Immunology research in Latin American countries: a bibliometric analysis of scientific productivity and collaboration covering the period 2000–2017

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ABSTRACT
Immunology publications by Latin American countries were analyzed for the period 2000–2017. The region showed a constant growth in article production during this time. The increase was mainly due to articles in Q1 and Q2 journals. The more productive countries in the total number of articles, in articles per million population and the countries with the highest increase in production, were identified. The subject of around 50% of the articles was infectious diseases that are severe burdens for Latin American countries. Countries with lower production were more dependent on international collaborations to increase their Q1 and Q2 articles, while the most productive countries were less dependent. International collaboration articles varied in proportion from country to country, and 50% were with the USA. Collaboration among Latin American countries was very low. Domestic Q1 and Q2 articles had impact factors (IF) higher than average and international collaboration increased IF for some countries but not for others. The role of Latin American journals in publishing immunology articles was also analyzed. Latin American immunology is experiencing steady growth and a competitive international presence.

KEYWORDS
Immunology; Latin America; publications; bibliometric analysis; international collaboration

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artigos, artigos por milhão de habitantes e os que tiveram os maiores aumentos em produção. O tema de 50% dos artigos foram as doenças infecciosas, que são um problema de saúde muito importante para os países da América Latina. Os países com produção mais baixa foram fortemente dependentes da colaboração internacional para aumentar seus artigos em revistas Q1 e Q2, enquanto que nos países mais produtivos foram menores. A colaboração internacional variou em proporção de país a país, e 50% foi com os EUA. A colaboração entre países da América Latina foi baixa. Os artigos domésticos tiveram fatores de impacto (FI) mais altos que a média e a colaboração internacional aumentou esses FI para alguns países, mas não para outros. Analisou-se também o papel das revistas da América Latina na publicação de artigos em imunologia. A imunologia da América Latina está experimentando um crescimento sustentado e uma presença internacional competitiva.

**Investigación inmunológica en los países Latinoamericanos: un análisis bibliométrico de la productividad científica y la colaboración durante el período 2000–2017**

**RESUMEN**
Se analizaron las publicaciones en inmunología de los países Latinoamericanos en los años 2000 al 2017. La región mostró un crecimiento constante en la producción de artículos en este periodo. El aumento fue debido principalmente a artículos en revistas Q1 y Q2. Se identificaron a los países más productivos en números totales de artículos, artículos por millón de habitantes y los que tuvieron los incrementos más grandes en producción. El tema del 50% de los artículos fue sobre enfermedades infecciosas que son un problema de salud muy importante para los países Latinoamericanos. Los países con producción más baja fueron muy dependientes de la colaboración internacional para incrementar sus artículos en revistas Q1 y Q2, mientras que los países más productivos lo fueron menos. La colaboración internacional varió en proporción de país a país y el 50% fue con los EUA. La colaboración entre países Latinoamericanos fue muy baja. Los artículos domésticos tuvieron factores de impacto (FI) más altos que el promedio y la colaboración internacional incrementó estos FI para algunos países, pero no para otros. Se analizó también el papel de las revistas Latinoamericanas en la publicación de artículos en inmunología. La inmunología Latinoamericana está experimentando un crecimiento sostenido y una presencia internacional competitiva.

**1. Introduction**

Immunology is an important branch of the biomedical sciences that studies the immune system which defends us against infections. When we are exposed to an infectious microorganism, non-specific immune mechanisms protect us from becoming infected. In some cases, these mechanisms are insufficient, and the individual becomes infected. In this case, what is called an adaptive or specific immune response recognizes molecules from the microorganisms, called antigens, and mounts an immune response against
these antigens, which finally eliminates the microorganism. After this, the individual becomes immune to that particular microorganism. In other cases, the immune system cannot get rid of the microorganism, and the individual gets sick and possibly dies. The immune response can also cause damage to the individual, as is the case of allergies where a particular type of immune response is mounted against common antigens, not necessarily derived from infectious microorganisms. The American Academy of Allergy, Asthma & Immunology estimates that, worldwide, 40% to 50% of schoolchildren suffer from some type of allergy (https://www.aaaai.org/about-aaaai/newsroom/allergy-statistics). Sometimes, the immune response is directed against self-antigens, and the immune system attacks our organism, resulting in what is called an autoimmune disease. More than 80 autoimmune diseases have been identified, and most of them have severe and long-term effects on health. They are widespread worldwide, and their incidence and prevalence are increasing (Lerner, Jeremias, and Matthias 2015). The immune system also has an essential role in controlling cancerous cells. Cancer develops when these cells manage to avoid destruction by the immune system. In the last decades, immunologists have devised ways to manipulate the immune system to defeat several types of cancer successfully (Yang 2015).

