom, South Korea, and Germany also reflects the geographical diversity of scientific production.

Furthermore, the research is spread across the globe, with 34 different countries participating. The presence of countries such as Turkey, Japan, China, and Australia underlines the international scope of research into bioimpedancemeters that are applied to renal problems.

These data demonstrate a global collaboration and interest in advancing BIA techniques to address chronic kidney disease, highlighting an international network of researchers committed to this developing field.

Figure 17 shows that the Scopus database offers a wide variety of journals, among which "Clinical Nutrition" (15 publications), "International Journal of Environmental Research and Public Health" (15 publications); "European Journal of Clinical Nutrition" (13 publications) stand out as the most prolific. These data reflect a notable interest and considerable research activity in the application of bioimpedancemetry to renal problems.

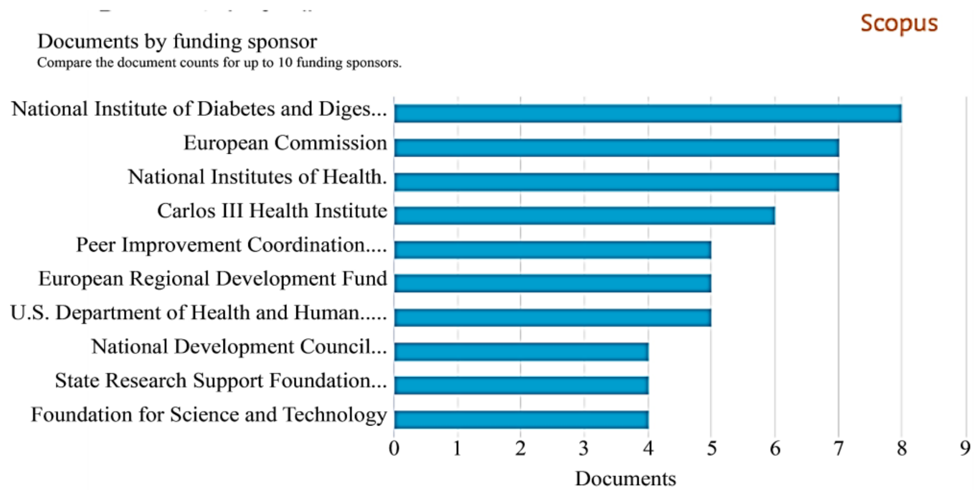

Fig. 18 Documents by funding sponsor

In addition, the presence of specialized nephrology journals such as "International Urology And Nephrology," "BMC Nephrology," and "Kidney International," with 8, 7, and 7 publications, respectively, is noteworthy, highlighting the importance of bioimpedancemetry in the research and management of chronic kidney diseases. This quantitative analysis underlines the breadth of the available literature. It suggests the relevance of carefully exploring the specific trends and approaches that these publications offer in relation to the application of bioimpedancemeters in the renal field.

Figure 18 reveals that the National Institute of Diabetes and Digestive and Kidney Diseases leads with 8 research projects on bioimpedancemeters and kidney problems, followed by European entities such as the European Commission with 7, and the U.S. National Institutes of Health with also 7 proposals. The Coordination for the improvement of higher education personnel and the European Regional Development Fund, both with 5 projects respectively. In addition, European entities such as the Instituto de Salud Carlos III stand out, with 6 projects. Also, government health agencies, such as the National Institute of Diabetes and Digestive and Kidney Diseases and the U.S. National Institutes of Health, highlight the global relevance of research in this field.

This overview shows a diversity of funders, both nationally and internationally, reflecting global interest in the relationship between bioimpedance meters and chronic kidney disease.

The involvement of leading universities and research centres, such as Auckland University of Technology and the Autonomous University of Barcelona, suggests a collaboration between academic institutions and research in this field. This analysis of funders provides a comprehensive overview of the funding sources and institutional support behind research related to bioimpedance and kidney disease, which is essential to understanding the importance and quality of research in this specific field.

Figure 19 reveals a clear predominance of the topic in the field of medicine, with a total of 458 articles exploring the relationship between bioimpedance meters and kidney problems. This indicates a notable interest and dedication towards the application of BIA techniques in chronic kidney disease research within the medical field. The prominent presence of medicine in this context highlights the importance of biomedical research in understanding and effectively addressing kidney disease.

