

Anatomical Sciences from a translational perspective: Bibliometric analysis

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SUMMARY

In the field of human morphology, despite its growing interest in translational anatomy research, its contributions are often unknown. Scientific articles and patents are highly reliable sources of knowledge for measuring scientific progress and technology transfer. The aim of this article is a bibliometric study of the potential of anatomical translational research. Our methodological framework has consisted of a combination of the analysis of two variables: 1) academic papers, and 2) patents of anatomical scientific achievements. The established time range has been 2000-2020 and the database used The Lens (<https://www.lens.org>), establishing “anatomical science” as the keyword. In the systematic analysis, 11,547 scientific documents and 1,511 patent registrations have been carried out; inclusion criteria were applied to both groups to identify their quantitative and qualitative trends. Our results identified that scientific articles on translational anatomical achievements have an exponential growth rate similar to the growth of patent applications for translational anatomical sciences. The maximum number of contributions of journal articles and patents corresponds to the temporal range of 2010 and 2020, with 2020 being the most productive year; academic docu-

ments represented 54.90% and patents produced represented 45.08%, which are significant data if they are compared with the year 2000, when the respective percentages were 76.40% and 23.50%, an indicator of a clear increase in the culture of patentability and the growing interest in translational anatomical research. The records of granted patents were 747 and 487 patent applications, which are significant data for the growth of the culture of patentability as well as the quality of the patents, since those granted represent 60.40%. These results identify the strong growth of anatomical science and its interest in the transfer of scientific achievements.

Key words: Bibliometrics analysis – Anatomical scientific production – Anatomical patents – Translation of knowledge

INTRODUCTION

The relevance of Anatomy has been maintained throughout history because it has proven to be a science whose usefulness is fundamental and essential for medical practice. Centuries ago, Hippocrates emphasized this importance: “The nature of the body is the beginning of science medicine” (Campohermoso et al., 2014).

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In the last 20 years, the advancement of science and technology and its transfer has improved the living conditions of citizens through the design of mechanisms capable of changing our environment and generating answers to questions raised (Fernández-Sánchez et al., 2020, Burget et al., 2017). In contemporary societies, there has been a global interest in strengthening the connections between scientific achievements and the problems of daily practice, obtaining an exponential development in translational research (Straus et al., 2011).

On the other hand, scientometrics allows the quantitative analysis of the documentary contributions of a certain science (Álvarez et al., 2014; Álvarez et al., 2022), which enables the development of different scientometric indicators (Rojas-Montesino et al., 2022). This is the criterion that we have followed in this article.

Bibliometric tools make it possible to accurately identify the information published around a thematic area and analyze its scientific and technological specificities. Current web tools make it possible to carry out more efficient and precise searches that facilitate better and more efficient meta-analyses (Chua et al., 2021). The measurement and evaluation of research performance focuses on metrically analyzing the scientific literature in a specific field of knowledge (Mingers et Leydesdorff, 2015). In this work, we have carried out a bibliometric analysis of the literature published in the field of achievements of the anatomical sciences following the studies of Aleshire (1970) and Muñoz-Leija et al. (2022). “Unlike the traditional or narrative review, the systematic review uses a more rigorous and well-defined approach to analyze the literature in a specific thematic area”; that is why systematic reviews are used in order to answer well-focused questions, and using systematic and explicit methods help identify, select, and critically evaluate research being conducted.

Consequently, we follow the guidelines for systematic review of the literature established by Al-Qaysi et al. (2020), and Al-Emran et al. (2018).

In the field of morphology in general and that of human morphology in particular, despite its

growing prominence (Aránega, 2022), the knowledge and application of anatomical translational research is often unknown because it is loosely articulated.

Anatomical research affects the resolution of biosanitary problems that require different diagnostic and therapeutic solutions with an interdisciplinary approach, where the role of anatomical knowledge is very important. Throughout time, anatomists with their scientific achievements have contributed significantly to the understanding and resolution of medical-surgical problems, although it is true that, in general, the rate of growth and production of basic translational research had not had the same rate of growth compared to basic translational research in other disciplines of Medicine.

At present, this trend has changed and anatomical researchers have assumed the importance of translational research; therefore, it has become a common component in scientific production that their scientific contributions can also have clinical utility, developing stable and effective collaborations. between basic and clinical sciences.

Translational research or applied research is making its way decisively in the academic world and has become a focus of attention in many academic circles.

Therefore, this work supposes, in the field of anatomical research, a reflective analysis on translational research and responsible innovation that is carried out in the translational anatomical area, during the period 2000-2021. We have analyzed scientometrically the scope and dimension of translational anatomical research through a systematic bibliometric study of the contributions of scientific papers and patent applications carried out in the last two decades. We intend to shed light on some of the keys to the biomedical translation of the scientific achievements obtained in the field of anatomy.

MATERIALS AND METHODS

Design and Planning

To carry out the study, a systematic review of the literature was used as a strategy to identify both

A.-the most relevant scientific documents on Anatomical Science and B.- Patent records produced.

Systematic reviews of the literature are the most widely used tool (MubarakAli et al., 2022; Heo et al., 2022) to identify, evaluate and interpret the data that we want to study, available in a given period of time and a field of research specific.

The review that has been carried out has taken into account the criteria of Kitchenham et al. (2010). First, we established the search strategy, selected the databases, chose the keywords and the temporal space, and proceeded to collect the results. Then the inclusion and exclusion criteria were applied, and we collected and identified the documents. Finally, the data were coded and evaluated and analyzed.

Search Criteria and Resources

The selection has been made based on the documents that are part of the scientific production in Academic Works and Patent literature in the anatomical sciences:

Keyword: *“anatomical science”*.

Temporal space: *2000-2020*.

Exclusion criteria: *Documents published on dates other than those established in our study and not focused on the established keywords.*

Search strategy

Database: *The Lens*

Lens is an academic database and metasearch engine that brings both academic papers and patents together into a unified and separate system, as each type of document has its place on the results page.

