Bibliometric Insights into Connectomics: Chemistry and Neuroscience Perspectives

Perspectivas bibliométricas sobre la conectómica: enfoques desde la química y la neurociencia

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Abstract

Introduction. Connectomics, an emerging omics science, has contributed to the preventive diagnosis of neurodegenerative diseases. This field integrates chemical and neuroscientific information, analyzing neurotransmitter functions and alterations within brain connections. Additionally, it enables theoretical simulations that link the brain´s biophysical structure with neuronal interactions, providing insights into brain function. **Objective.** This study explores connectomics as an omics science and its contributions to chemistry and neurosciences. **Methodology**. A bibliometric analysis was conducted using Scopus, RStudio and VOSviewer to identify global research trends in connectomics. **Results.** Co-citation and keyword co-occurrence analyses key aspects of connectomics research. The findings highlight the need to promote studies on this emerging omics science in Colombia. **Conclusions.** Connectomics plays a crucial role in understanding neural networks and advancing treatments for neurodegenerative disorders. The field benefits from instrumental techniques such as magnetic resonance imaging and machine learning models for data processing.

These tools emphasize the significance of connectomics research in neuroscience and cognitive sciences.

Keywords: Bibliometric analysis, Brain connections, Magnetic resonance imaging, Neurodegenerative disorders, Neural networks.

Resumen

Introducción. La conectómica, una ciencia ómica emergente, ha contribuido al diagnóstico preventivo de enfermedades neurodegenerativas. Este campo integra información química y neurocientífica, analizando las funciones de los neurotransmisores y las alteraciones dentro de las conexiones cerebrales. Además, permite realizar simulaciones teóricas que vinculan la estructura biofísica del cerebro con las interacciones neuronales, proporcionando conocimientos sobre la función cerebral. **Objetivo.** Este estudio explora la conectómica como ciencia ómica y sus contribuciones a la química y las neurociencias. Metodología. Se llevó a cabo un análisis bibliométrico utilizando Scopus, RStudio y VOSviewer para identificar las tendencias globales de la investigación en conectómica. **Resultados.** La co-citación y la co-ocurrencia de palabras clave analizan aspectos clave de la investigación en conectómica. Los hallazgos resaltan la necesidad de promover estudios sobre esta ciencia ómica emergente en Colombia. **Conclusiones.** La conectómica juega un papel crucial en la comprensión de las redes neuronales y en el avance de tratamientos para trastornos neurodegenerativos. Este campo se beneficia de técnicas instrumentales como la resonancia magnética y los modelos de aprendizaje automático para el procesamiento de datos. Estas herramientas enfatizan la importancia de la investigación conectómica en la neurociencia y las ciencias cognitivas.

Palabras clave: Análisis bibliométrico, Conexiones cerebrales, Resonancia magnética, Redes neuronales, Trastornos neurodegenerativos.

1. Introduction

Omic sciences represent a current point of research, generating interdisciplinary research projects that allow the connection between different fields of knowledge. However, the new generations of researchers are few who know about the existence of these sciences and the potential they have in the development of scientific advances. Therein lies the importance of exploring omic sciences, knowing their history and evolution, in addition to understanding the evaluative power that this type of science has for human development. If we talk about the origin of omic sciences, it is necessary to mention the Human Genome Project, since it gave rise to the first omic science that emerged, which is genomics. This project represented a starting point for the development of later sciences such as transcriptomics, proteomics and metabolomics (Frigolet & Gutiérrez-Aguilar, 2017).

When we talk about these first four sciences, we are referring to the presentation and development of the first omics that allowed the divergence of research. However, biologically, the information obtained by each of these sciences enables a convergence of data to generate a complete study in a given organism. Thus, from genomics, transcriptomics, proteomics and metabolomics, the development of new research sub-branches was established. Each of these sub-branches becomes more specific depending on the type of minimum unit structure in which the science is emphasized. For example, in the case of metabolomics, the development of sub-branches such as volatilomics (Betancourt-Arango et al., 2024), lipidomics and peptidomics has been reported, with both targeted and untargeted approaches (Han et al., 2023). However, when the study becomes more specific, such as determining specific metabolites (target) in response to the presence of xenobiotic agents, sub-branches like xenometabolomics, xenovolatilomics and xenolipidomics emerge, as shown in **Figure 1** (Betancourt-Arango et al., 2025). Subsequently, when the research study focuses on identifying sequential metabolites and metabolite intermediates within a biochemical pathway, it becomes necessary to conduct a fluxomics-type study (Emwas et al., 2022).

