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Bibliometric Analysis of The Top 100 Most Cited Articles on The Thalamus Anatomy

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ABSTRACT

Objective: The thalamus regulates complex tasks like motor function and executive control while transmitting sensory information to higher centers. Bibliometric analysis analyzes studies in a research area and guides planning studies in that area. Despite bibliometric analysis in anatomy, there is no study on the thalamus' anatomy. This study aims to perform a bibliometric analysis of the 100 most cited articles on the anatomy of the thalamus, a clinically important region, to guide research in this area, as there is no study on this topic in anatomy.

Material and Methods: Bibliometric analysis was used to evaluate human studies on the anatomy of the thalamus that were published in the Web of Science database between 2004 and 2023. As a result of the analysis, 1704 documents from the last twenty years were found. The data of the first 100 most cited articles were obtained.

Results: The average number of citations of the articles was 229.14. The publication years of the first 5 most cited studies were 2006-2010. The most cited study was by Heckemann et al. (2006). Articles were mostly published in NeuroImage. The United States has the strongest bibliographic link, publishes the most articles and is the most cited. Snyder Abraham Z. is the author with the most articles on this topic. Keyword co-occurrence analysis revealed 4 different clusters: the thalamus and its relationship to related anatomical structures, the connection between the thalamus and psychiatric and mood disorders, the relationship of the thalamus to the cerebral cortex, and the function of the thalamus.

Conclusion: Researchers show high interest in studies on the anatomy of the thalamus. The fact that the studies to be planned on the anatomy of the thalamus have to do with neuroimaging is one of the factors that may increase the number of citations.

Keywords: Thalamus, anatomy, bibliometric analysis, neuroimaging

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INTRODUCTION

The thalamus is a nuclear complex that borders the upper part of the 3rd ventricle from both sides (1), and is located in the diencephalon (2). It plays an important role in many sensory and motor functions such as arousal, cortical synchronization, emotion, cognition and memory (3, 4). The thalamus is not only a relay, but also plays a role in controlling executive networks and regulating complex behaviours such as behavioural flexibility and reward-directed behaviour (5, 6).

The thalamic nuclei are roughly divided anatomically into anterior, medial and lateral nuclei of the thalamus (7) by a white matter called the internal medullary lamina of the thalamus (8) , which divides the internal structure of the thalamus in the shape of a "Y". In the posteroinferior region, the thalamic nuclei are also divided into core groups, which include the medial and lateral geniculate bodies (7). In the clinic, it is very important to know the anatomy of the thalamic nuclei and the vascular system that supplies them. This is because vascular dysfunction in one of the thalamic nuclei can lead to infarcts and loss of function in certain areas (9).

The thalamic vascular areas are divided into 7 regions: anterior, inferolateral, paramedian, posterior, anteromedian, central and posterolateral (9, 10). Memory loss, hemiparesis and emotional disturbances are located in the anterior region; contralateral hemianesthesia, hemibody pain and movement disorders are located in the inferolateral region; visual disturbances, hemiparesis, memory loss and akinetic mutism are located in the paramedian region; hemianopsia, contralateral hemianesthesia, hemibody pain in the posterior region; vertical gaze paresis, amnesia, aphasia and abnormalities in the anteromedian region; cognitive loss, vertical gaze paresis, loss of arousal and ataxia in the central region; aphasia, ataxia and loss of executive function in the posterolateral region (9).

In addition, thalamic nuclei are associated with many diseases such as attention deficit hyperactivity disorder (11), Parkinson's disease (12), multiple sclerosis (13), cognitive disorders and dementia (14) and autism (15). The insufficient evidence of the pathways associated with the connection of thalamic nuclei to disease (13, 16) increases researchers' interest in anatomical studies of the thalamus.

The synthesis of previous studies in the field is an important component for organizing new research in the future (17). Bibliometric analyses provide cumulative information by mapping and visualizing the publications published and indexed in a scientific field, their characteristics, and their literature status (18, 19). In bibliometric studies, the publications in the literature are analyzed quantitatively using statistical methods. The bibliometric study aims to determine which topics current research focuses on (20, 21). In this way, it helps researchers plan future research using the information from past research. Bibliometric studies on anatomy, one of the basic medical fields, have already been conducted (21, 22). However, no bibliometric study on the anatomy of the thalamus was found. Considering the clinical importance of the thalamus, a bibliometric analysis of the 100 most cited articles on the anatomy of the thalamus could be useful to guide future studies. Therefore, this study aims to perform a bibliometric analysis of the 100 most cited articles on the anatomy of the thalamus.