Lens enables document analysis to create an open mapping of the world of knowledge- driven innovation. All the software that comprises the Lens platform itself is open source and uses different databases that bring together academic documents and patents in a unified and separate system, incorporating more tools that allow viewing the interaction of academic document citations and patent registration, and providing innovative solutions (Ezeamuzie et al., 2022; Cas-

telló-Cogollos et al., 2018) The Lens is considered the “most comprehensive scholarly literature database, surpassing in width and depth two leading databases (Web of Science and Scopus)” (Dash and Kalamdhad, 2022). It is the search engine for academic documents and patents that support the implementation of metadata standards and offers interaction with other sources of information, both scientific and technological (Penfold, 2020; Jefferson et al., 2021). That is why we have used this database, due to the fact that it provides specific and complementary information that allows researchers’ access to full text documents and allows locating book citations, theses, and reports, among others.

Regarding the search for patents, The Lens provides precise information on patents applied for and granted.

Data Extraction and Verification

The data of the documents that met the criteria based on the keyword were extracted independently by 2 of our authors and divided into two groups.

A.-Scientific documents B.- Patent documents

In the two groups, the collection and evaluation of the scientific publications as well as the patents produced were carried out using the most current quantitative and qualitative bibliometric indicators (Durieux and Gevenois, 2010).

To carry out the main purpose of this work, several steps were followed; the flowchart of Fig. 1 shows the route of the bibliographic search and the respective selection of the analyzed document.

Data mining and Selection

Bibliometric analysis

A.-Academic Works

Quantitative Analysis

The published academic documents were selected and the collected data were organized and processed to obtain a quantitative representation of the distribution and evolution of the academ-

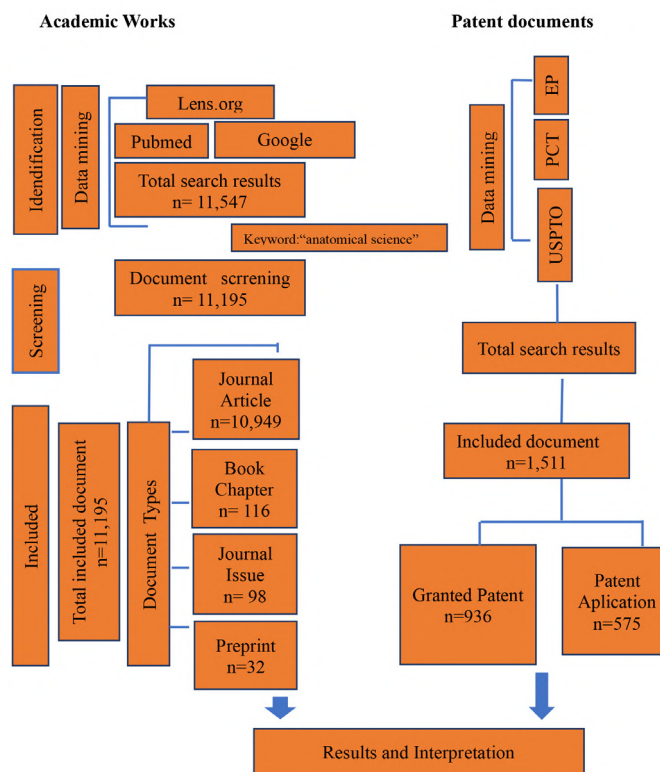


Fig. 1.- Flowchart of the development of the work: Route of the bibliographic search and the respective selection of the academic documents and of Patents analyzed.

ic documents produced in the established time range. Documents included: Journal Article, Book, Chapter Book, Report, Conference, Proceedings Article, Dissertation, Preprint and News.

Qualitative Analysis

For the qualitative analysis, the documents were divided according to the type of article published in indexed journals and with the impact factor of Books Chapter, Journal Issue and Preprint. This criterion has been used because it is currently one of the most widely used bibliometric quality indicators (Torres-Salinas et al., 2009).

To obtain Trends evidence, the distribution of the number of documents was also analyzed according to the main fields of study in which the academic documents were published. Likewise, the most active authors, the most productive academic institutions in translation of the achievements of morphological knowledge, as well as the journal with the largest number of articles, were also selected and analyzed to obtain evidence of their trend.

B.- Human Anatomy Patents

Likewise, the selection of scientific patent registries was carried out to obtain a quantitative representation of patents focused on anatomical sciences in the established period of time.

The Total Patent Documents corresponded to: Application Patent, Granted Patent, Search Report, Amended Application that were used for the quantitative analysis.

The qualitative analysis has been made based on two variables: Patent Application, Granted Patent, as these two variables constitute patentability standards (De Rassenfosse and Jaffe, 2018).

To obtain evidence of their success trend, the distribution of the number of records according to their legal status was also analyzed: active, pending, discontinued, expired, inactive and patented, the most active authors, the institutions were also selected and analyzed. Most productive academic institutions, the Top Agents & Attorney and the Top Proprietary Institutions in translation of the achievements of morphological knowledge to obtain evidence of their evolutionary trend of progress.

RESULTS

A.- Academic Works

Once the search was carried out in the indicated databases, 11,547 documents produced and published in the period of time analyzed were obtained. Total documents include: Journal Article, Book Chapter, Journal Issue, Preprint, Report, Book and Conference Proceedings.

Quality filters were applied to the total of 11,547 documents to analyze them qualitatively and draw conclusions about the research trend on Anatomical Achievements.

The qualitative analysis showed $n=11,195$ of total documents and are distributed: Journal Article $n=10,949$, Book Chapter $n=116$, Journal Issue $n=98$ and Preprint $n=32$, its evolution is reflected in the temporal range analyzed in Fig. 2a.

The quantitative analysis indicates that the most significant growth occurs in the decade 2010-2020 and the most productive year is 2020, with 1,103 documents, which represents 9,9 % of the total production (Fig. 2b).