Historically, one of the most significant impacts of immunology on public health has been the development of vaccines, which have saved countless lives since the nineteenth century. One of the most devastating diseases known to humanity, smallpox, was declared eradicated from the world in 1980 thanks to vaccination, and polio is close to following the same fate. Although a couple of dozen vaccines are currently in use, many millions of individuals, mainly in underdeveloped or developing countries, continue to suffer from infectious diseases for which there are no effective vaccines. That is particularly important for a group of tropical diseases caused by microorganisms that affect a high proportion of the most impoverished populations living in developing countries. Called neglected tropical diseases (NTDs), they receive much less attention from developed countries regarding scientific research, or the development of vaccines or pharmaceuticals in relation to diseases that affect developed countries. Many of these NTDs are a severe burden in Latin American countries (Hotez et al. 2008).

In recent decades, advances in immunological knowledge have resulted in pharmaceutical developments that had a significant impact on the pharmaceutical industry, and significant economic impact on countries capable of capitalizing on their immunological research. In 2017, seven out of the ten best-selling drugs worldwide were monoclonal antibody drugs (https://www.reuters.com/brandfeatures/venture-capital/article?id=101636), a product developed thanks to immunology.

Kofi Annan, former Secretary-General of the United Nations, stated that “ninety-five percent of the new science in the world is created in the countries comprising only one-fifth of the world’s population, challenging the world’s scientists and scientific institutions to find ways to close this gap and deal with problems that afflict many people in the world, such as those related to health (Annan 2003). The contribution of developing countries to science, as measured by their scientific publications output, is scant compared to developed countries (OECD 2016). Nevertheless, this contribution has been growing steadily more recently, particularly for Latin American countries. Holmgren and Schnitzer (2004) have shown that the proportional change in the number of scientific publications from 1990 to 2000 has increased much more rapidly in Latin America than in the United States or
Canada. Hermes-Lima et al. (2007) have shown that in the period 1991–1995, Latin America contributed 1.8% of all world’s scientific publications, and this contribution almost doubled to 3.4% in the period 1999–2003. Here we focus exclusively in Latin American countries where Portuguese or Spanish are official languages.

Despite its importance, the current situation of immunology in Latin America has not been thoroughly analyzed other than a limited number of historical studies including Mexico (Jiménez Zamudio 2015), Brazil (Sant’Anna 2007), and Cuba (Serrano Barrera 2017). Thus the output of postgraduates can be considered one relevant dimension of performance (Schmoch and Schubert 2009). Mexico was the first Latin American country to establish a PhD program in 1967 (Jiménez Zamudio 2015), followed by Brazil in 1970 (Sant’Anna 2007). Also, in 1984, the Latin American Association of Immunology, now Latin American and Caribbean Association for Immunology, was founded and currently includes 11 immunological societies from countries in the region.

Bibliometric analysis can provide further insight into the status of a specific scientific field in a country or a geographical region and its contribution to the generation of new scientific knowledge. The analysis of the volume of publications allows determining how the field is evolving; impact and visibility of publications can be estimated by citation data; and the quality and international competitiveness of the research topics being developed can be estimated by the quality of the journals where the results are published. Bibliometric indicators can be used as lead indicators for the preliminary assessment of the performance level of a geographical region and its countries (Schmoch and Schubert 2009).