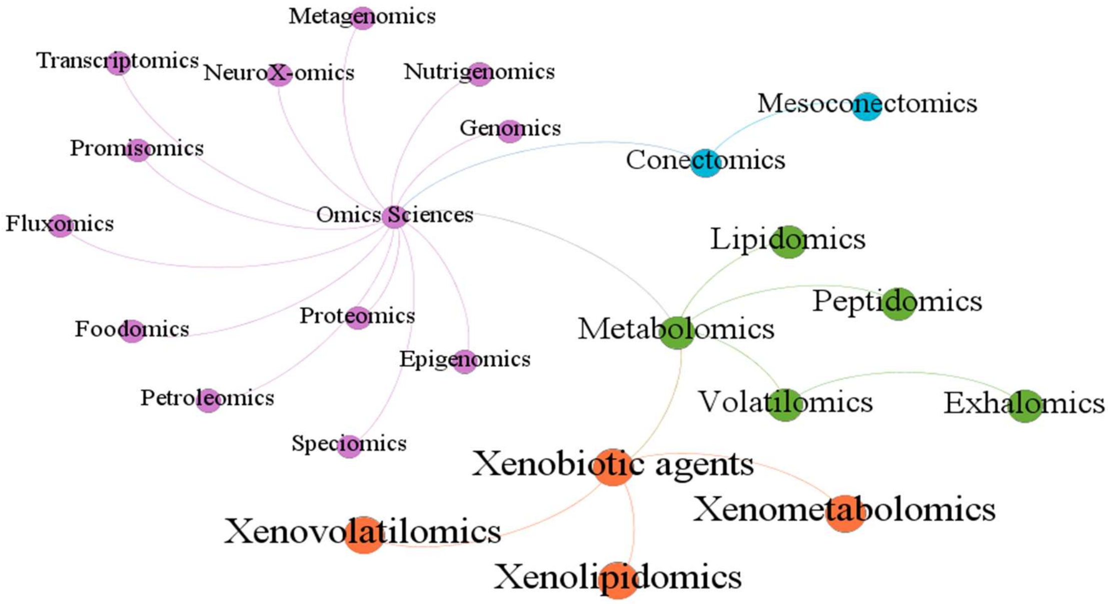


Figure 1. Network analysis of current omics sciences. *Own elaboration.*

However, just as in the world of science the identification of metabolites through metabolomic studies and their flux through fluxomics research is of interest, it is also important to understand the connections that are expressed at the biological level. When there is a cellular and neural metabolic flux, it allows the development of cell signaling processes and the transfer of functions to generate the fulfillment of a certain function (Emwas et al., 2022). Thus, a new omics science emerges for the study of brain connections and to evaluate the metabolic flow of neurotransmitter-like compounds that enable brain signaling processes and neuronal synapses. Hence, it is important to investigate these types of compounds and the representative roles they have within the basic processes of brain functioning. From this need, the term “connectomics” emerges as an omics science to be explored. There is a relationship between metabolic flux and the different neurotransmitters within connectomics. This relationship lies in the biochemical and metabolic processes inside neurons and how they influence the production, release, and even degradation of neurotransmitters such as glutamate, norepinephrine (NE), dopamine, serotonin, gamma-aminobutyric acid (GABA). These neurotransmitters depend on neuronal metabolism for their subsequent biosynthesis. Therefore, connectomic studies have the ability to trace the different neurotransmitters involved in metabolic processes, which are essential for connectivity and brain functionality.

These neurotransmitters are characterized as small molecules essential for neuronal communication processes. They allow the transmission of signals that enable brain modulation, thereby regulating the neuropsychological behavior expressed by each individual (Egea et al., 2004). Currently, a variety of neurotransmitters have been reported, for example, acetylcholine (ACh) is a key compound in the central and peripheral nervous system. Its precursors, choline and Acetyl-CoA, undergo a reaction catalyzed by choline acetyltransferase (ChAT), leading to the formation of CoA and acetylcholine. The latter is stored in synaptic vesicles until it is released in response to an action potential (Flores-Soto & Segura-Torres, 2005). Dopamine (DA) is a catecholaminergic neurotransmitter involved in the regulation of movement, motivation and emotional control. This compound is synthesized from the amino acid tyrosine, which acts as a precursor. Tyrosine is first transformed by tyrosine hydroxylase (TH), into L – DOPA. Then, through the action of DOPA decarboxylase (DDC), L-DOPA is converted into dopamine, which is stored until its release in the synaptic processes (Egea et al., 2004).
Glutamate (GLU) is the main excitatory neurotransmitter in the brain. It is involved in synaptic plasticity, learning and memory, as well as regulation of neuronal development and neuroplasticity. GLU is biosynthesized from glutamine through the action of the enzyme glutaminase or via the tricarboxylic acid (TCA) cycle (Albarracín et al., 2016). Serotonin (S) plays a key role in emotional regulation and social behavior, in addition to being involved in pain modulation. It is biosynthesized from the amino acid tryptophan, which is first converted to 5-hydroxytryptophan (5-HTP) by the enzyme tryptophan hydroxylase. Then, 5-HTP is further processed by 5-HTP decarboxylase to form serotonin (Sebastián Domingo & Sebastián Sánchez, 2018). GABA is a neurotransmitter that modulates neuronal excitability, controls relaxation processes, and regulates sleep, anxiety and motor control. Its biosynthesis occurs through the conversion of glutamate by the enzyme glutamate decarboxylase (GAD) (Ochoa-de la Paz et al., 2021).

Additionally, NE, also called noradrenaline, is a key neurotransmitter within the sympathetic nervous system. It regulates fight-or-flight responses, alertness, mood control and sleep facilitation. NE is biosynthesized from the amino acid tyrosine, which is first converted to L-DOPA (L-3,4-dihydroxyphenylalanine) by tyrosine hydroxylase. L-DOPA is then converted to dopamine by L-DOPA decarboxylase, and finally, dopamine is transformed into noradrenaline through the action of dopamine β-hydroxylase (Tellez Vargas, 2000). Research on the glutamate-glutamine cycle in the brain indicates its involvement in GLU biosynthesis. However, altered glutamine levels are associated with neurodegenerative disorders such as Alzheirmer's disease. The disruption of GABA biosynthesis is closely linked to oxidative stress processes, mitochondrial energy metabolism, and the dysregulation of metabolic pathways involved in dopamine formation. These alterations contribute to neurodegeneration, as seen in diseases like Parkinson´s (Saenger et al., 2017). Connectomic approaches reveal their roles in the brain, and their impact on brain development and function is fundamental within connectomics. This research focuses on exploring connectomics as an omics science and examining its contributions to chemistry and neuroscience.

2. Chemistry in the connectomics

The origin of connectomics is linked to the development of network theory and the transition towards a connectionist model. A simple example of connectomics in action can be observed in human speech acquisition. When learning a mother tongue, the process is associated with the creation of neural networks. This mechanism can be explained through both neuroanatomy and connectomics (Rodríguez-caso & López-rodríguez, 2016). This science demonstrates the importance of studying the brain stimulations, which modulate brain circuits. By analyzing these stimulations, researchers can perform a connectomic analysis to identify specific brain circuits and their relationship to behaviors (Yan et al., 2022). In 2009, provided a stimulus to investigate the connectivity of the brain and its functionality. This allowed researchers to understand functional networks and neural connections within the nervous system. However, connectomics remains an emerging science with significant potential for future research within the omic sciences (Shah et al., 2022). Connectomics research, particularly in the context of deep brain stimulation (DBS) is centered on cognitive neurosciences. It focuses on evaluating brain connections in relation to human cognitive functions. DBS facilitates new research into the modulation of cognitive networks expressed in neural connectivity. These functional analyses include the inhibition of synaptic responses, learning processes, replication and memory (Grospietsch et al., 2022).

The evolution of the human brain from its primate state has been influenced by the development of connectomics. Neuroimaging research has helped to understand brain structure, function and connectivity in both humans and non-human primates (NHPs) (**Figure 2**), leading to the emergence of comparative connectomics. This type of research allows scientists to identifying associations between cortical neurons and the size of social groups in primates (Yokoyama et al., 2021). The study of differentiated connectomes among animal species has been advanced using techniques such as microscopy, molecular biology, data processing and computational neuroscience. These methods have contributed to our understanding of the brain´s conceptome in both humans and various animal species (Barsotti et al., 2021).

Current connectomic studies report two types of information: resting-state functional connectivity (FC) and structural connectivity based on diffusion MRI (SC) (Jütten et al., 2021). Technological advancements have furthered the understanding of these types of connectomes. For example, computational neuroscience has enabled the development of applications such as FARCI (Fast and Robust Connectome Inference), which uses MATLAB packages to generate effective neuronal-level connectome inference from two-photon calcium fluorescence data *in silico*. To address the challenge of the neuronal connectome (NCC) and the data generated from neural anatomy simulators and optimal microscopy (NAOMi), additional computational algorithms have been developed. Methods such as generalized transfer entropy (GTE) and the fluorescence single neuron and network analysis package (FluoroSNNAP) have been used to generate chemical and biological interpretation of the obtained data (Meamardoost et al., 2021).