MATERIAL and METHODs

In this study, studies on the anatomy of the thalamus in the Web of Science database from the last 20 years were analyzed. The date of data collection was 13.02.2024. Since the year 2024 has not yet ended, publications in 2024 were not included in the study to prevent them from influencing the results of the study. No language restrictions were applied for this bibliometric analysis. Human anatomy studies, research articles, articles indexed in the Science Citiation Index Expanded, the Social Sciences Citiation Index and the Emerging Sources Citiation Index, and articles from the last 20 years (2004-2023) were included in this study. Exclusion criteria were animal studies (studies with mice, rabbits, rats, zebrafish, monkeys, gerbils or primates), proceeding papers, book chapters, early access papers, reviews and/or meta-analyses. In view of all this information, our search query is ((TS=(“thalamus" AND "anatomy”)) OR TS=(“thalamic anatomy”)) OR TS=(“thalamus" AND "anatomical”)) OR TS=(“thalamus" AND "neuroanatomy”)) OR TS=(“thalamic" AND "nuclei" AND "anatomy”)) OR TS=(“thalamic" AND "nucleus" AND "anatomy”)) OR TS=(“thalamocortical" AND "anatomy”)) OR TS=(“thalamo-cortical"AND "anatomy”)) OR TS=(“corticothalamic" AND "anatomy”)) OR TS=(“cortico-thalamic" AND "anatomy”)) NOT TS=("mouse")) NOT TS=("mice")) NOT TS=("rabbit")) NOT TS=("rat")) NOT TS=("monkey")) NOT TS=("zebra fish")) NOT TS=("zebrafish")) NOT TS=("primate")) NOT TS=(gerbil) (https://www.webofscience.com/wos/woscc/summary/2b264d9e-d067-4380-b704-38162e88c68b-cbe909e6/times-cited-descending/1).

Initially, 2648 documents were retrieved with our research request. When the document type (research article) and the Web of Science Index were taken into account, the number of documents decreased to 2224 and 2195 respectively. After removing "zoology" and "veterinary science" categories, which we assumed to include possible animal studies from the WOS categories, 2122 documents were obtained. Finally, when the studies from the last 20 years were considered, the total of 1704 documents were reached. The titles, abstracts and/or full texts of these studies were checked for compliance with the possible inclusion criteria, and the data of the first 100 most cited articles were extracted from the Web of Science database and transferred to an Excel file.

Statistical Analysis

In this study, the descriptive data of the studies on the anatomy of the thalamus in the Web of Science database for the last 20 years were presented as tables or graphs in the form of numbers and percentages. In addition, a bibliometric analysis of the reviewed studies was performed using the VOSviewer software (version 1.6.17 of VOSviewer). VOSviewer is a free program developed for the creation and display of bibliometric maps (23). In bibliometric maps, items are represented by circles. These circles are labeled, and the size of each circle indicates the weight of the corresponding item (24). In other words, the more important an item is, the larger its label and the larger the area of the circle. The lines between the circles on the map show the total link strength; higher total link strength indicates a stronger relationship between items (23).

RESULTs

Descriptive Information about the top 100 most cited articles

The average citation number of the top 100 most cited studies on the anatomy of the thalamus in the Web of Science database published between 2004 and 2023 is 229.14 (range: 125-670). The most cited study is Heckemann's "Automatic anatomical brain MRI segmentation combining label propagation and decision fusion" published in 2006. The top 5 most cited studies on the anatomy of the thalamus between 2004 and 2023 were mostly published between 2006 and 2010. Only one study (Automated anatomical labeling atlas 3) was published in 2020. All articles are written in English. Authors with more than one publication as first author are Zhang S (n=2), Butson (n=2), Zang DY (n=2), Nosarti (n=2), Haznedar (n=2) and Rose (n=2). The 100 most cited articles are listed in Appendix 1. Most of these articles were published in NeuroImage (n=27) (**Figure 1**).

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Bibliographic Coupling Analysis of the Countries

Bibliographic coupling evaluates the similarity between documents based on the number of shared references (25). Martyn introduced the term as "two papers that share one reference contain one unit of coupling, and the value of a relationship between two papers having one or more references in common is stated as being of strength one, two, etc., depending on the number of shared references." (26). Kessler confirmed the existence of a subject relationship between bibliographically matched documents (27).

A bibliographic coupling of countries occurs when documents from two countries cite documents from a third country (28). When we review the most cited studies in the field of anatomy related to the thalamus, the bibliographic matching of countries is shown in Figure 2. The scale in Figure 2 shows the relationship between the colors and the number of citations in each country. The figure shows that the country with the strongest connection is the United States of America (USA) (TLS=4532). After the USA, the countries with the highest number of similar studies to other countries are the United Kingdom (TLS=4317), France (TLS=2788), and Germany (TLS=2056).