Likewise, the study showed that the Research and Preprint Articles obtained a total of 8,602 citations. The top most active authors of research

papers (Fig. 3a and Table 1) were: R Shane Tubbs (649), Marios Loukas (584), Joe Iwanaga (209), Paul R Manger (190), Rod J Oskouian (166) and the 5 most active journals are: *Progress of Anatomical Sciences* (1347), *Anatomical Sciences Education* (871), *Anatomical Science International* (813), *Clinical Anatomy* (293) and *Anatomical Sciences Education* (236) (Fig. 3b, Fig. 4a). The institutions that produced the most scientific papers and in which fields of study they were selected (Fig. 3c): our results show that the most productive university is St. George's University, with a total of 864 contributions, University of Louisville, with 827 research articles; University of Missouri and University of the Witwatersrand contributed 627 and 619 respectively.

Top Journals by Publisher has been *Anatomical Sciences Education*, from the Wiley Online Library publishing house, and *Anatomical Science International*, from the Springer publishing house: both journals multiply by three the number of articles published in *Clinical Anatomy*, which is the third of the Top Journals by Publisher.

The most active countries were: United States (4,206), Iran (2,369), Grenada (845), South Africa (667), Japan (646) and China (631) (Fig. 4b).

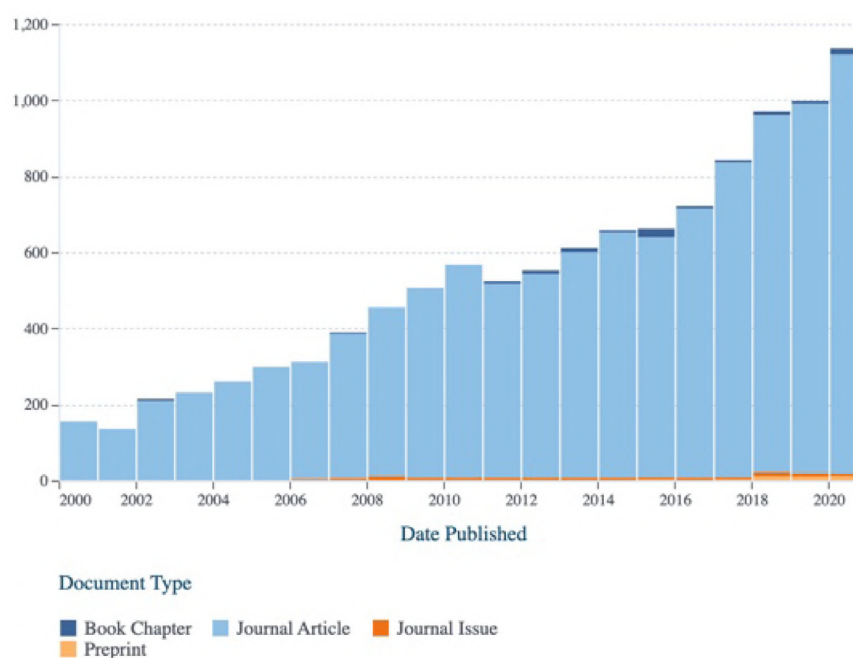


Fig. 2a.- Journal Article, Book Chapter, Journal Issue and Preprint over time.

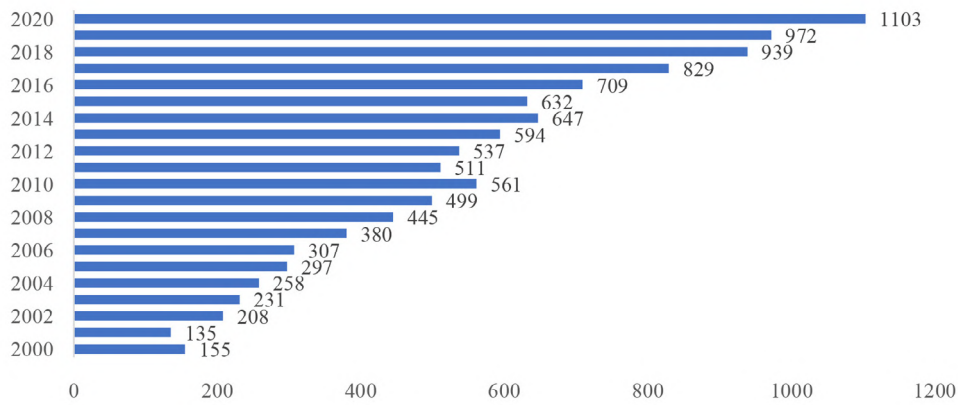


Fig. 2b.- Journal Article: annual distribution in the period 2000-2020.

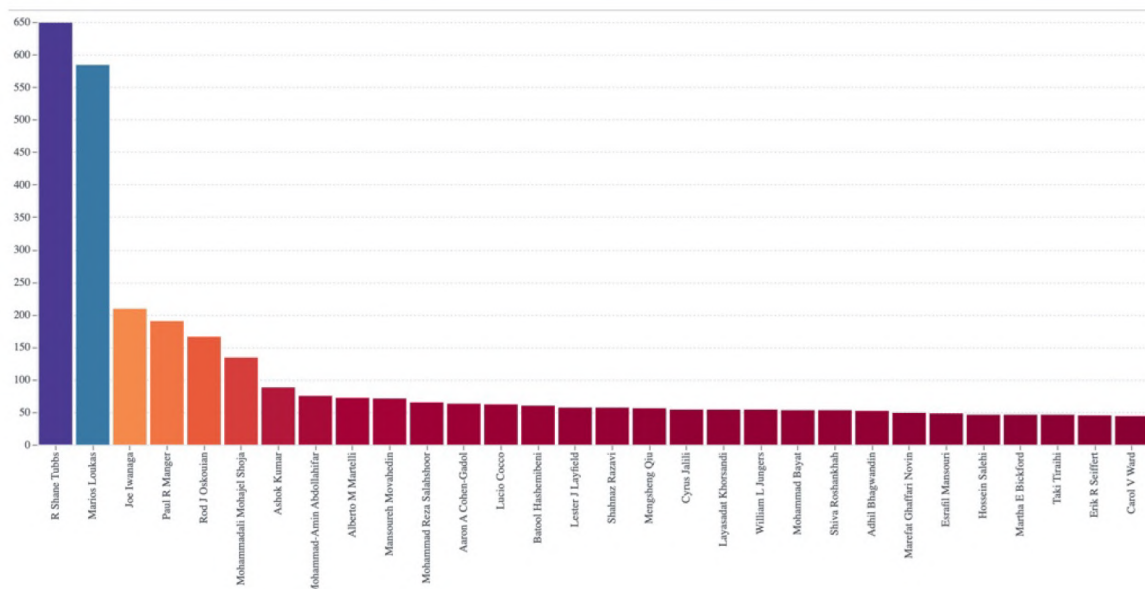


Fig. 3a.- Most productive Authors.