Bibliometric analysis has been used in the Latin American context to analyze scientific collaboration between countries. Chinchilla-Rodríguez et al. (2015) and Zacca-González et al. (2014) applied bibliometric analysis to study the scientific production and collaboration in public health in Latin America, a branch of the biomedical sciences. Chinchilla-Rodríguez, Benavent-Pérez, and Moya-Anegón (2012) have studied international collaboration in medical research in Latin America and the Caribbean using bibliometric techniques and social network analysis. Collaboration is, in general, encouraged by governments with the expectation to improve scientific excellence, visibility, and the country’s international reputation; it is easily estimated in bibliometric analysis by looking at co-publications between countries. Although it does not look at all aspects of collaboration, it remains a valid, though partial, parameter (Georghiou 1998).

One way to assess the scientific strength of a developing country in a particular research area is by looking at what could be called independent or national research capability, or the capability to produce new scientific knowledge without the necessity of collaboration with developed countries, estimated by looking at the number of “domestic” publications in well-recognized journals, where all authors are from the same country. In the case of collaborative articles between countries, for biomedical sciences, the corresponding author’s country allows identifying which country was the most important contributor to the publication. Man et al. (2004) have used this approach to identify the source nation for co-publications in high-ranked medical journals. They argue that: “the corresponding author is usually the one primarily responsible for the study project, including securing of research funding, assemblage of the research team and preparation of the final manuscript.” Moya-Anegón et al. (2013), after an in-depth and extensive study, also conclude that the corresponding author (CA), and his/her research group, institution
or country, play a leading role in the published research. That is the case for most scientific subjects, including microbiology and immunology. Chinchilla-Rodríguez, Sugimoto, and Larivière (2019) used the corresponding authorship to identify the leadership role of nations in collaborative international co-publications. They found that countries with a high proportion of publications in international collaboration have a lower proportion of publications where the country plays a leadership role. Although the use of the CA to identify the scientific-leader country has a margin of error due, among other things, to the fact that the criteria to decide who is the CA varies among disciplines, for biomedical sciences it is a good proxy.

Another indicator of the scientific strength of a country is the kind of journal where the scientific production is published. First quartile (Q1) journals are generally argued to publish articles that are the result of scientific research of the highest quality. The classification in quartiles is usually based on the impact factor (IF) of the journal, which is the yearly average number of citations that the articles published by the journal receive in a specific time, usually three years. However, the journal’s IF has been criticized as a measure of quality as journals have devised strategies to increase their impact factors without improving the quality of their articles (Baum 2011). SCImago, and other bibliometric portals, have introduced other algorithms to calculate the impact factor of journals that also considers the “quality” of their citations. They give different weights to the citations depending on the “prestige” of the citing journal and without the effect of journal self-citations (Falagas et al. 2008; Torres-Salinas and Jiménez-Contreras 2010), counteracting, in part, some of the strategies that several journals have adopted to increase their IFs artificially. So, although the quartile classification of journals is not a perfect indicator of the quality of the science published in a journal, the analysis of a large amount of journals and articles can still provide an adequate indicator of the quality of the science being produced by a region or country.

Another interesting topic is the role of journals published by developing countries, Macías-Chapula (1994, 2010) has analyzed the visibility and influence of publications in Latin American journals in the health field. Collazo-Reyes et al. (2008) have studied impact factors, citation patterns, and growth dynamics for Latin American journals in the Science Citation Index. The general conclusion is that Latin American journals, in general, have from very low to low impact and international visibility. Vessuri (1995) argues that they have a potentially important role in disseminating Latin American science and recognizes that Brazil and Mexico have taken actions to identify, select, and promote their domestic scientific journals of good quality.