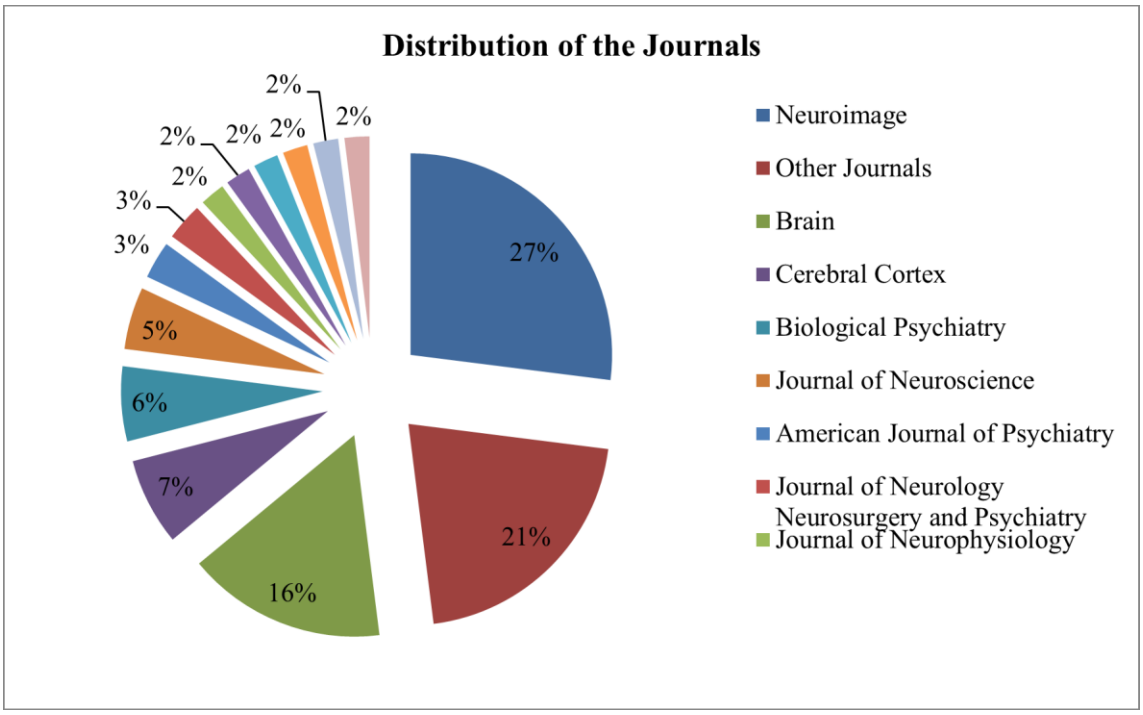

Figure 1. Distributions of the journals

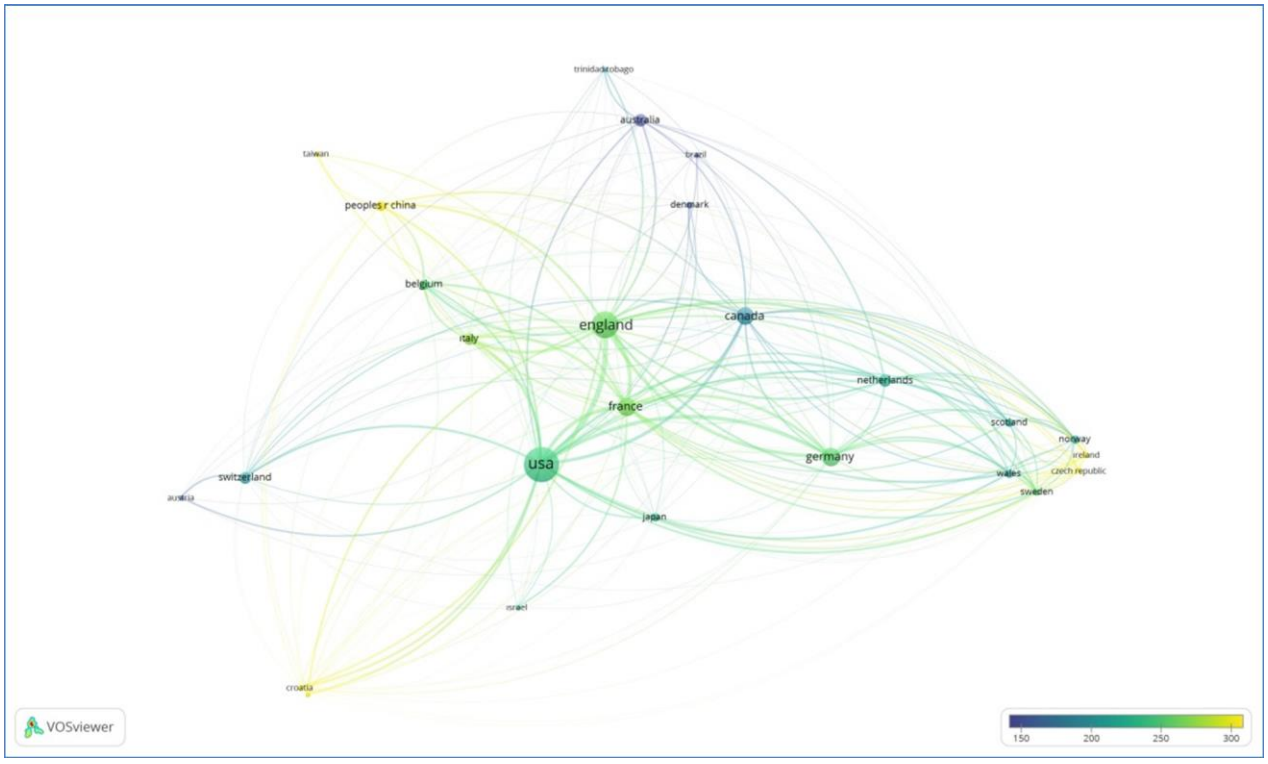

Figure 2. Bibliographic coupling analysis of the countries

The number of articles published, the number of citations and the total link strength values of the countries are shown in Table 1. The top three countries with the highest number of publications (taking into account the country of affiliation of all authors) are the USA, England and France. These countries are also the three most cited countries. Taiwan has the highest average number of citations per article (n=573).