Table 1. Ten top scholarly paper authors and patent inventors.

Top 10 academic papers authors	Top 10 patent inventors
R Shane Tubbs	Baker Joffre B
Marios Lukas	Azamián Bobak Robert
Joe Iwanaga	Cronin Maureen
Pablo R. Pesebre	Coe Jonathan Allen
Rod J. Oskouian	Vafai Scott Bradley
Mohammadali Mohajel Shoja	Giljohann David
Ashok Kumar	Kamboj Rajender Kumar
Mohammad-Amin Abdollahifar	Karche Navnath Popat
Mohammad Reza Salahshoor	Karche Navnath Popat
Aaron A. Cohen-Gadol	Makarov Vladimir

B.- Human Anatomy Patents

Data processing of the patent documents obtained: the total search results were 1,314 documents and they were analyzed quantitatively and qualitatively with the objective of drawing conclusions about the evolution of the patentometry trend of anatomical scientific achievements.

The total 1,314 documents include: Patent Application, Granted Patent, Search Report, Amended Application, Amended Patent. Fig. 5a reflects the Total Patent Documents and their Annual Distribution.

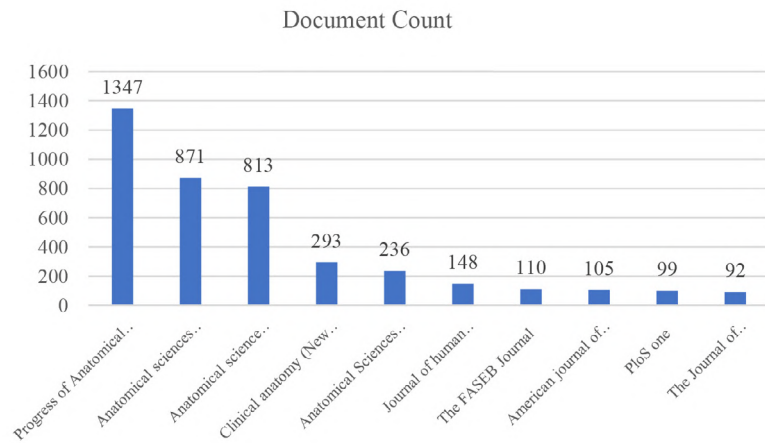


Fig. 3b.- Top Journals by Publisher.

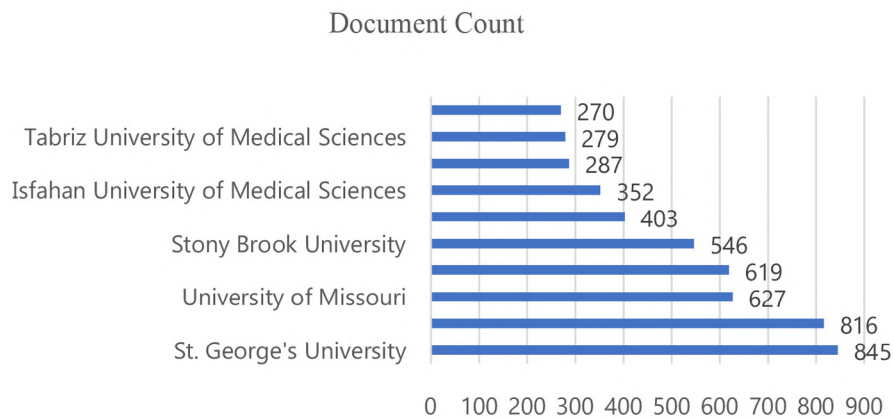


Fig. 3c.- Most Active Academic Institutions.

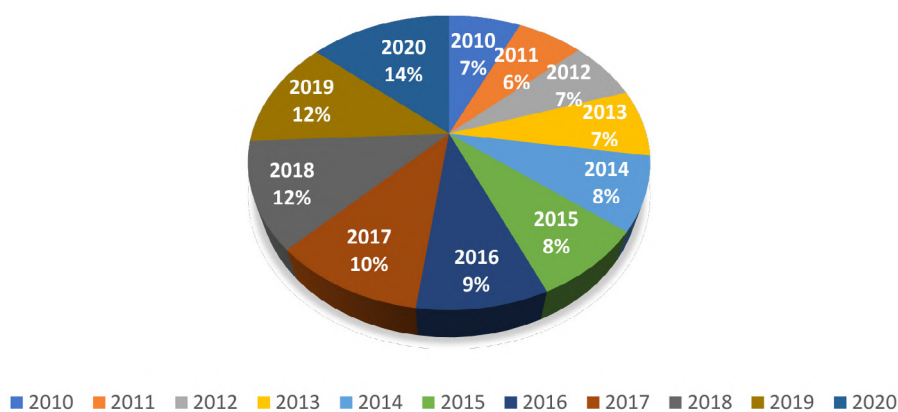


Fig. 4a.- Journal Article: annual percentage distribution in the period 2010-2020.

The results show that the year 2000 accounted for 0.05% of the total applications, while 2020 has accounted for 6.87%, evidencing an upward progression of patents.

The quantitative data are found in Fig. 6a, showing that there are 936 granted patent registrations and 575 patent applications (Fig 7a). The quantitative evolution by years is shown in Fig. 5b, and

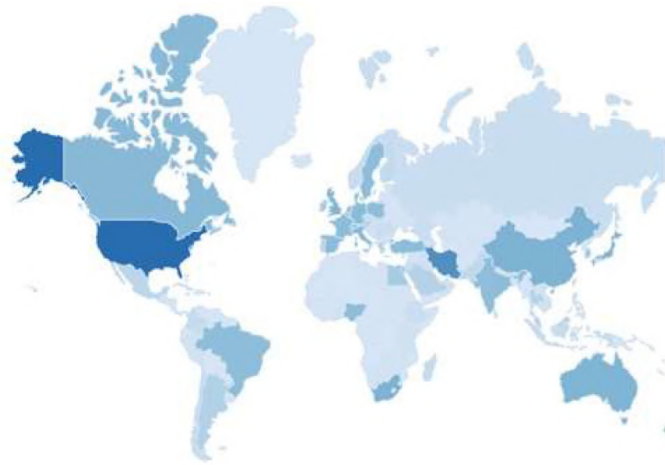


Fig. 4b.- Most active Countries.