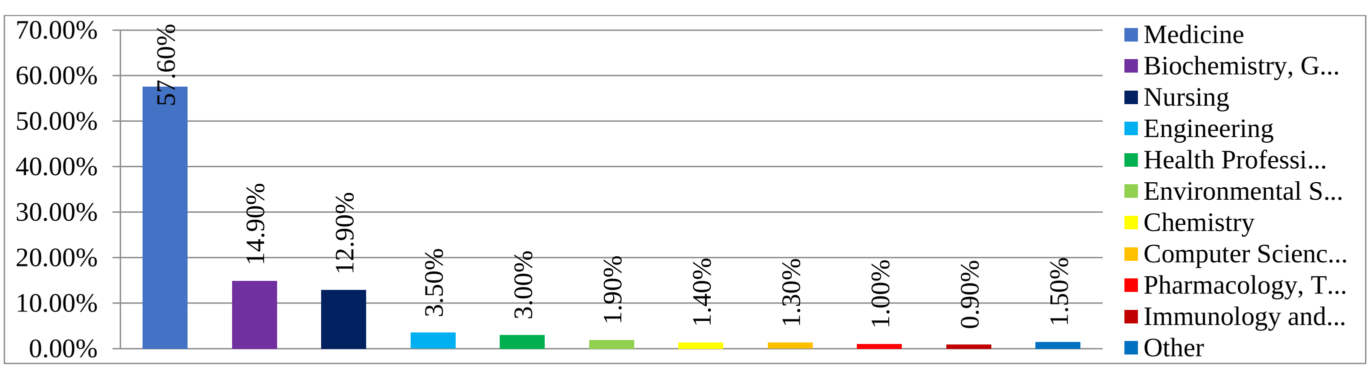

Fig. 19 Documents by subject area

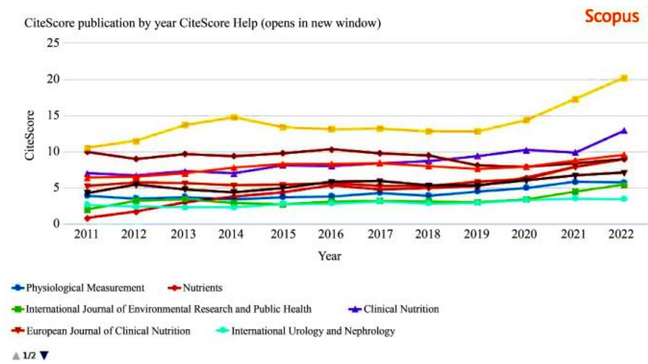

Fig. 20 CiteScore publication by year CiteScore

In addition, significant interest is evident in disciplines such as Biochemistry, Genetics and Molecular Biology, with 119 articles, and Nursing, with 102 articles. This suggests a multidisciplinary collaboration in the study of renal problems using bioimpedancemeters. This holistic approach may prove to be fundamental to obtaining a complete understanding of trends in chronic kidney disease, addressing not only medical aspects but also care and molecular aspects.

In summary, the diversity of disciplines represented in the search underlines the interdisciplinary nature of research related to bioimpedance meters and kidney disease.

Figure 20 presents the CiteScore of several journals related to the systematic review of the application of bioimpedancemeters (BIA) in the context of chronic kidney disease and volumetric analysis. The CiteScore serves as an indicator that reflects the number of citations received by articles published in a journal during a specific period.

According to the graphical representation, Physiological Measurement, Nutrients and International Journal of Environmental Research and Public Health are the journals with the highest CiteScore in this field, recording values of 25, 20 and 15, respectively, in 2021. Other relevant publications include the European Journal of Clinical Nutrition, Clinical Nutrition and International Urology and Nephrology, with CiteScores of 10, 5 and 5, respectively, in the same year.

This graph is useful for identifying prominent, high-impact journals in the field of study, which facilitates the selection of relevant information sources for the systematic review. Including articles from high-quality, relevant journals can improve the systematic review by increasing the likelihood of incorporating well-designed and relevant studies into the analysis.

The terms in Figure 21, “childhood obesity”, “obesity”, “body fat distribution”, “adiposity”, “fat-free mass”, “muscle mass”, and “anatomy and histology”, are associated with the study of adipose tissue and body composition, aspects relevant to the application of bioimpedancemeters in the volumetric analysis of chronic kidney diseases.