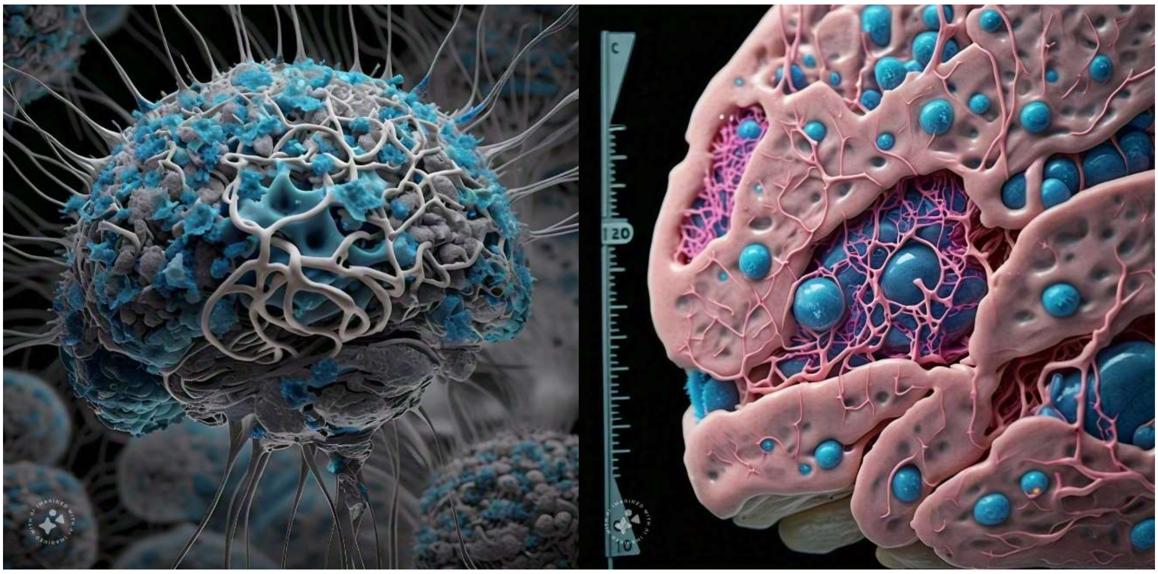


Figure 2. Illustrative example of different types of connections that may exist within the brain. Source: Meta AI (https://www.meta.ai/).

Research in the field of neurosciences and connectomics requires interdisciplinary approach, involving statisticians, data scientists, engineers, biologists, chemists, and others specialists. This collaboration has led to the development of new sciences, such as NeuroX-omics (Nalls et al., 2015), which has emerged from advances in genomics, transcriptomics, proteomics and metabolomics. However, it is necessary to expand knowledge in each of these disciplines to establish a precise interconnection of the information obtained through omics sciences, specifically in the case of connectomics (Hoy, 2021). Despite significant progress, there is still a long way to go in connectomics. In this regard, the discipline can learn from genomics, particularly in handling vast amounts of data required to analyze the human or animal brain. Generating a global brain mapping of organisms remains a challenge. This process aims to establish neural circuits in a given organism, evaluate which sections are preserved across species, and identify those that show variation between different organisms (Chen & Flint, 2021).

The current scientific world continuously generates new omics sciences, bringing promises and expectations of scientific advances. These promises influence various spheres of power, including politics, scientific funding, and public perception. This dynamic has led to the emergence of the term promisomics, which emphasizes responsible research practices and the importance of contributing to social expectations. Promisomics ensures credibility in science for the benefit of society (Gomez-Marin, 2021), addressing questions raised by the neuroscientific community. It also plays a key role in managing expectations related on the understanding of the brain.

3. Neuroscience and connectomics

Neurosciences as well as neuropsychology try to make contributions towards the study of the brain (Rojas-Leguizamon et al., 2021). Within neuroscience, brain modeling is generated to build a connectome, established through a network of interconnected nodes (expressing a biophysical entity of the brain), showing a connection network where the union of nodes is given by edges (expressing the connection of a neuronal section with another), identifying the connectome as an abstract and mathematical model that exemplifies the brain network (Chung et al., 2021). Neuroscience, on the other hand, studies and deciphers the characteristics and functionality of the brain, which is why it is necessary to use connectomics to evaluate the different connections that this organ has within the human being; however, studying these networks, their transport and flow of information represents an arduous task of study (DeFelipe, 2010). Both connectomics and neuroscience allow the exploration of problems from a qualitative-theoretical perspective, playing an important role in the analysis of network architecture for processes of cognition, disease, development (Betzel, 2021), aging and correlations between flow trains at the cerebral level that a neuron may present (Krempl et al., 2021).

It is important to understand this type of diagram of nervous circuits, to understand the synaptic flow that allows representing the ultrastructural connectivity generating an approach towards the synaptomic explanation, since, currently a transition is being made from connectomics to synaptomics to understand the synaptic flow of neurotransmitter metabolites involved in the process and the different nervous connections that are established to conduct the information; establishing the importance of understanding the structural disposition of the brain. Given this, the term connectomics arises as a representative way to express the variety of connections that the brain has in humans, however, to establish an analysis on the flow of information within a system is complex, therefore, it is important to generate approaches on the concepts connectomics and synaptomics using circuit diagrams that allow to simulate the nervous system (DeFelipe, 2010). Similarly, electrical stimulation has been an important tool in neurosciences expressing the study of excitatory and inhibitory synaptosomal processes for cono-horizontal cells present at the retinal level (Tsai et al., 2017).

Neuroscience has provided information on the very neuroanatomy of cognitive processes and with the help of connectomics it is possible to increase the level of detail, identifying the connectivity network that is involved in this process (Rodríguez-Méndez et al., 2022). A “volitional network” uses graph theory to evaluate adversarial properties within a network graph (Rodríguez-Méndez et al., 2022). Currently, neuroscience is applied to systems, reporting the presence of brain regions for the transmission of information, however, almost no research on a hierarchical structure is reported, so it is necessary to decode the information efficiently, having the idea of how the information is encoded and transmitted through a metabolic economy (Zhou et al., 2022). In this way, connectivity allows us to evaluate efficient coding and assess the minimum rate for sending messages between brain regions, showing that efficiency of comprehension increases fidelity in development, increasing metabolic resources and giving rise to hierarchical organization, demonstrating how macro-level connectivity enables efficient acquisition (Zhou et al., 2022).