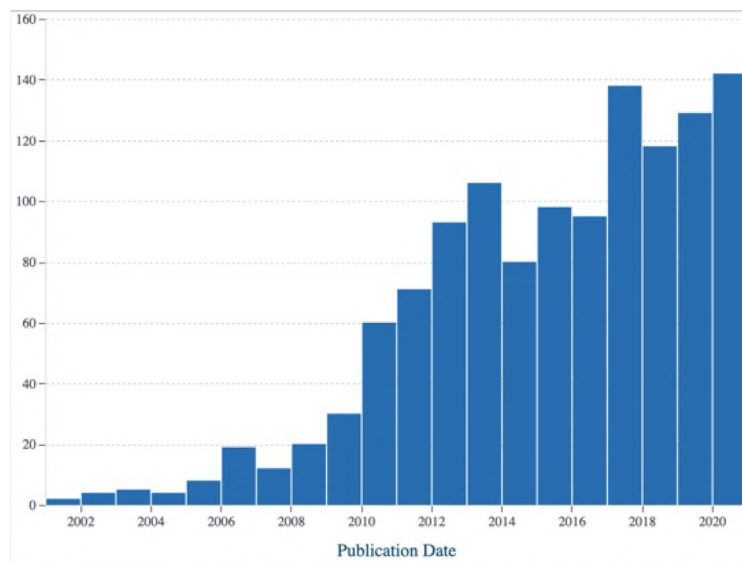


Fig. 5a.- Patent Documents over time.

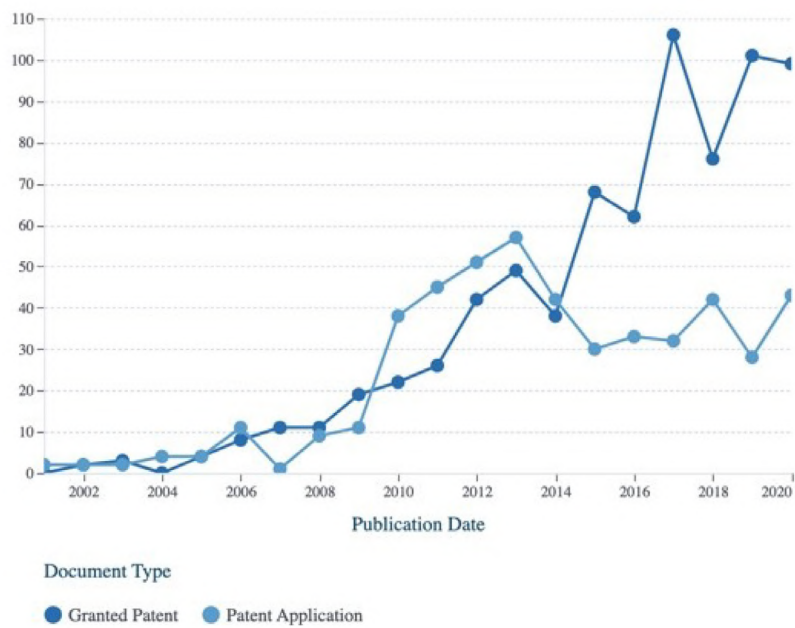


Fig. 5b.- Granted Patent and Applicant Patent over time.

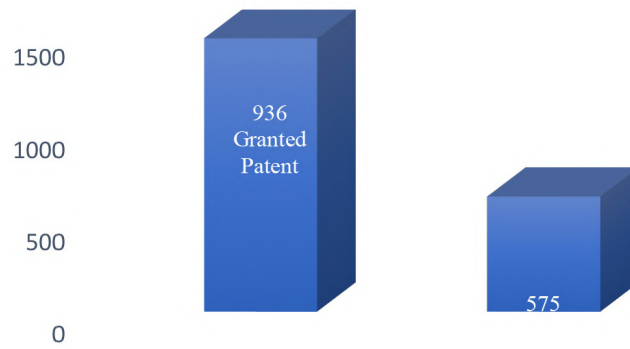


Fig. 6a.- Total Granted Patent and Applicant Patent.

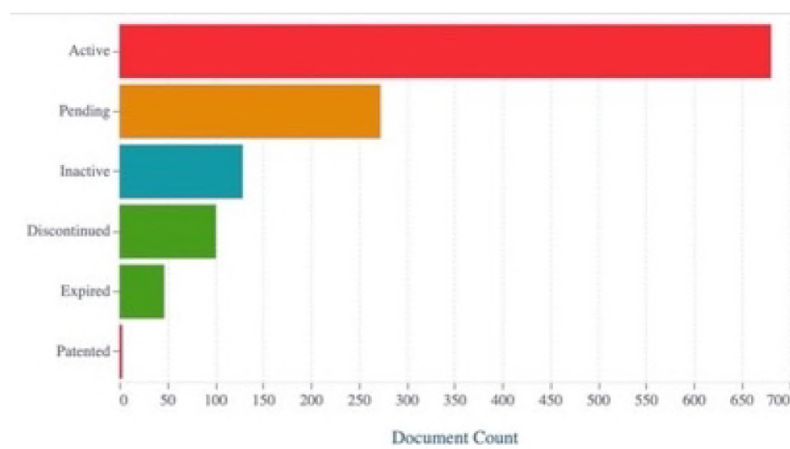


Fig. 6b.- Legal status of all Patents.