Co-authorship Network Analysis

Reporting co-authorships, author citations, and identifying authors who have contributed most to studies on the thalamus aid researchers in staying updated on current developments and understanding the dynamics of the topic.

In this analysis, we excluded studies with more than 25 authors due to the high number of authors and author collaborations. The links in Figure 3 indicate co-authorships or collaborations between authors. A high total link strength indicates a high number of documents that the author has co-authored with other authors. The size of the circles labeled with the authors' names is related to the number of documents of the author. A larger circle indicates that the author is more productive in the related field (23). The top 3 authors with the highest number of collaborations with other authors in the related field are Williams Steven C. R. (TLS=22), Lu Guangming (TLS=20) and Snyder Abraham Z. (TLS=19). Snyder Abraham Z. is also the author with the most documents and the most citations in the related field (Table 2). Table 2 lists the authors with 2 or more documents in the related field in descending order by number of citations.

Tablo 1. Number of documents and citations, and bibliographic coupling details according to the countries

Ranking	Countries	Documents (taking into account the country of affiliation of all authors), n (%)	Documents (taking into account the country of affiliation of all authors), n (%)	Citiation number	The average number of citations per article	TLS
1	USA	46 (27.71)	39 (39)	11110	241,52	4532
2	England	27 (16.27)	18 (18)	6931	256,70	4317
3	France	13 (7.83)	5 (5)	3408	262,15	2788
4	Germany	13 (7.83)	8 (8)	3269	251,46	2056
5	Canada	12 (7.23)	5 (5)	2262	188,50	1591
6	Italy	5 (3.01)	1 (1)	1354	270,80	1231
7	Netherlands	6 (3.61)	2 (2)	1335	222,50	1135
8	Wales	3 (1.81)	-	630	210,00	1017
9	Sweden	2 (1.20)	-	490	245,00	935
10	Belgium	4 (2.41)	2 (2)	986	246,50	855
11	People's Republic of China	4 (2.41)	4 (4)	1363	340,75	761
12	Scotland	3 (1.81)	1 (1)	635	211,67	754
13	Norway	3 (1.81)	1 (1)	627	209,00	602
14	Australia	6 (3.61)	5 (5)	935	155,83	591
15	Czech Republic	1 (0.60)	-	308	308,00	570
16	Ireland	1 (0.60)	-	308	308,00	570
17	Croatia	1 (0.60)	-	320	320,00	468
18	Slovenia	1 (0.60)	-	320	320,00	468
19	Switzerland	5 (3.01)	4 (4)	1010	202,00	467
20	Austria	1 (0.60)	5 (5)	165	165,00	216
21	Trinidad Tobago	1 (0.60)	-	196	196,00	207
22	Denmark	2 (1.20)	2 (2)	325	162,50	186
23	Japan	3 (1.81)	1 (1)	675	225,00	153
24	Israel	1 (0.60)	-	232	232,00	147
25	Taiwan	1 (0.60)	-	573	573,00	136
26	Brazil	1 (0.60)	1 (1)	157	157,00	105

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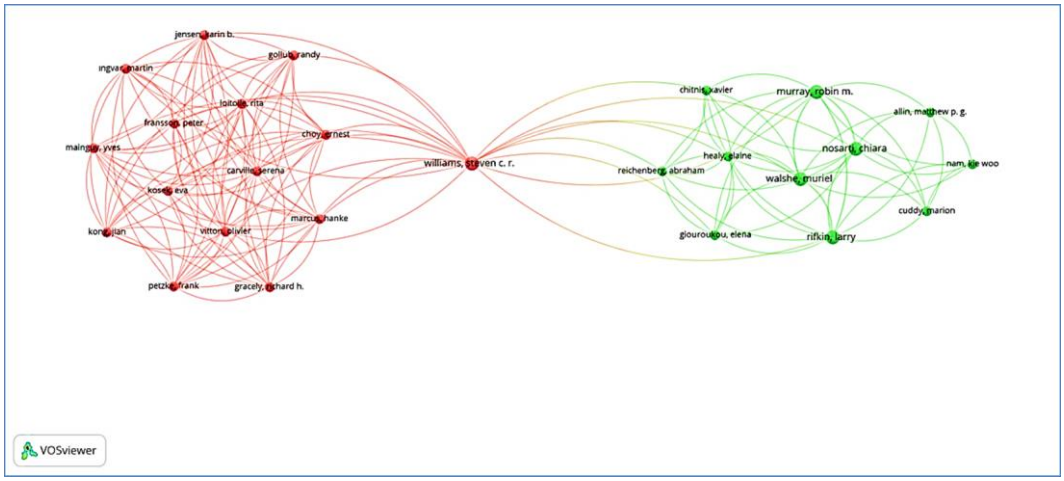