Bibliometric and collaboration studies that include Latin America have also been published: Collazo-Reyes et al. (2008) for journals covered by the Science Citation Index, Chinchilla-Rodríguez, Benavent-Pérez, and Moya-Anegón (2012) for medical research, Chinchilla-Rodríguez et al. (2015) and Zacca-González et al. (2014) for public health. Chinchilla-Rodríguez et al. (2018) for nanoscience and nanotechnology, and Zacca-González, Chinchilla-Rodríguez, and Vargas-Quesada (2018) for medicine. As far as we know, for immunology, there is only one study on collaborations between Colombia and Brazil (Roa-Atkinson and Velho 2005). The current pandemic caused by the SARS-CoV-2 virus has put immunology at the forefront as one of the branches of the biomedical sciences that might help control this and future pandemics, mainly through the development
and use of vaccines (Mallapaty 2021). Nevertheless, there are no broad studies on the status of immunology in Latin American countries.

The objective of our study is thus to gather basic information on the status of immunology in Latin America and its countries in the present millennium through the analysis of its scientific publications output. We focus on three general topics: production of immunology articles, international collaboration, and immunological areas studied. For each topic, we formulated three sets of research questions.

Production of immunology articles in Latin America:

(1) What is the yearly publications output?
(2) What is the distribution of the publications in international journals in the top and bottom 50% of quality?
(3) What is the role of journals from Latin American countries in the publication of immunology articles?
(4) Which are the most productive countries considering total production and considering their population?
(5) Which are the countries that show the highest growth in publications?
(6) In what proportion of the publications is the scientific leader from a Latin American country?

International collaboration:

(1) What proportion of the publications involves international collaboration?
(2) What is the magnitude of collaboration between the Latin American countries?
(3) Is international collaboration helping to increase the impact of the publications?

Immunological areas:

(1) Which are the immunological areas being studied by Latin American immunologists?

By answering these questions, we expect to provide a diagnosis and points of reference for the current situation of immunology in Latin America and its countries. We think that this information could serve as a starting point for decision-makers, policy-makers, or national and international agencies interested in promoting the development of immunology in Latin America. It could also be of interest to the immunology communities of Latin America, the national societies of immunology, and the Latin American and Caribbean Association of Immunology. Scientists and academics interested in the relations between science and society might find this information also helpful.

2. Data and methodology

2.1. Bibliographic search

Documents were retrieved from Scopus in September 2018. The search string: “immun*” was used for a wide first search in the title, abstract, and keyword fields. The searches covered the years 2000–2017 and were carried out separately using the “affiliation
country” for each of the 19 countries selected for this study (see below). Only articles and review articles were selected in the “documents” field. Books, book chapters, conference papers, and other items were excluded. The results of each search were downloaded into a master file per country. The total number of articles obtained for the 19 countries at this stage was 92,874 in more than 4,000 different journals. Although this first selection was made with the search string “immun*,” a review of the journals’ titles revealed that most of them were not directly related to immunology. For this reason, we considered this set of results inappropriate for our study.

To further distill articles directly related to immunology, we used the following strategy. First, in each country’s master file, we selected the journals with a word in their title indicating a direct relation to immunology. These words were all that contained the string “immun” and, or the words: allergy, antibody, cytokine, hybridoma, inflammation, vaccine, or vaccinology. A total of 179 journals were selected by this criterion and are listed in Supplemental Material Tables S1 and S2. All the articles in these journals were selected for this study. Immunology has become an interdisciplinary discipline that impacts several branches of the biomedical field, so a set of journals not directly related to immunology do publish a (variable) proportion of immunology articles. To include a representative sample of articles from these journals, we identified 31 journals that, though their title did not indicate a direct relation to immunology, had more than 80 articles published by the three most productive countries of the region (see results). Although these articles were originally selected by the search string “immun*,” not all were immunology articles, requiring one of us (LHFC) to manually inspect the articles in these journals to identify those that were related to immunology.