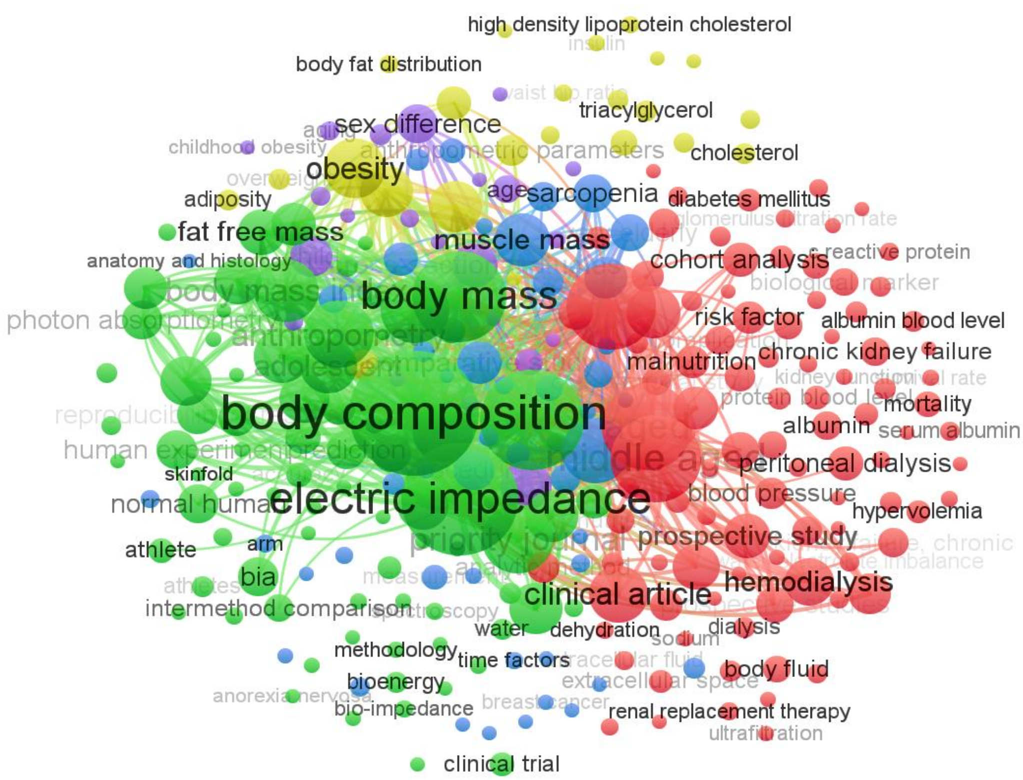

Fig. 21 Clustered co-occurrence map of keywords

On the other hand, terms such as "Anthropometry", "skinfold", "arm", "high-density lipoprotein cholesterol", "triacylglycerol", "metric parameters", and "human experiment" refer to methods and parameters used in the analysis of body composition and related health. In addition, terms such as "Sex difference", "agesarcopenia", "Diabetes mellitus", "reproductive body composition", and "malnutrition" are related to demographic and health factors that may influence body composition and kidney function.

On the other hand, "BIA", "bio-impedance", "normal human electric impedance", "bioenergy", and "cohort analysis" are directly related to the bioimpedancemeters technique and the analysis of body composition and associated health. While terms such as "Hypervolemia", "hemodialysis", "water dehydration dialysis", "middle asperitoneal dialysis", "renal replacement therapy", "ultrafiltration", "chronic kidney failure", "albumin blood level", and "od mortality" are linked to chronic kidney diseases and their treatment methods.

4. Discussion

The systematic review on the application of bioimpedancemetry (BIA) in volumetric analysis of chronic kidney disease (CKD) has identified several key findings. First, there has been a remarkable growth in research related to BIA and CKD, evidenced by a significant increase in the number of publications in recent years. This boom can be attributed to technological advancement, increased data availability, and the pressing need to develop more accurate diagnostic and monitoring methods for CKD. However, the predominance of observational studies has limited the ability to establish direct causal relationships between the use of BIA and CKD, which underlines the importance of conducting randomized controlled clinical trials to validate the efficacy of this technology.

The analysis of scientific production shows a total of 458 articles, 23 reviews, 22 conference papers, and 1 letter to the editor, with an exponential increase since 2000. It is projected that by 2024, approximately 41 publications will be reached, with 2023 standing out as the most active year, with about 56 papers published in each. Of this corpus, 85% corresponds to observational studies (428), while only 15% (76) are randomized controlled clinical trials, suggesting a limited capacity to draw firm causal conclusions regarding the impact of BIA on the management of CKD due to the preponderance of observational studies.

Furthermore, the methodological heterogeneity observed across studies, reflected in the diversity of bioimpedance analyzers used, measurement protocols, and outcome variables, presents a considerable challenge for comparing results and performing meta-analyses. This diversity underscores the need to standardize BIA protocols to facilitate more robust comparisons across studies.

Despite these challenges, BIA has shown promise as a tool, documented in 235 studies for body composition assessment, 112 for early detection of CKD, and 87 for monitoring treatment response. However, there are significant limitations, such as the influence of demographic and physiological factors (age, sex, race, hydration) mentioned in 54 studies, which may affect the accuracy of BIA measurements.