Figure 3. Co-authorship Network Analysis

Tablo 2. List of most cited authors

Ranking	Author	Documents	Citiations	The average number of citations per article	Total link strength
1	Snyder, Abraham Z.	4	1428	357,00	19
2	Shimony, Joshua S.	3	1123	374,33	15
3	Alexander, Daniel C.	2	915	457,50	17
4	Parker, Geoff J. M.	2	915	457,50	17
5	Hammers, Alexander	2	809	404,50	10
6	Rueckert, Daniel	2	809	404,50	10
7	Feng, Jianfeng	2	786	393,00	14
8	Li, Chiang-Shan R.	3	703	234,33	4
9	Lu, Guangming	2	639	319,50	20
10	Fox, Michael D.	2	619	309,50	9
11	Raichle, Marcus E.	2	619	309,50	9
12	Zhang, Dongyang	2	619	309,50	9
13	Schuepbach, Michael	2	573	286,50	18
14	Zhang, Sheng	2	570	285,00	3
15	Brody, Al	2	558	279,00	15
16	Smith, Ec	2	558	279,00	15
17	Calhoun, Vince D.	2	550	275,00	13
18	Pearlson, Godfrey	2	550	275,00	13
19	Butson, Christopher R.	2	545	272,50	4
20	Mcıntyre, Cameron C.	2	545	272,50	4
21	Williams, Steven C. R.	2	496	248,00	22
22	Jeanmonod, Daniel	2	465	232,50	7
23	Murray, Robin M.	2	457	228,50	14
24	Nosarti, Chiara	2	457	228,50	14
25	Rifkin, Larry	2	457	228,50	14
26	Walshe, Muriel	2	457	228,50	14
27	Gustin, Sylvia M.	3	451	150,33	18
28	Henderson, Luke A.	3	451	150,33	18
29	Barker, Gareth J.	2	447	223,50	17
30	Duncan, John S.	2	447	223,50	17
31	Koepp, Matthias J.	2	447	223,50	17
32	Symms, Mark R.	2	447	223,50	17
33	Paulson, Olaf B.	2	325	162,50	11
34	Murray, Greg M.	2	308	154,00	14
35	Peck, Chris C.	2	308	154,00	14
36	Wilcox, Sophie L.	2	308	154,00	14
37	Ide, Jaime S.	2	292	146,00	3
38	Deuschl, Guenther	2	283	141,50	14
39	Herzog, Jan	2	283	141,50	14
40	Volkmann, Jens	2	283	141,50	14

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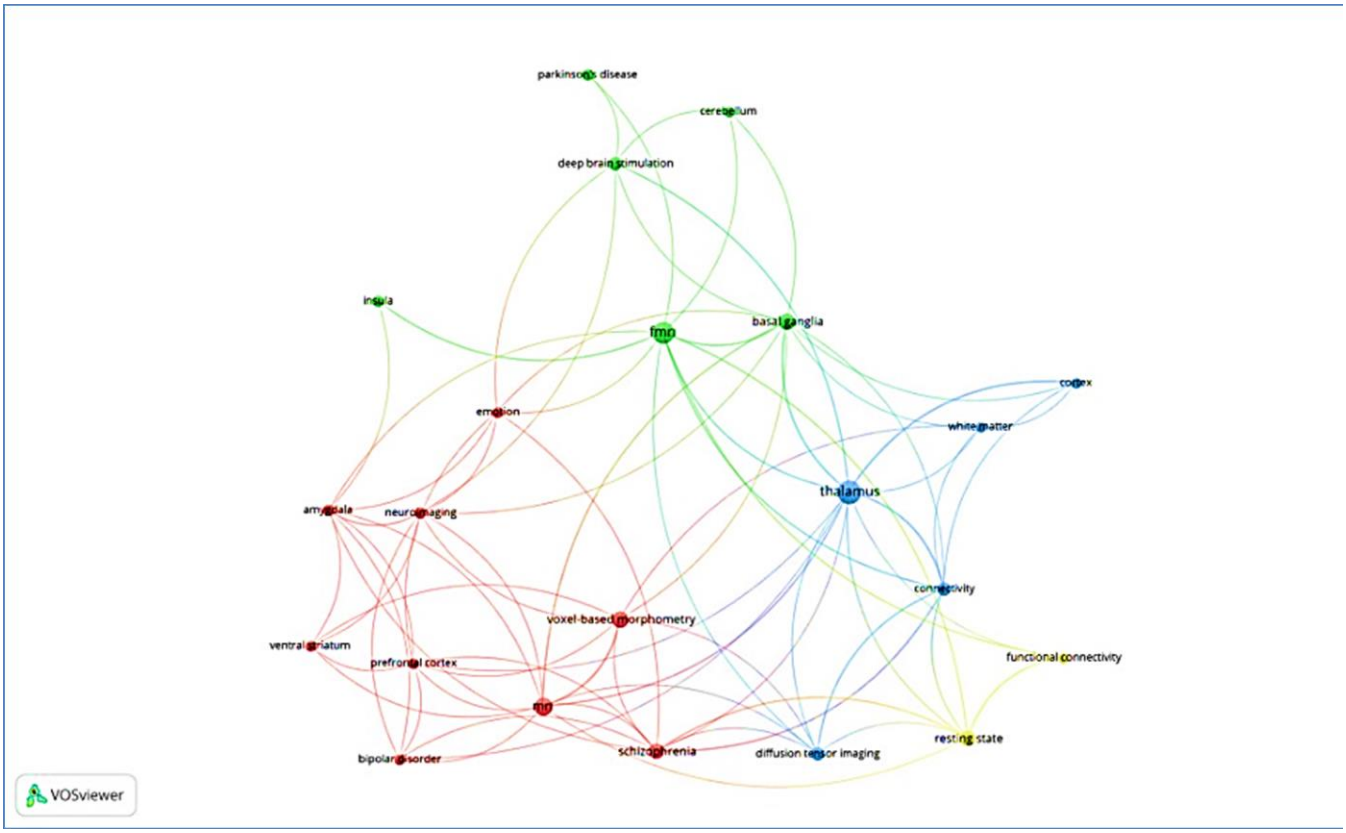
Keyword Mapping Co-Occurrence Analysis