From these 31 journals, we found 19, shown in Supplemental Material Table S3, with 50 or more immunology articles. These journals were identified in each country’s master file and manually inspected to select the immunology articles. A total of 603 articles were found in these journals for the 19 Latin American countries. The quartile ranking was looked up in the SCImago Country & Journal Rank (SJR) portal (https://www.scimagojr.com/) for all journals included. Quartile classification may vary in different years for a specific journal. In that case, the quartile assigned was the more frequent in the years 2000–2017 or the years of publication for journals that stopped their publication before

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**Table 1.** Increase in publications in immunology articles in Latin American countries when comparing the first five years of the period of study with the last five years.

| Country   | 2000–2004 | 2013–2017 | Fold increase |
|-----------|-----------|-----------|---------------|
|           | Total*    | Q1Q2      | Total         | Q1Q2          |               |
| Peru      | 14        | 12        | 133           | 89            | 9.5           | 7.4           |
| Colombia  | 82        | 67        | 451           | 265           | 5.5           | 4.0           |
| Chile     | 113       | 42        | 454           | 316           | 4.0           | 7.5           |
| Uruguay   | 23        | 17        | 83            | 68            | 3.6           | 4.0           |
| Ecuador   | 13        | 13        | 43            | 41            | 3.3           | 3.2           |
| Mexico    | 480       | 313       | 1221          | 844           | 2.5           | 2.7           |
| Brazil    | 1395      | 673       | 3394          | 2269          | 2.4           | 3.4           |
| Argentina | 440       | 284       | 803           | 596           | 1.8           | 2.1           |
| Cuba      | 167       | 75        | 235           | 112           | 1.4           | 1.5           |
| Venezuela | 87        | 44        | 116           | 55            | 1.3           | 1.2           |

*Articles published in all kinds of journals considered in this study.
+aArticles published in Q1 or Q2 journals.
2017 or started it after 2000. Six journals were not found in SJR, and their quartile was assigned using the impact factor reported in other sources, mainly Bioxbio (https://bioxbio.com). Immunology journals that were Q1 or Q2 are listed in Supplemental Material Table S1 (104 journals). Immunology journals that were Q3 or Q4 are listed in Supplemental Material Table S2 (73 journals). Journals that were not directly related to immunology but published a significant portion of immunology articles are listed in Supplemental Material Table S3 (19 journals, all of them were Q1 or Q2).

From each country’s master file, all the articles from Q1 and Q2 journals in Supplemental Material Tables S1 and S2, both supplementary information, were copied into a single file (Q1Q2 files, for each country). The same was done for the Q3 and Q4 journals in Supplemental Material Table S2 (Q3Q4 files, for each country). Each country file had articles where there was at least one author from that country, and also some others with authors from other Latin American countries. These articles were registered in each of the respective country’s file. We identified in the country’s master files 156 journals published by Latin American countries. Three of them were related to immunology, were Q4 journals, and were included in Supplemental Material Table S2. Two of them were Q2 journals not directly related to immunology, published a substantial amount of immunology articles, and were included in Supplemental Material Table S3. The other 151 Latin American journals were

### Table 2. Leadership in Q1Q2 articles by country.

| Country | Q1Q2 articlesb | Articles in leadershipc | Percent leadership | Ranking in total articlesd | Ranking in APMPé |
|---------|-----------------|-------------------------|-------------------|--------------------------|------------------|
| Brazil  | 5356            | 4242                    | 79.2              | 1                        | 5                |
| Cuba    | 371             | 267                     | 71.9              | 6                        | 1                |
| Mexico  | 1913            | 1356                    | 70.8              | 2                        | 7                |
| Argentina| 1542           | 1088                    | 70.5              | 3                        | 2                |
| Chile   | 563             | 356                     | 63.2              | 4                        | 3                |
| Venezuela| 176             | 97                      | 55.1              | 7                        | 9                |
| Uruguay | 140             | 75                      | 53.5              | 9                        | 4                |
| Colombia| 597             | 313                     | 52.4              | 5                        | 8                |
| Costa Rica| 106            | 32                      | 30.2              | 10                       | 6                |
| Peru    | 205             | 41                      | 20                | 8                        | 11               |

aOnly countries with more than 100 Q1Q2 articles are shown.  
bTotal numbers of Q1Q2 articles published by the country.  
cNumber of Q1Q2 articles where the leadership was assigned to the country.  
dRanking in total articles published, as shown in Figure 2(a,b).  
eRanking in APMP, as shown in Figure 3(a,b).