Technological and methodological advances have allowed the development of qualitative and quantitative methodologies to advance the development of oncological and immunological problems, in addition to advancing the understanding of physiological, pathophysiological and pharmacological interventions that can occur in the brain, from various pathophysiologies (Bloomingdale et al., 2021). Microphysiological systems using human induced pluripotent stem cells (IPSC), different digital biomarkers, in addition to large-scale imaging, allow obtaining a large amount of data for the preclinical to clinical translation of therapies, which is why connectomics is identified as a scientific-technological advance within the therapeutic area and neurosciences, achieving a significant advance in the world of neurosciences. Therefore, the diseases that are generated in response to different brain alterations are also studied, focusing their origin on biochemical explanations and erroneous connections within the connectome (Hansen et al., 2022). Thus, it is important to develop studies that try to explain the different alterations that the connectome may present. Hanse *et al*., (2022) used morphometric analysis (MRI) to construct maps of cortical abnormalities for thirteen neurodevelopmental, neurological and psychiatric disorders.

Therefore, given the current technological advances in the production of neuroimaging analysis at a structural and functional level, an advance in the study of basic mechanisms of perception and cognition has been generated, allowing the development of new sciences such as cognitive psychology, cognitive neuropsychology and cognitive neurosciences, as well as contributing to the field of omics evolution, through the process of proteomics and connectomics (Galaburda & Wong, 2017). The approaches to connectomic study can be transversal or longitudinal (Liao et al., 2016), and in both directions contributions have been generated to understand diseases expressed in alterations of small blood vessels, damage that is characterized by generating different vascular lesions at the parenchymal level of the human brain, generating lesions of white matter (WM) and gray matter (GM), explaining a primary cortical neurodegenerative process for the development of this type of alterations (Gutierrez Zuniga et al., 2022). Hence the emergence of neuropsychological study methods using brain imaging techniques such as magnetic resonance imaging (MRI), functional magnetic resonance imaging (fMRI), computed axial tomography (CT), positron emission tomography (PET), electroencephalography (EEG) (McGrath et al., 2022), electrocorticography (ECoG) (Shimono & Hatano, 2018), single photon emission computed tomography (SPECT), tractography (Wende et al., 2024), and functional near-infrared spectroscopy (fNIRS), in addition to new noninvasive technologies for brain and disease diagnosis through the use of real-time fMRI neurofeedback (rtfMRI), generating new tools for the diagnosis of human brain-behavioral relationships and interactions (Val-Laillet et al., 2015).

Similarly, new approaches to non-invasive neuromodulation explore the use of repetitive transcranial magnetic stimulation (rTMS) and transcranial direct current stimulation (tDCS) techniques (Val-Laillet et al., 2015). This allows highlighting the development of research on the brain for the development of new ways of diagnosis and treatment of neurodegenerative diseases, in addition to establishing a sense at the time of establishing biological markers of brain functions, highlighting the important role of new technologies towards the evolution of neuroimaging and neuromodulation (Val-Laillet et al., 2015). Other research is focused on the use of functional ultrasound (fUS) as a basis for obtaining functional neuroimaging allowing high resolution at a spatiotemporal level and a varied field of view, evaluating brain activity in different systems (Martinez de Paz & Macé, 2021).

The application of this type of technological tools in function of a connectomic objective, has allowed us to perform scans and obtain a better understanding of brain areas and functions such as: brain area (phrenology), brain function (memory, attention, language and cognitive processes), complex functional system (functional and brain blocks) and networking (functional, structural and dynamic connectivity) (Rojas-Leguizamon et al., 2021;Burbano, 2024), thus establishing a greater understanding of basic processes in humans such as cognition (comprising memory, attention, perception, language and executive functions), emotions (comprising emotion regulation and stress response processes) and behavior (comprising motivation, social behavior, impulsivity and impulse control processes) (Rojas-Leguizamon et al., 2021;Burbano, 2024).

4. Conectomics applications

Among the applications of connectomics are framed through different types of research reported towards the mapping of neural networks, pharmacological interventions, neuroplasticity, among others, for example, there are currently approaches in the analysis of disorders of consciousness (DOC), demonstrating that connectomics and network neuroscience, can generate a qualitative analysis to explain such disorders of the brain connectomics, Therefore, MRI methodologies allow to identify abnormal connectivity patterns and topological structuring at brain level, affecting the resting networks (RSN), which in turn are related to the senses, in this way, the DOC are characterized by generating a decrease in the global processing of information, which integrates the network and generates an increase in local processing of information (Plosnić et al., 2023).

For its part, the important brain concometomics within neurosciences, supported by MRI type techniques, electrophysiology and PET, have allowed the evaluation of neuronal activity, proteinopathies on cognitive processes, neurotransmission and the different pathologies that can present synaptic systems at the brain level, these techniques are efficient on instrumental criteria such as timeliness, validity, resolution and reproducibility in the identification techniques (Sala et al., 2023). In addition, neural network mapping has been performed through three-dimensional electron microscopy (3D-EM) (Schmidt et al., 2024), serial section electron microscopy (SSEM) and correlated light serial scanning electron microscopy (CoLSSEM) (Hirabayashi et al., 2018), allowing further study of the understanding of descending and ascending neurons that are indispensable in signaling and sensorimotor control itself (Stürner et al., 2024). This type of research harmonizes connectomics and the networks described through additional techniques such as resting-state functional magnetic resonance imaging (rs-fMRI), mitigating the bias of the specific site of analysis, which in turn compromises the type of subsequent results when interpreting these types of images when they are together, so the harmonization of the information obtained by connectomics and the derived networks is indispensable and requires new mathematical models of information theories to process these data and ensure efficiency in these types of techniques (Roffet et al., 2022).

Neuroimaging has made it possible to investigate the brain and the different pathologies it presents, highlighting the connection between the morphological and physiological structure and images of these to correlate this information; therefore, neuroimaging has made it possible to advance in these fields in combination with machine learning (Sheikh et al., 2024), performing anatomical measurements, segmentation, detection and quantification of different types of lesions generated in this organ (Nenning & Langs, 2022). Establishing a diagram of the constituent wiring of the human brain is the first step in deciphering the cognitive processes of the brain, delimited by technological advances in neuroimaging and the progressive development of omics, which allow the study of brain functions and the pathologies of neurological and psychiatric disorders to induce a better diagnosis of these types of diseases (Li & Yap, 2022). Thus, advances in structural connectivity (EC) and functional connectivity (FC), through the construction of generative computational models that allow to generate a simulation of the response profile of a complex system, have been achieved through the evolution of the classical models of Hodgkin and Huxley on the same computational neuroscience, predicting collective properties of neurons, synapses and activity-dynamic relationship in a network process (Li & Yap, 2022). Depending on the neural models developed, the scoping process is different; thus, generative models of connectomics are currently classified into the dynamic causal model (DCM), biophysical network model (BNM) and the dynamic neural model (DNM) (Li & Yap, 2022).

Connectomics emerges as an irreplaceable neuroscience research, allowing the development of research on the evolution of viral pathogens, through viral transneuronal tracing (Ugolini, 2020). However, it is important to understand the relationship between neurobiology and the connectome, in order to generate a biological analysis for the understanding of different natural processes of neuronal connection, representing this information from structural networks using MRI, in addition to the interpretation of the network nodes within the brain, the comparison between networks and the application of this emerging omics science (Schirmer et al., 2023). Identifying a dynamic flow of connectivity, the compatibility between structural and functional connectivity to understand biological processes and develop computational programs such as machine learning, deep learning and the development path that this science has (Schirmer et al., 2023).