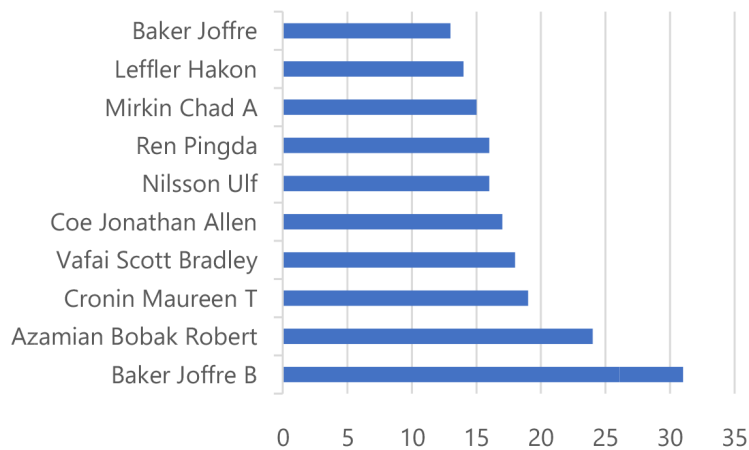


Fig. 6c.- Most Active Patent Inventors.

Fig. 7a shows the percentage of Patents Granted and Patent Applications.

The results that included Application Patent and Granted Patent as quality indicators shows that the time range between 2010 and 2020 con-

stitutes the one with the highest growth. Likewise, this period is where the greatest balance between the number of patents applied for and granted per year occurs, which indicates the quality of the applications, since the percentage of patents grant-

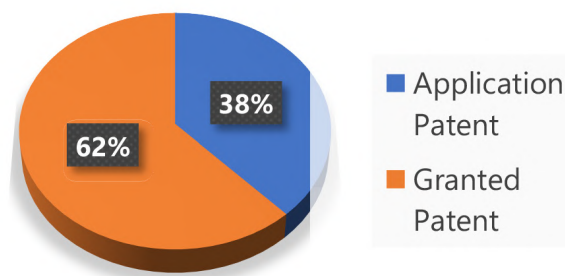


Fig. 7a.- Granted Patent and Application Patent: % Distribution.

ed increases. The results show that the decade between 2010 and 2020 is when the most important success rate is generated both for application patent documents and for granted patents. Specifically, it is demonstrative in the year 2020: of the total patent documents, 69% are granted patents and 31% are application patent.

The legal status analysis showed that most of the patents are active, representing 51% of the total patent and 22% are pending. (Table 2).

Table 2. Legal status patents: Document Count %.

Legal Status	Document Count%
Active	51%
Pending	22%
Inactive	10,5%
Discontinued	8,2%
Expired	3,8%
Patented	0,3%

The Most Active Patent Inventors analysis showed the 10 most productive patent authors (Fig. 6c and Table 1), heading this ranking Baker Joffre B from the Medical University of California and occupying tenth place Makarov Vladimir L from the University of Michigan.

The results of this study have shown that the top five companies in patent applications have been: Genomic Health INC (45), Infinity Pharmaceuticals INC (18), Metavention INC (18), California University (18) and Northwestern University (16) (Fig. 7b, Fig. 8a). Similarly, the top companies

Owner of patents were: Infinity Pharmaceuticals INC (24), Metavention INC (24), Genomic Health INC (22) (Fig. 7c, Fig. 8b). The United States of America leads the position of the most active countries in patents (Fig. 9a).

In the analysis of selected patents, we have detected that purely anatomical articles, such as ‘A review of the thoracic splanchnic nerves and celiac ganglia’ (Loukas et al., 2010) is cited in the text of 32 patents, several of them related to nerve splenic ablation, neuromodulation of the adrenal gland or liver.

The article ‘EMG activity of trunk muscles and torque output during isometric axial rotation exertion: a comparison between back pain patients and matched controls’ (Ng et al., 2002) is cited for 15 patents, mainly sensors for pain management. Also, the article ‘Convergence and cross talk in urogenital neural circuitries’ (Hubscher et al., 2013) is cited for 14 patents related to the therapy of stimulation.

The article ‘The clinical anatomy of the internal thoracic veins’ (Loukas et al., 2007), where the author describes the pattern of branching and adequacy of the internal thoracic veins, is cited for 14 patents related to the implantation of medical devices in the thoracic cavity. Recently in 2022, patents: Azygos, Intercostal and/or Internal Thoracic Vein Implantation and Use of Medical Devices applied for by Cardiac Pacemakers Inc, whose inventors are Reddy et al., designed a method of treating a patient by implanting electrodes in the internal thoracic veins and the azygos, implantable cardiac pacing or monitoring system.

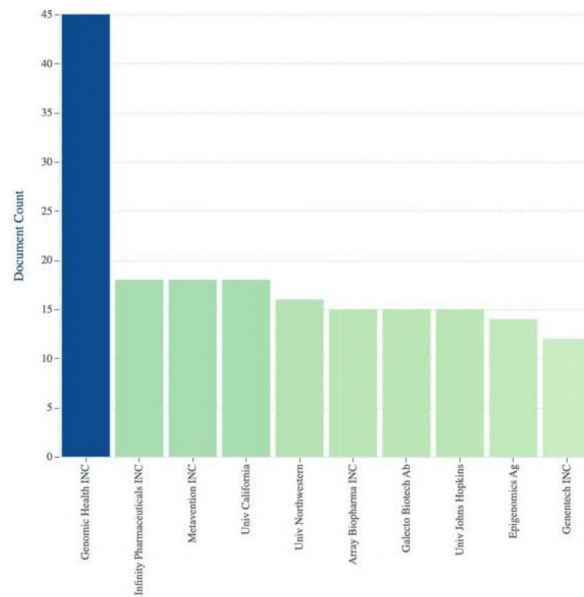


Fig. 7b.- Top applicant companies / institutions.