Keywords give an idea about the topic, purpose and method of scientific research (19). This makes it easier for researchers to quickly scan for literature in the related field without having to read the full text of the article. The co-occurrence refers to the number of occurrences of two keywords in the same article. During the analysis, words with the same meaning were combined into a single word (e.g. "magnetic resonance imaging" and "mri"). Keywords with at least 3 co-occurrences were included in the analysis. The size of the circles correlates with the overall frequency of co-occurrence of the keyword. Keywords indicated with larger circles are topics more closely related to the anatomy of the thalamus. The lines between the keywords indicate the strength of the association between the keywords. When analyzing the co-occurrence of keywords, 4 different clusters were obtained. In the green cluster, FMRI (TLS=17), basal ganglia (TLS=15) and deep brain stimulation (TLS=7) are the top 3 keywords by TLS size. The top 3 keywords in the red cluster are MRI (TLS=15), schizophrenia (TLS=12) and amygdala (TLS=10). In the blue cluster, the top 3 keywords with the highest TLS scores are thalamus (TLS=23), connectivity (TLS=14) and cortex (TLS=6). The yellow cluster consists only of the keywords resting state (TLS=13) and functional connectivity (TLS=6) (Figure 4). The green cluster shows the relationship between the thalamus and related anatomical structures; the red cluster shows the connection between the thalamus and psychiatric disorders and mood disorders; the blue cluster shows the relationship between the thalamus and the cerebral cortex; and finally, the yellow cluster shows the function of the thalamus.

Co-citation Network Analysis of the Documents

A co-citation occurs when two different documents are cited by another document. In other words, it is an analysis of the frequency with which a group of publications is cited together in other publications. It is based on the co- occurrence of references in a bibliography. With this analysis, it is possible to identify articles that provide guidance and different perspectives in a field of study (29). This analysis is useful to explore the knowledge base of a particular research group (30). In this study, we used this analysis to identify the most frequent references to documents related to the anatomy of the thalamus in the last 20 years and presented them in a table and visualization. Documents that were cited at least 5 times were included in the analysis (Figure 5). The size of the circles in the figure shows the frequency of co- cited documents, while the connections between the circles represent the relationship between the references. The top 3 studies with the highest total link strength are Fox MD's "The human brain is intrinsically organized into dynamic, anticorrelated functional networks" (31); Behrens TEJ's "Non-invasive mapping of connections between human thalamus and cortex using diffusion imaging" (32) and Biswal B's "Functional connectivity in the motor cortex of resting human brain using echo-planar MRI" (33). The top three most frequently cited studies are "Non-invasive mapping of connections between human thalamus and cortex using diffusion imaging"(32), "Co-planar stereotaxic atlas of the human brain" (34) and "Parallel organization of functionally segregated circuits linking basal ganglia and cortex" (35) studies (Appendix 2).