Analyzing the human brain through the use of complex networks, plays a challenge in the interpretation of data, given the number of dimensions involved in the interpretation of these, in addition to the variability between individuals, therefore, the concept of “network comparison” arises to generate a capture of differences between groups and the use of mechanical networks for integration of connectomic data, coupling this information with programming languages for the development of machine learning, deep learning and various geometric techniques (D’Souza & Venkataraman, 2023). In addition, this task of analyzing connectomic data becomes more complex due to the variety of level maps (synaptic connections) and level mappings (neural functions, behavior and cognitive processes), resulting in the understanding of the brain functions of an organism, hence the complexity in the development of this type of analysis (Gomez-Marin, 2021). However, even with the high degree of complexity in the interpretation of the data, connectomics is already emerging as an omics science and is generating a variety of reported applications within the scientific community, for example, research has been done on the connectivity information expressed in the L4 layer in the thalamus for the transport of sensory signals, advanced in the knowledge of this through three-dimensional electron microscopy for connectomic analysis to generate a structuring of the L4 network of the thalamus (Hua et al., 2022). Hua *et al*., (2022) report a strong sensory activity that generates a hyperpolarization that activates stellate pyramidal-like cells, being 1.5 times greater than spiny stellate, generating a differential window for excitatory neuron activity within the disinhibitory circuit that is induced by the thalamus.

Connectomics has also developed applications in chronic neurological conditions such as epilepsy (Mithani et al., 2019), affecting cognitive and affective function; thus, connectomic studies allow the identification of biomarkers that allow early identification of this type of disease (Rodriguez-Cruces et al., 2022). Multiple sclerosis (MS) has also been investigated, which acts as a syndrome that generates a disconnection in the brain network, whereby the disconnection mechanism of this disorder is still under study (Kamagata et al., 2019). Timonidis *et al*., (2020) made a contribution toward the prediction of the cell class-specific mouse mesoconectome using gene expression data. In this way, the importance of integrating multimodal data to improve the accuracy in mesoconectome for the support of research cases in neurosciences is demonstrated. In this case, mesoconectomics, being a science that studies the intermediate connections in different biological networks at micro and macro scale, allows to evaluate the different interactions that occur at mesoscopic level, applied towards the understanding in relation to the global functioning of biological systems, generating an integrated and complex function (Timonidis et al., 2020).

Other research presents an evolution in the field of neurosciences to understand auditory processing, however, in humans it represents a computational challenge to understand this process, hence models of integration of the connectome to the neuronal circuits expressed by organisms such as Drosophila have been reported, evaluating the physiological response to exposure to musical waves (Bates & Jefferis, 2022), in addition to acting as a model organism to generate an exploration of the functioning of basic motor circuits (Hasegawa et al., 2016). Similarly, there is the study of different types of tumors that occur at the brain level, allowing to generate a pre-surgical planning of how to approach this type of brain gliomas, through the construction of meta-networks, allowing to address the problem taking into account the different vascularizations of the tumor distributed as critical cortical and subcortical circuits, allowing to generate analysis options in front of brain sections that may become inoperable (Duffau, 2021), as well as to study the connective change expressed under the presence of brain lesions within the same topographic architecture of the brain functional network, through the use of multivariate regressions of support vectors for functional imaging data (Yuan et al., 2017).

Mental health is a point of research within connectomics, within this omics science it has been tried to find reliable indicators of mental health, in this way, the canonical correlation analysis (CCA) is applied, using MRI for the determination of positive - negative measurement patterns at brain level, explaining neurotypical relationships between connectivity and phenotype, generating neuroscience applications towards clinical research (Goyal et al., 2022). Additionally, neurodegenerative diseases are another point of application of this science, for example, Alzheimer's disease (AD) is still under study because the understanding of its mechanisms of action still does not have a complete understanding, developing computational brain simulation methods for AD, to understand the neurodegenerative process of this disease; currently reported is the brain network simulator "The Virtual Brain" (https://www.thevirtualbrain.org/tvb/zwei/brainsimulator-software), open source software for the analysis of whole brain simulation that allows to contribute to the understanding, diagnosis and treatment for a variety of neurodegenerative diseases through the application of neuroinformatics (Stefanovski et al., 2021). This type of simulations allows the evaluation of neuronal morphometry and connectomics at the brain level, generating a monitoring, visualization, quantification and possible quantification of the neuroanatomy present in a given organism (Arshadi et al., 2021). The United States, for example, using a STEM-type educational methodology, is inducing the creation of virtual experiences that allow research in a laboratory environment, creating brain and connectomic maps (BMC) that can be key for future neuroscientists, generating learning in labeling brain neurons, cytoarchitecture analysis and brain chemoarchitecture (Khan et al., 2021).

The information obtained is taken to a process of application of predictive models using machine learning (ML) for the interpretation of ML, MRI and fMRI data (Mohanty et al., 2020), allowing the correlation of various dimensions of the connectome at the human level, making interpretations, findings and recommendations on the reproducibility of the results obtained from the interpretation of data obtained from neuroimaging, advancing in the determination of imaging biomarkers that allow the detection of brain disorders (Cwiek et al., 2022). Some established tools to perform morphological representations of neurons for the visualization of interconnections at the synaptic level is SynCoPa, allowing to explore and analyze the connectivity in different neuronal circuits that are present at the level of the connectome (Galindo et al., 2021).

5. Methodology

5.1 Search for information

The information search was conducted on September 14, 2024, using the scopus database. The search terms were selected based on the ScienceDirent Topics thesaurus. The objective of this search was to explore connectomics as an omics science, its origin, and its main research contributions within fields of chemistry and neurosciences. Additionally, the search aimed to identify studies that highlight scientific progress in connectomics within Colombia. In general, 310 articles were identified worldwide with this search equation. However, none of these articles were developed in Colombia. In constrast, several other countries reported significant contributions within this field of study. This result highlights a gap in knowledge about connectomics and its relevance to scientific research in Colombia. Therefore, this bibliometric analysis seeks to provide an overview of the different contributions of connectomics and its applications in the world of chemistry and neurosciences. The finding may help to initiate discussions and promote research on omics sciences in Colombia, contributing to the continuous advancement of science.