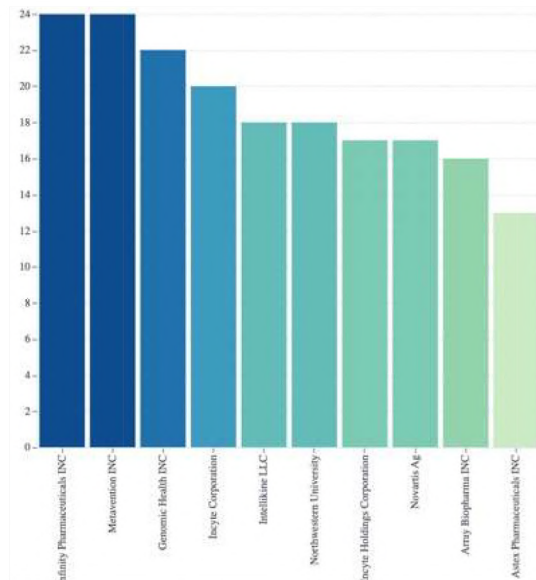


Fig. 7c.- Top owners companies / institutions.

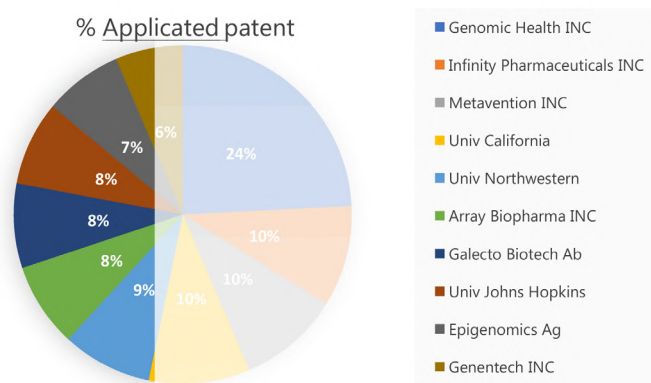


Fig. 8a.- Total companies/ institutions: % of applications.

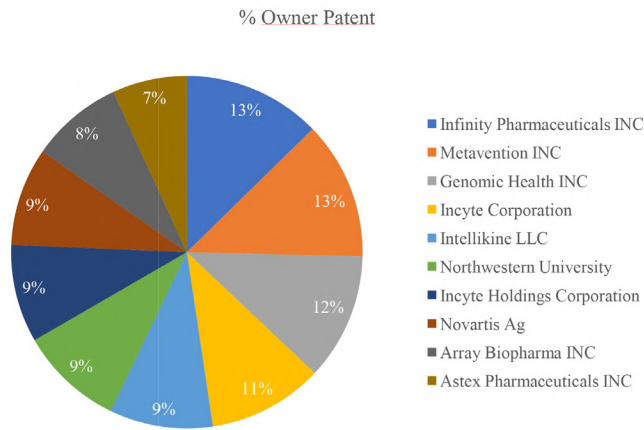


Fig. 8b.- Total company/ institutions: % Ownership.

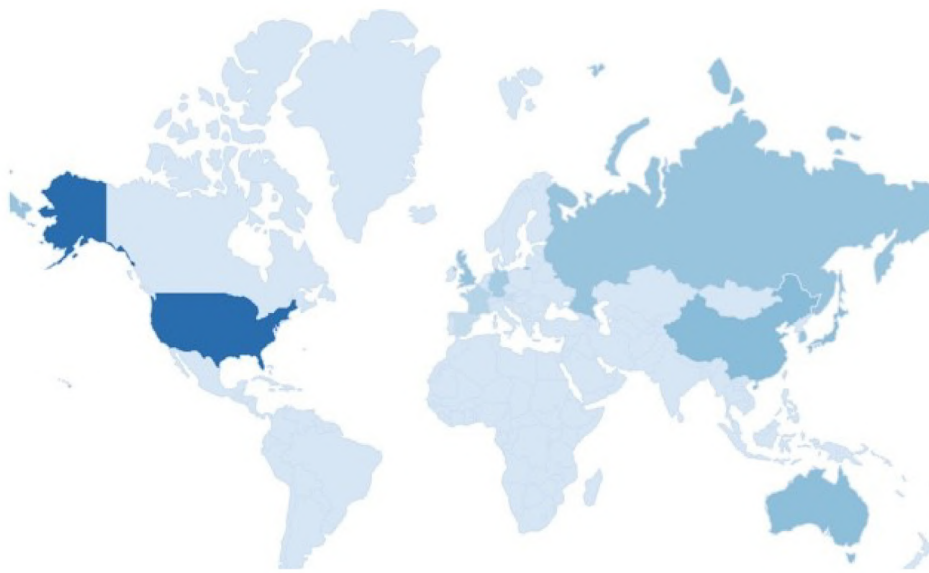


Fig. 9a.- Most active Countries in patents.

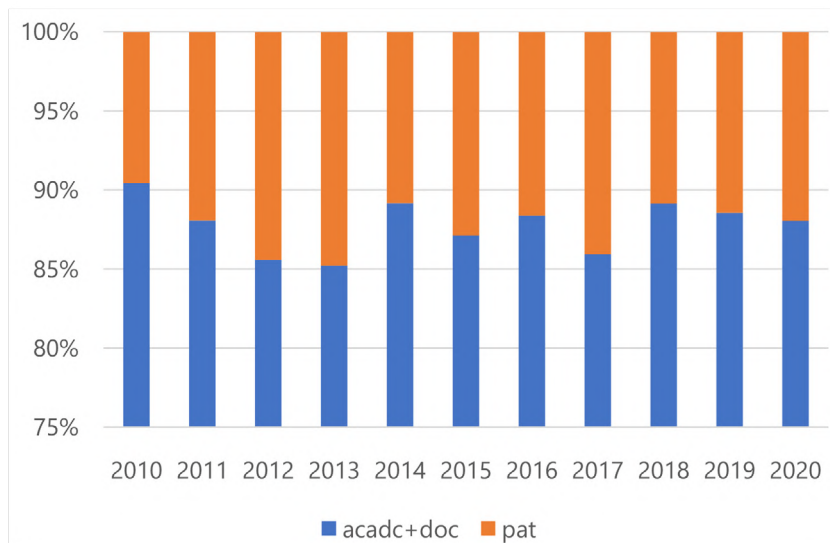


Fig. 9b.- Evolution of % growth in Academic Papers and Patents: 2010-2020.