Şekil 4. Keyword co-occurence of thalamus anatomy documents

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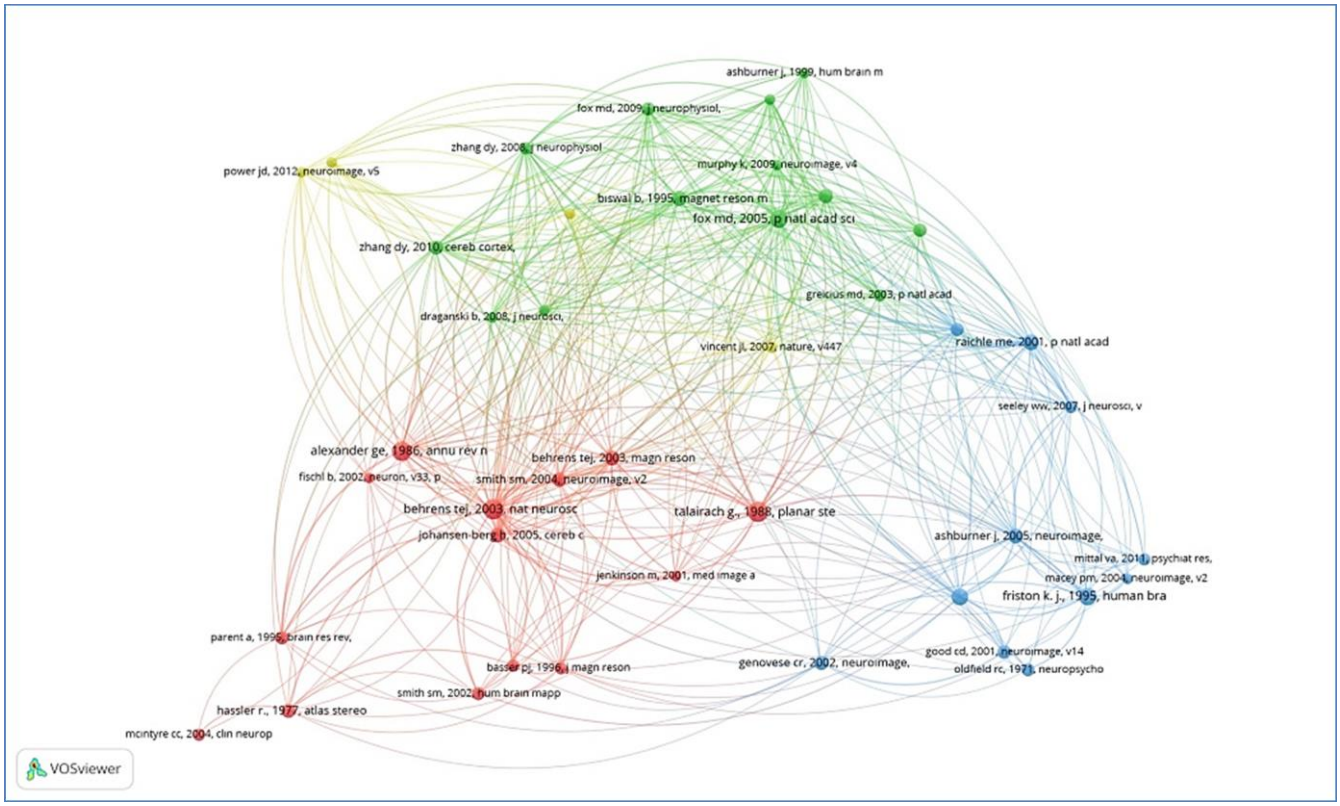

Şekil 5. Highly Cited Documents and Co-citation

DISCUSSION

This study performed a bibliometric analysis of the top 100 most cited articles published between 2004 and 2023 on the thalamus's anatomy. As a result of the study, it was found that the average number of citations of 100 articles was 229.14 and the most cited study was by Heckemann. Most of the most cited articles on the anatomy of the thalamus were published in NeuroImage. The USA is the country with the strongest bibliographic matching. The author with the most collaboration is Williams Steven C. R. In addition, Snyder Abraham Z. is the most productive author in the related field. When analyzing the co-occurrence of keywords, 4 different clusters were obtained. Among the first 100 articles listed, the study with the highest TLS score in terms of co-citations is "The human brain is intrinsically organized into dynamic, anti-correlated functional networks", while the study with the highest number of citations is "Non-invasive mapping of connections between human thalamus and cortex using diffusion imaging".

The most cited paper on the anatomy of the thalamus between 2004 and 2023 presents a procedure for automating anatomical segmentation based on MRI images of the human brain. The study experimentally determines how label propagation and decision fusion can be combined to automate the segmentation of the human brain. Although the procedure described in the study has been described previously, Heckemann's study is the first comprehensive study using data from 30 subjects. The authors also found that the propagation-fusion approach provides consistent segmentations for most macroscopic brain structures, such as the hippocampus, thalamus and orbitofrontal cortex, which will shed light on functional research and the study of disease progression in related brain structures (36).

It is believed that such anatomical modelling studies of the thalamus have attracted more attention from researchers and the number of citations of such studies has increased because they can be used to better understand the structure and functions of the thalamus, to examine different regions of the thalamus and their connections to the cortex, and to investigate diseases in which the thalamus plays a role and develop treatments. Also, the fact that 3 of the top 5 most cited studies (36-38) in this bibliometric study were related to anatomical modelling of the thalamus supports this theory that studies on anatomical modelling of the thalamus are attracting more attention from researchers.