6. Results and Discussion

A search for information was performed in the Scopus database for the bibliometric analysis (Betancourt-Arango et al., 2022), using the following search equation:

((connectomic OR connectomics) AND (neuroscience OR neurosciences))

With this, a total of 310 articles were obtained, performing the search on September 14, 2024. This total of articles obtained indicates a worldwide value and without the application of any type of filter, however, to date when trying to find which of these 310 articles obtained are from Colombia, a result of 0 articles reported is obtained, indicating the lack of research on this omics science that is relatively new for Colombia, but for a variety of other countries research on this science is already reported. To verify this information, a graph of co-citation between countries was made using the VOSviewer program, evaluating the current contributions on the development of this science (**Figure 3**), in this way, countries such as the United States, United Kingdom, China, Germany, Canada, Spain, Australia and France present a representative node size over the others, indicating a greater production of primary and secondary research related to the concept of connectomics, applications and pioneering research in the development and understanding of a variety of neurodegenerative diseases, in addition to understanding the connections of this science to the chemical aspect and its contributions in the neuroscientific field.

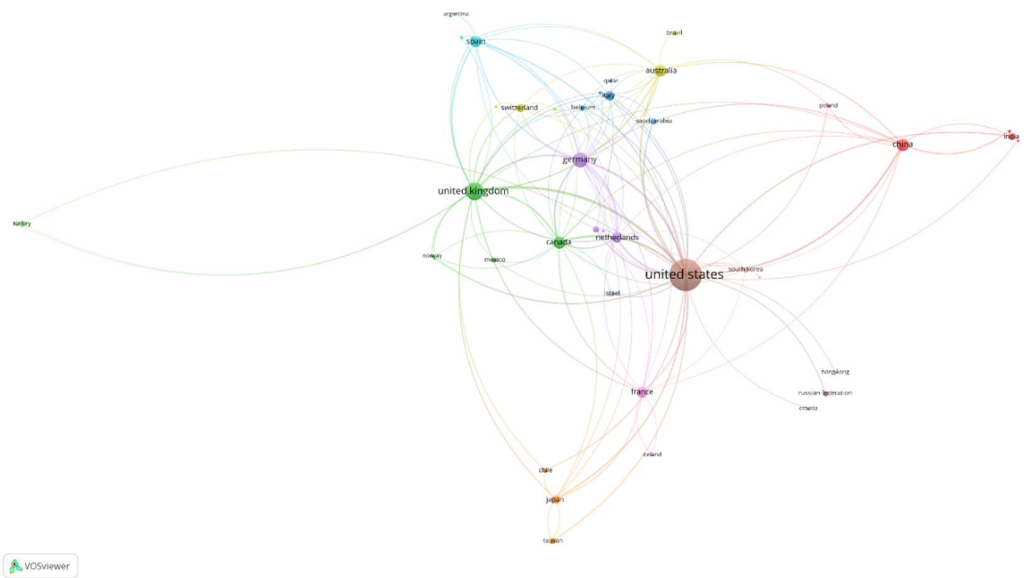


Figure 3. Graph of co-citation of connectomics research in countries, obtained through bibliometric information in Scopus, elaborated using the VOSviewer program.

Additionally, connections with other countries such as Italy, Argentina, Brazil, India, Qatar, Chile, Japan, Hong Kong, Croatia, Russia, Saudi Arabia, among others, are observed, which also express collaborative research developments between these countries, thus generating advances on the knowledge of the connectomic world, its development and potential use in the interconnection of information with other omic sciences and towards the understanding of this type of approaches. When we talk about neurosciences and their relationship with connectomics, a variety of important concepts are integrated for the transversalization of information and towards a better understanding of this emerging omics science from the neuroscientific and chemical point of view. In **Figure 4A** and **Figure 4B**, one can observe the keyword co-occurrence graphs that are integrated and interconnected to form two types of representative graphs about this type of information, relating terms such as: the connection between connectomics and neurosciences for the development of research that evaluates human and animal neuroanatomy, using different instrumental techniques for the exploration of networks of synaptic connections that are altered in the development of neurogenerative diseases or expressed neuronal disorders (epilepsy, schizophrenia, alzheimer, cancer, among others), but that the mapping of these connections through neuroimaging techniques, gives information regarding the vitality of these nerve connections in the processes of learning, cognition, emotional regulation processes.

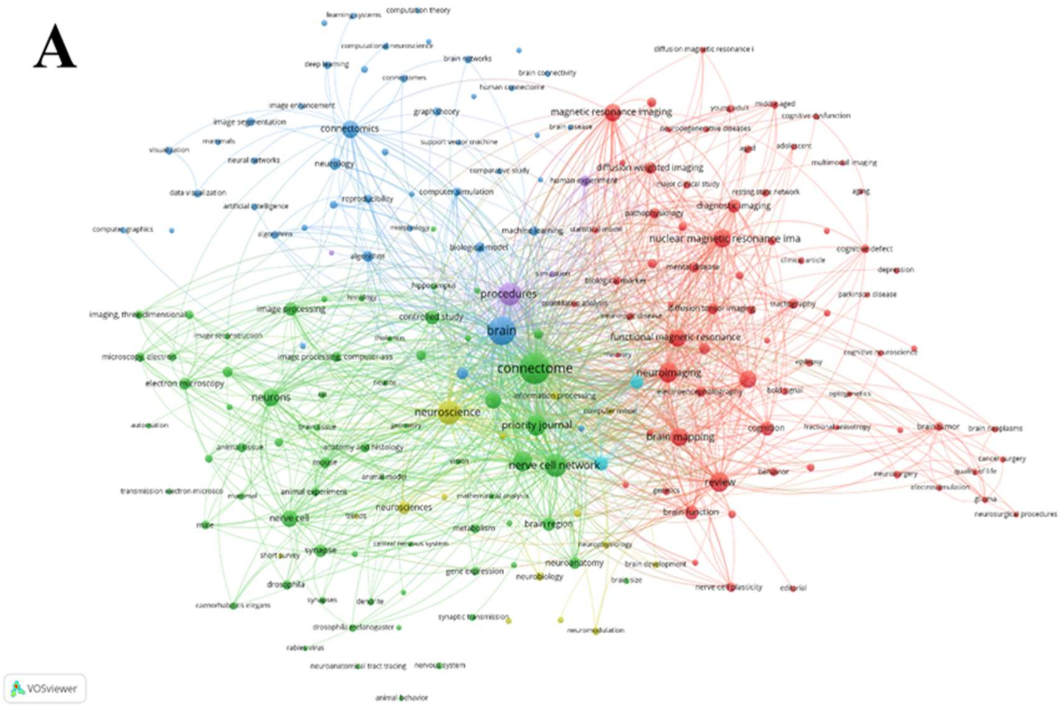
Hence the importance of using graph theory within a connectomic study, for the interconnection and determination of the functionality, structure and synaptic stimulation processes carried out through the construction of these neural networks. In addition, the use of techniques such as Machine Learning for the interpretation of this variety of information obtained by electron microscopy, resonance imaging, image segmentation, for the exploration of neural circuits, development of new research approach type genetic - connectomic neuroimaging to study brain anatomy is highlighted (Ortiz-Teran et al., 2021). The development of connectomics research involves generating an understanding of the different neuroimaging, today it is being widely used in the fields of medicine, neurosciences and partly by chemistry, however, the most limiting factor for the growth of this type of science is the acquisition and processing of this type of information. From there is where it is explained why research on this matic has not been found for Colombia, because we are still growing in the genomic, transcriptomic, proteomic and metabolomic aspect, independently and trying to make multiomic studies that allow connecting this type of information, however, this information of these omic sciences is the beginning for the understanding of the synaptic connections from the chemical environment and understand how these brain branches are developed to generate cognitive and motor processes, hence the importance of merging this type of information with the connectomics.