DISCUSSION

We have carried out a bibliometric analysis on the current state of the latest developments in the academic literature on anatomical scientific papers and patents around “anatomical science” using The Lens database to develop an informed roadmap on this topic, and, to the highest extent possible, stimulate future anatomical research so that it is relevant to biomedical transfer (Bozeman and Boardman, 2014; Franchi, 2020).

The rigorous analysis of the development of human anatomical science as translational science has allowed us to demonstrate that it establishes a direct relationship with the growth of the anatomical patent.

The quantitative and qualitative analysis of the literature of journal articles and patent documents on anatomical science allows us to conclude that the increases in the number of patents have been related to the number of journal articles, this being an irrefutable proof. This article shows that the subject of translational anatomical research must be analyzed in consideration of two elements, (1) academic documents, and (2) patents, since these two variables actively participate in the generation and transfer of anatomical knowledge, and through patents it is possible to commercialize the results of the research, contributing achievements to biomedical innovation and increasing the diagnostic and therapeutic utility of the practice of Medicine. Results are in line with previous research (Franchi, 2020), which indicate that the achievements in the field of anatomical science are part of a dynamic ecosystem, with actors at the individual level, i.e., researchers, and at an institutional level, i.e., organizations and academic institutions.

The systematic review of the academic documents of translational anatomical achievements showed an evident growth in the period analyzed, the production being very significant in the decade 2010-2020 (Fig. 2a, Fig 2b), especially for documents in Journal Article format and published in journals with a high impact factor—a specific quality indicator data. The number of Journal Article documents represents 78.55% and shows a clear predominance of all academic articles pro-

duced, the most productive author being R Shane Tubbs with 649.

Journal articles were mainly published in *Progress of Anatomical Sciences* (n=1,347), *Anatomical Sciences Education*, (n=871), *Anatomical Sciences* (n=813), and *Clinical Anatomy* (n=293).

Analyzing the five most productive countries, the United States is in first place (4,206), representing 48.16% of the total. We select the most productive universities based on scientific articles the field of study (Fig. 4b). The results showed that the 10 main countries had 77.93% of the production of scientific documents and that the most efficient top university is St. George’s University, with n=845 contributions. Patent documents have grown significantly in the two decades analyzed, and, based on the inclusion criteria applied, patent applications represented 38,1% of the total and granted patents 61,9% (Fig 7a) – these data are equivalent to those shown in patentability in other areas.

The patent success rate is evident and is based on data on the growth evolution of granted patents compared to those applied for, which follow an increasing evolution (Fig 5b). This increase in granted patents is evidence of the scientific and methodological rigor of the requested patents, hence its high grant rate.

The inventor with the highest number of published patents was Baker Joffre B, School of Medicine, University of California, followed by Azamián Bobak Rober, Cronin Maureen T company: Affymetrix, Santa Clara, California, Coe Jonathan Allen and Vafai Scott Bradley (Fig. 6c).

The most active geographical territory in patents: the bibliometric analysis carried out showed that the most productive jurisdiction has been the USA, with Europe in third place.

The analysis relative to the percentage relationship between the number of articles published and the number of patent applications per year (Table 3) shows that, in 2020, academic documents represented 54.90% and patents produced 45.08%, significant data, since when compared with the year 2000, the respective percentages were 76.40% and 23.50%, data, indicating a clear

increase in the culture of patentability and the growing interest in translational anatomical research. These results agree with those provided by Fadavi and Mansouri, A. (2022) and demonstrate a sustained growth in the period between 2000 and 2020.

Table 3. Percentage distribution of Academic and Patent Documents by year analyzed.

Year	Acad Doc.	Pat. Doc.
2000	76,40%	23,50%
2001	70,00%	30,00%
2002	52,94 %	47,07%
2003	50,00%	50,00%
2004	44,26%	55,73%
2005	52,33%	47,66%
2006	47,50%	52,50%
2007	54,68%	45,31%
2008	49,52%	50,47%
2009	50,32%	49,67%
2010	56,57%	43,42%
2011	63,86%	36,13%
2012	71,23%	28,76%
2013	73,20%	26,79%
2014	59,74%	33,25%
2015	59,55%	40,44%
2016	69,11%	30,89%
2017	69,86%	30,13%
2018	70,75%	29,24%
2019	68,13%	31,86%
2020	54,90%	45,08%

It should be noted that the decade 2010-2020, which is the most active in the number of contributions to the journal of articles and in the registration of patents (Fig. 9b), indicates that the trend for the interest of the culture of the translation of scientific texts achievements is increasing exponentially. Therefore, it seems that researchers are increasingly assuming that you first apply for a patent and then submit your scientific achievements to a qualified journal, which could partly explain the results shown in this article.

We want to point out that the identification of the main productive authors in scientific articles

and patent applications (Table 1) allows researchers to find possible collaborators among the most prolific authors and to know the leading journals in the publication of articles, useful information for the publication of your future research.

Through the analysis of application patent activity in the area of atomic science, this study shows the trend of patent success in this field, as the number of applications for patents and granted patents increases significantly and annually.

Therefore, it can be considered that the contribution of useful anatomical research increases exponentially, this being a relevant fact and showing the growing interest and positive assessment of modern society for scientific achievements. It has been the coronavirus pandemic that has highlighted the value of translational research, which has led to rethinking the approach toward assessing and enhancing the effectiveness of scientific advances.

In order to discuss the findings of the study based on its possible limitations, we consider that the findings of our study should continue with future research, and it would be interesting to know the parameters analyzed based on the subject areas addressed to the different pathologies. In order to discuss the possible limitations of this study, we consider that the findings of our study should continue with future research and it would be interesting to know the parameters analyzed based on particular subject areas of the different pathologies.

CONCLUSIONS

The analysis of the development of Human Anatomy as a translational science has allowed us to show how the progress of anatomical science and its achievements are closely related to the diagnostic, prognostic and therapeutic problems of complex diseases. In the same way, these results show that the anatomical researcher and his scientific achievements play an important role in the efficient resolution of medical practice, connecting anatomical achievements with the possibility of being part of the solution of medical problems.

ACKNOWLEDGEMENTS

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