NeuroImage ranks first among the journals in which the most frequently cited studies on the anatomy of the thalamus are published. Brain and Cerebral Cortex follow in 2nd and 3rd place on the list. All three journals have in common that they have the Open Access publishing option and are fundamentally concerned with research on the brain, even if their aims are different (39-41). NeuroImage focuses on neuroimaging studies investigating the relationships between structure- function and brain- behaviour (39). Brain is a journal in the fields of clinical neurology and translational neuroscience with a broad spectrum of topics ranging from studies to elucidate disease mechanisms to new clinical trials for brain disorders (40). Cerebral Cortex publishes articles on the development, organization, plasticity and function of the cerebral cortex, including the hippocampus, as well as on thalamocortical relationships and cortical-subcortical interactions (41).

Brain has the highest impact factor of the three journals. However, most of the most cited articles on the anatomy have been published in NeuroImage because anatomical imaging studies are among the most frequently cited studies.

Looking at the countries in which the top 100 most cited articles in the field of thalamus anatomy were conducted, the countries with the strongest relationship in terms of bibliographic similarity are the USA, England and France respectively. At the same time, these countries have the highest number of citations and publish the most articles in the related field. As the number of studies conducted in the countries has increased, so has the strength of the cross-country research network and the number of citations. Indeed, this result is not surprising given the socio-economic level of the countries concerned and the amount of funding allocated to scientific research in the countries (42).

As a result of the analysis conducted in this study found that Williams Steven C. R., Lu Guangming, and Snyder Abraham Z. were the top 3 authors who collaborated most frequently with other authors. In addition, Snyder Abraham Z. was found to be the most productive and most cited author in the field. Although Williams, Steven C. R. contributed 2 studies on the anatomy of the thalamus, we assume that his collaboration with other authors is high based on his studies with multiple authors. The author has contributed to studies on neurodevelopmental brain differences in adolescents with a history of prematurity and on pain-related functional connectivity in individuals with fibromyalgia (43, 44). Lu, Guangming also has 2 studies on epilepsy (45) and brain network changes in mental illness (46). He also participated in studies with several authors, so the degree of collaboration with other authors is high. Snyder Abraham Z. has 4 documents in the related field. The studies in which the author is involved are on the development of neuronal networks in preterm infants (47), functional relationships between cerebral cortex and thalamus (48), differences in gray matter between smokers and non-smokers (49) and affected brain structures in Parkinson's disease (50). Since he was involved in articles with fewer authors than the other authors, we think that his influence on the collaboration as co-author is less than that of the others. In addition, the highest citation rate may be associated with a larger number of documents.

Co-occurrence analysis of keywords resulted in four different themes: the thalamus and its relationship with related anatomical structures, the connection between the thalamus and psychiatric and mood disorders, the relationship of the thalamus with the cerebral cortex, and the function of the thalamus. All of these topics summarize the topics covered in the most frequently cited publications on the anatomy of the thalamus. The anatomical connections of the thalamus with other brain regions, its association with diseases, and the active multifunctional role of the thalamus in the regulation of all senses except olfaction, motor function, cognitive function, mood and motivation (51) are likely to increase the diversity of topics in the literature on the anatomy of the thalamus. The fact that the functional connectivity of the thalamus is so extensive will contribute to multidisciplinary studies by researchers from different fields.

When reviewing the co-references of the top 100 most cited papers in the field of thalamus anatomy, the study with the highest TLS score is the one that uses fMRI to examine how the human brain is organized at rest. The study shows that the activation and deactivation dichotomy routinely observed in attentional tasks is also present in the resting human brain without the presence of a task or behavior. Furthermore, the study changes the perspective on the functional role of the brain by suggesting that the brain behaves like a sensory autonomic system that responds to changing conditions (31). The fact that such studies investigating the brain's functional networks provide important data for researchers in the fields of anatomy, psychology and psychiatry has strengthened their relationship with other cited studies. In addition, based on the bibliometric data of this study, it was found that the most co-cited document was "Non-invasive mapping of connections between human thalamus and cortex using diffusion imaging". This study by Behrens et al. focuses on the specific connections between the human thalamus and cortex. The study provides the first quantitative evidence of mapping anatomical connections between the grey matter structures of the human thalamus and cortex using diffusion imaging. In addition, this study provides a comprehensive description of the connections between the subregions of the human thalamus and cortex (32). Therefore, it is believed to be of interest for studies on the anatomy of the thalamus.

CONCLUSION

In conclusion, it is recommended that neuroimaging studies may be more popular and multidisciplinary studies in different fields related to the anatomy of the thalamus can be carried out.

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Author Contributions: EH: Designed and directed the study, Literature search, Data collection, Statistics **EH:** Article writing, Final revisions. All authors reviewed the results and approved the final version of the manuscript.

Ethical approval: The present study was conducted in strict accordance with the principles outlined in the Declaration of Helsinki. Ethical approval for the study was obtained from the appropriate ethics committee. Informed consent was obtained from all participants of this study.

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