Being an emerging science, there are few researches obtained in Scopus in relation to other commonly studied omics, however, 24 scientific journals have been found in this bibliometric study that have been in charge of publishing researches that correlate scientific advances in relation to the concept of connectomics, highlighting the different techniques of data acquisition in images, cranial and intracranial evaluation of synaptic connections, interpretation of the brain environment, elaboration and adaptation of mathematics for the resolution of problems in this aspect and also the creation of brain simulation environments with programming languages that allow the execution of algorithms for the preprocessing and processing of computational data.

Revistas Científicas

Biosalud
REVISTA CIENCIAS BÁSICAS

A



B

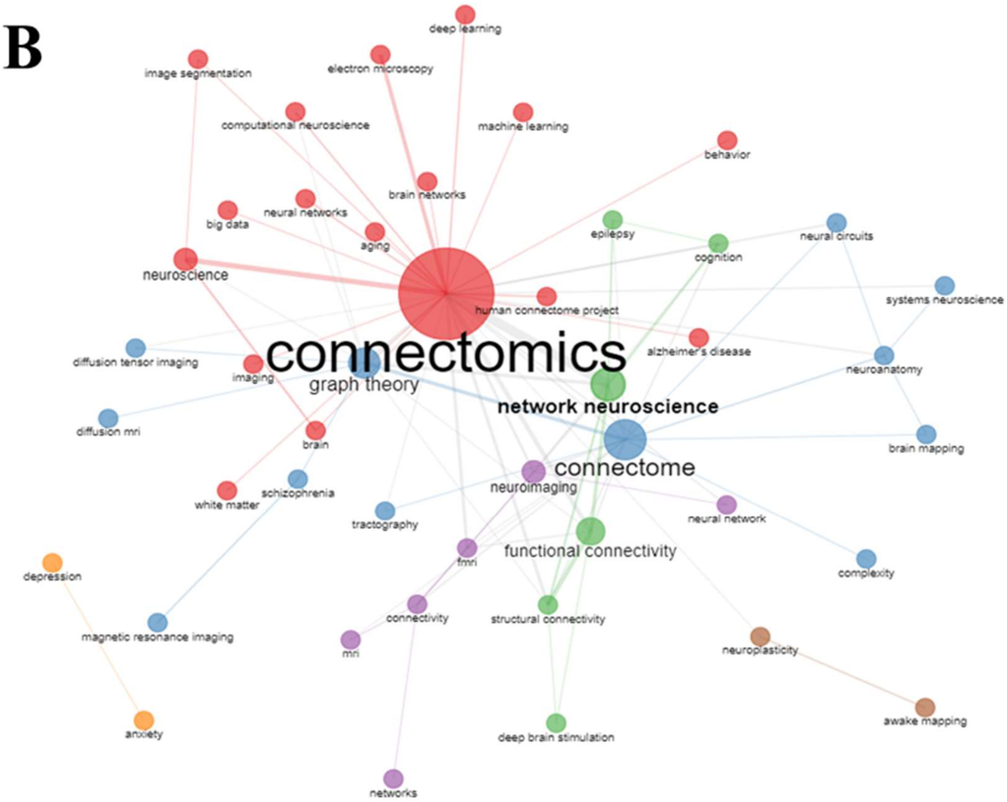


Figure 4. Keyword co-occurrence graph obtained through bibliometric information in Scopus elaborated by means of the programs. **A.** VOSviewer. **B.** RStudio.

Thus, **Figure 5** shows that the journals Neuroimage, Lecture notes in computer science, Network neuroscience, Frontiers in neuroinformatics, Current opinion in neurobiology, Frontiers in neuroscience and Journal of neuroscience methods, are the main journals that publish the different scientific advances reported over time on research in connectomics, they are specialized journals in the field of neuroscience and exalt the relationship of this with this omics science. Also other journals found that publish this type of information, in **Table 1** you can find a list of all of them, highlighting the impact factor that each one has and the respective category in which it is located.

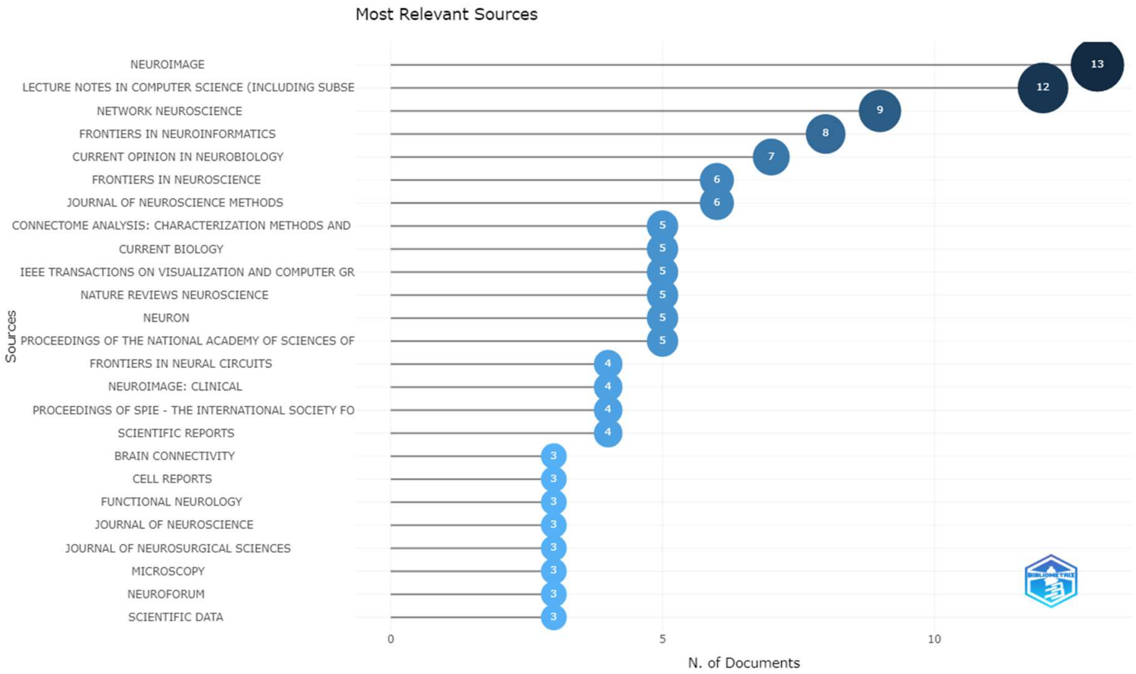


Figure 5. Number of articles identified for the main authors reported for the present bibliometric study.