Given the relevance of these findings, the need for further randomized controlled clinical trials and for standardizing BIA protocols to improve comparison between studies is emphasized. Stating Compartmental Balance Disorder (CBD) in each of the pathologies is a proposal that should be analyzed. Future research should also focus on better understanding the influence of specific variables on BIA results and on developing new algorithms that optimize the accuracy of these measurements. Further evaluations of the clinical utility of BIA in the assessment, diagnosis, and management of CKD are essential to advance this field.

References

[1] Ana Cláudia da Rosa Hise, and Maria Cristina Gonzalez, "Assessment of Hydration Status Using Bioelectrical Impedance Vector Analysis in Critical Patients with Acute Kidney Injury," *Clinical Nutrition*, vol. 37, no. 2, pp. 695-700, 2018. [CrossRef] [Google Scholar] [Publisher Link]

[2] Leigh C. Ward, "Bioelectrical Impedance Analysis for Body Composition Assessment: Reflections on Accuracy, Clinical Utility, and Standardisation," *European Journal of Clinical Nutrition*, vol. 73, pp. 194-199, 2019. [CrossRef] [Google Scholar] [Publisher Link]

[3] Nathan R. Hill et al., "Global Prevalence of Chronic Kidney Disease – A Systematic Review and Meta-Analysis," *PloS One*, vol. 11, no. 7, pp. 1-18, 2016. [CrossRef] [Google Scholar] [Publisher Link]

[4] Gregory Roth et al., "Global, Regional, and National Age-Sex-Specific Mortality for 282 Causes of Death in 195 Countries and Territories, 1980–2017: A Systematic Analysis for the Global Burden of Disease Study 2017," *The Lancet*, vol. 392, no. 10159, pp. 1736-1788, 2018. [CrossRef] [Google Scholar] [Publisher Link]

[5] Percy Herrera-Añazco et al., "Prevalence of Chronic Kidney Disease in Peruvian Primary Care Setting," *BMC Nephrology*, vol. 18, pp. 1-7, 2017. [CrossRef] [Google Scholar] [Publisher Link]

[6] Gautam Anand et al., "Bioimpedance Analysis as a Tool for Hemodynamic Monitoring: Overview, Methods and Challenges," *Physiological Measurement*, vol. 42, no. 3, 2021. [CrossRef] [Google Scholar] [Publisher Link]

[7] Ursula G. Kyle et al., "Bioelectrical Impedance Analysis—Part I: Review of Principles and Methods," *Clinical Nutrition*, vol. 23, no. 5, pp. 1226-1243, 2004. [CrossRef] [Google Scholar] [Publisher Link]

[8] Nalini Mishra, Ruchi Gupta, and Nomita Singh, "Decision Delivery Interval in Emergency and Urgent Caesarean Sections: Need to Reconsider the Recommendations?," *The Journal of Obstetrics and Gynecology of India*, vol. 68, pp. 20-26, 2018. [CrossRef] [Google Scholar] [Publisher Link]

[9] Ednilson Fornazari, Nelson Anthony Los, and Sergio Luiz Stevan Jr, "Bioimpedance: Introduction and Uses of Bioimpedance Techniques," *Electronics and Automation Seminar – SEA 2017*, pp. 1-5, 2017. [Google Scholar]

[10] Jie Hou, Naimahmed Nesaragi, and Christian Tronstad, "Electrical Bioimpedance in the Era of Artificial Intelligence," *Journal of Electrical Bioimpedance*, vol. 15, pp. 1-3, 2024. [CrossRef] [Google Scholar] [Publisher Link]

[11] Enrique Romero-Velarde et al., "Neck Circumference and its Relation with Body Fat Percentage in Children 5-10 Years Old," *Children*, vol. 11, no. 7, pp. 1-8, 2024. [CrossRef] [Google Scholar] [Publisher Link]

[12] P.E. Watson, I.D. Watson, and R.D. Batt, "Total Body Water Volumes for Adult Males and Females Estimated from Simple Anthropometric Measurements," *The American Journal of Clinical Nutrition*, vol. 33, no. 1, pp. 27-39, 1980. [CrossRef] [Google Scholar] [Publisher Link]

[13] C.H. Yeung et al., "Human Sperm Volume Regulation. Response to Physiological Changes in Osmolality, Channel Blockers and Potential Sperm Osmolytes," *Human Reproduction*, vol. 18, no. 5, pp. 1029-1036, 2003. [CrossRef] [Google Scholar] [Publisher Link]

[14] Nicos Mitsides et al., "Extracellular Resistance is Sensitive to Tissue Sodium Status; Implications for Bioimpedance-Derived Fluid Volume Parameters in Chronic Kidney Disease," *Journal of Nephrology*, vol. 33, no. 1, pp. 119-127, 2020. [CrossRef] [Google Scholar] [Publisher Link]

[15] Kimio Watanabe et al., "Role of the New Bioimpedance Monitoring Device (Seca®) in Assessing Dry Weight in Hemodialysis Patients," *Clinical and Experimental Nephrology*, vol. 26, pp. 460-465, 2022. [CrossRef] [Google Scholar] [Publisher Link]

[16] Huaping Zhu et al., "Clinical Analysis of 10 Neonates Born to Mothers with 2019-nCoV Pneumonia," *Translational Pediatrics*, vol. 9, no. 1, pp. 51-60, 2020. [CrossRef] [Google Scholar] [Publisher Link]

[17] Glenn M. Chertow et al., "Development of a Population-Specific Regression Equation to Estimate Total Body Water in Hemodialysis Patients," *Kidney International*, vol. 51, no. 5, pp. 1578-1582, 1997. [CrossRef] [Google Scholar] [Publisher Link]

[18] Sali El Dimassi et al., "Body Water Volume Estimation Using Bio Impedance Analysis: Where Are We?," *IRBM*, vol. 45, no. 3, pp. 1-13, 2024. [CrossRef] [Google Scholar] [Publisher Link]

[19] Leila Itani et al., "Association between Dietary Practice and Gait Speed in Community-Dwelling Older Adults with Overweight and Obesity: A Cross-Sectional Study," *Diseases*, vol. 12, no. 3, pp. 1-11, 2024. [CrossRef] [Google Scholar] [Publisher Link]

[20] Hanneke Pierre Franciscus Xaverius Moonen, and Arthur Raymond Hubert Van Zanten, "Bioelectric Impedance Analysis for Body Composition Measurement and other Potential Clinical Applications in Critical Illness," *Current Opinion in Critical Care*, vol. 27, no. 4, pp. 344-353, 2021. [CrossRef] [Google Scholar] [Publisher Link]

[21] Busayo I. Ajuwon et al., "Hepatitis B Virus Infection in Nigeria: A Systematic Review and Meta-Analysis of Data Published between 2010 and 2019," *BMC Infectious Diseases*, vol. 21, pp. 1-15, 2021. [CrossRef] [Google Scholar] [Publisher Link]

[22] Mohd Azizul Ladin et al., "A Computer-Based Advisory System for Motorcycle Safety at Campus," *Journal of Advanced Research in Applied Sciences and Engineering Technology*, vol. 48, no. 2, pp. 225-234, 2025. [CrossRef] [Google Scholar] [Publisher Link]

[23] Zamri Zakaria et al., "Systematic Review of Risks in Energy Performance Contracting (EPC) Projects," *Journal of Advanced Research in Applied Sciences and Engineering Technology*, vol. 48, no. 2, pp. 235-250, 2025. [CrossRef] [Google Scholar] [Publisher Link]

[24] Wei Yuan et al., "The Value of Bioimpedance Analysis in the Assessment of Hydration and Nutritional Status in Children on Chronic Peritoneal Dialysis," *Renal Failure*, vol. 46, no. 1, pp. 1-7, 2024. [CrossRef] [Google Scholar] [Publisher Link]

[25] Josephine Reinert Quist et al., "Bioelectrical Impedance Analysis as a Clinical Marker of Health Status in Adult Patients with Benign Gastrointestinal Disease: A Systematic Review," *Clinical Nutrition ESPEN*, vol. 59, pp. 387-397, 2024. [CrossRef] [Google Scholar] [Publisher Link]

[26] E.A. Bushmanova, and A.Yu. Lyudinina, "Bioimpedance Analysis of Body Composition and Rest Energy Expenditure in Highly Trained Cross-Country Skiers," *Voprosy Pitaniia*, vol. 93, no. 3, pp. 23-30, 2024. [CrossRef] [Google Scholar] [Publisher Link]

[27] Ana Flávia Sordi et al., "Comparison between Measured and Predicted Resting Metabolic Rate Equations in Cross-Training Practitioners," *International Journal of Environmental Research and Public Health*, vol. 21, no. 7, pp. 1-14, 2024. [CrossRef] [Google Scholar] [Publisher Link]

[28] Jonathan P. Bennett et al., "Variations in Bioelectrical Impedance Devices Impact Raw Measures Comparisons and Subsequent Prediction of Body Composition Using Recommended Estimation Equations," *Clinical Nutrition ESPEN*, vol. 63, pp. 540-550, 2024. [CrossRef] [Google Scholar] [Publisher Link]