Of the total number of journals identified, 54.16% were in the Q1 category (national and international journals with the highest impact factor), 25% in Q2 (They are journals that have a good impact and are recognized), 4.16% in Q3 (scientific journals with a moderate impact factor) and 16.66% were not included in the Scimago Journal and Country Rank classification system, which indicates that these journals are incipient in publications and are not yet registered in this cataloging system.

Table 1. Main journals for the publication of research on connectomics.

Magazine number	Magazine	Category	H-Index	SJR 2023
1	Neuroimage	Q1	418	2.44
2	Lecture notes in computer science	Q2	470	0.61
3	Network neuroscience	Q1	31	1.57
4	Frontiers in neuroinformatics	Q2	77	0.77
5	Current opinion in neurobiology	Q1	250	2.98
6	Frontiers in neuroscience	Q2	153	1.06
7	Journal of neuroscience methods	Q2	175	0.94
8	Connectome analysis: characterization methods and analysis	-	-	-
9	Current biology	Q1	361	2.98
10	IEEE transactions on visualization and computer graphics	Q1	166	2.06
11	Nature reviews neuroscience	Q1	474	7.86
12	Neuron	Q1	530	7.73
13	Proceedings of the national academy of sciences of the United States of America	Q1	869	3.74
14	Frontiers in neural circuits	Q1	81	1.53
15	Neuroimage: Clinical	Q1	95	1.43
16	Proceedings of spie – the international society for optical engineering	-	193	0.15
17	Scientific reports	Q1	315	0.9
18	Brain connectivity	Q2	65	0.79

19	Cell reports	Q1	224	4.28
20	Functional neurology	-	49	-
21	Journal of neurosurgical sciences	Q2	41	0.42
22	Microscopy	-	-	-
23	Neuroforum	Q4	10	0.25
24	Scientific data	Q1	120	1.94

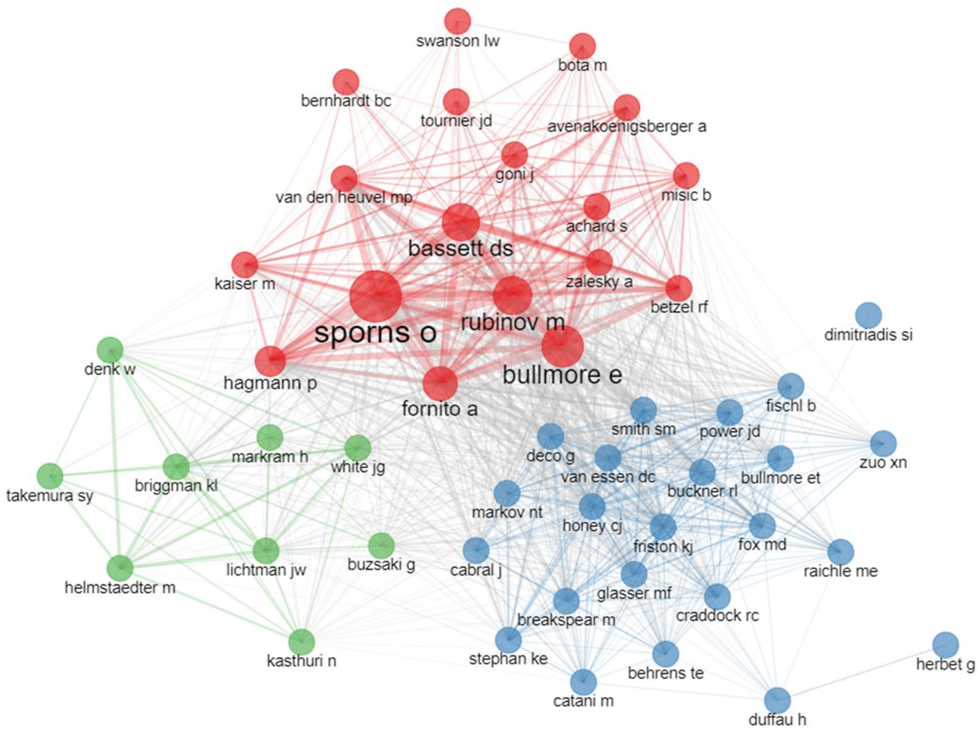


Figure 6. Graph of co-citation among the main researchers reported during the present bibliometric analysis, elaborated through the RStudio program.

The most representative authors in the development of connectomic research can be seen in **Figure 6**, identifying Sporns, O., Bassett DS., Rubinov M., Bullmore E., and Fornito A., as central authors in the development of this type of research, since, through a co-citation graph, a larger node size can be observed for these, indicating that they are central authors in this type of studies. However, three color clusters were established, establishing collaborative connections with other researchers worldwide, which indicates the development of interdisciplinary and collaborative studies between countries to give a clearer and deeper understanding of this type of analysis and results for the development of connectomics.

7. Conclusions

Connectomics itself has proven to be a key omics science in the advancement of neurosciences, allowing to generate a mapping of the different existing neural networks and generate a deep understanding of neurological disorders associated with diseases such as epilepsy, multiple sclerosis, Alzheimer's, among others. Supporting these advances from technologies such as magnetic resonance imaging and three-dimensional electron microscopy, for the identification of abnormal structural patterns. Similarly, the integration of multidisciplinary approaches such as neuroimaging, graph theory, machine learning and deep learning have enabled the development of connectomics itself, allowing to advance in brain simulations and identify biomarkers for early diagnosis of brain disorders, as well as to understand neural morphometry and synaptic connectivity.

In spite of the world advances in connectomics, in the case of Colombia there are still no significant reports of research in this field in contrast to other countries that are world powers. Therefore, the need to promote this type of research and generate an integration with other omics sciences such as genomics, transcriptomics, proteomics and metabolomics that are more advanced worldwide and particularly in Colombia is highlighted, thus highlighting the need to generate strategic alliances that allow building advances in the development of connectomic studies through international collaborative approaches to generate growth in this emerging omics science. These alliances will allow to generate a better understanding of complex neural systems, improving the diagnosis and treatment of various neural and psychiatric conditions, as well as to generate planning prior to the development of surgical interventions.

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Author contributions

JPBA: Drafting of the document and revision of the document on connectomics. **APO:** Validation of information and work methodology. **MCSM:** Bibliometric analysis and information synthesis. **GTO:** Revision and correction of the final document.

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Ethical approval and consent to participate

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Consent to publication

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Conflict of interest

The authors declare that they have no conflict of interest with respect to the content of this article.

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