### Table 3. Classification of the articles published by Latin American countries by immunological areas.

| Area                  | Articlesa | Percent |
|-----------------------|-----------|---------|
| Infectious diseases   | 3206      | 40.6    |
| Vaccines-infectious diseases | 947  | 10.7    |
| Autoimmunity          | 595       | 6.7     |
| Basic immunology      | 551       | 6.2     |
| Vaccines              | 458       | 5.2     |
| Allergy               | 415       | 4.7     |
| Cancer Immunology     | 258       | 2.9     |
| Reproductive Immunology| 176  | 2.0     |
| Transplant Immunology | 91        | 1.0     |
| Immunodeficiencies    | 66        | 0.7     |
| Not Classified         | 1137      | 12.8    |
| Total                 | 7900      | 100     |

aNumber of articles published in Q1Q2 journals where the corresponding author is from a Latin American country.
mostly biomedical or veterinary and were Q3 or Q4. Their article’s titles were scanned with words common in immunology articles to identify the immunology articles in these journals, which were copied into another file for each country (LATAM files). Each country’s Q1Q2 file was analyzed in the “correspondence address” field. Those articles where the corresponding author was affiliated to an institution belonging to the country were selected and copied into another file for each country (CA files). For global analysis, files with the same denomination from all countries were consolidated into a single file. Duplicated records were identified and removed to have only one record for records that were in more than one country. Consolidated files were: Q1Q2 with 10,315 articles, Q3Q4 with 2,152 articles, LATAM with 3,877 articles, and CA with 7,900.

3. Countries selected

Brazil and all the predominantly Spanish-speaking countries in America were included in this study. The 19 Latin American countries selected were: Argentina (ARG), Bolivia (BOL), Brazil (BRA), Chile (CHI), Colombia (COL), Costa Rica (CR), Cuba (CUB), Dominican Republic (DR), Ecuador (ECU), El Salvador (SAL), Guatemala (GUA), Honduras (HON), Mexico (MEX), Nicaragua (NIC), Panamá (PAN), Paraguay (PAR), Peru (PER), Uruguay (URU) and Venezuela (VEN).

3.1. Identification of the immunological areas of research

To analyze the different immunological areas of research of the articles published by Latin American countries, we used the most common areas listed by most of the immunology societies (see, for example, https://www.immunology.org/public-information/what-is-immunology). They were classified in the following areas: Allergy; Autoimmunity; Basic Immunology; Cancer Immunology; Immunodeficiencies; Infectious diseases; Reproductive Immunology; Transplant immunology; Vaccines. To identify the immunological areas of the articles in the CORRAUTH consolidated files, we selected all the articles from journals whose title indicated that the journal was entirely dedicated to publishing articles in that specific immunological area. For other areas and journals, we looked for articles that had in their title words or word strings that indicated their area. For example, for infectious diseases, we used words like “brucella,” “plasmodium,” “tuberculosis,” etc. For the Immunodeficiencies area, we used the search string “immunodeficienc,” for the Transplant Immunology area, the words “transplant” or “grafts,” etc. The titles of the articles selected in this way were analyzed by one of us (LHFC) and classified in the area if the full title indicated that it matched the area. If the article could be classified in more than one area, it was classified in the area where its title indicated that it made the principal contribution. The articles that the previous strategies could not classify were analyzed one by one and classified after examining the title more closely. Articles that studied basic mechanisms of immunology were classified as Basic Immunology. For 1137 articles (14.4%), it was not possible to classify them by the criteria mentioned above.

The diseases considered as autoimmune were those listed by the American Autoimmune Related Diseases Association (https://www.aarda.org/diseaselist/). Many of the articles in the Vaccines area were related to infectious diseases and were reclassified as Vaccines-Infectious Diseases. Articles related to newborn immunity were included in the Reproductive Immunology area.
3.2. Identification of collaborating countries

A Python script was written to extract the information of the different countries listed in the field “Affiliations” for each article.

3.3. Citation rates

Citation rates were calculated according to Glänzel, Leta, and Thijs (2006), for articles published in the period 2013–2015. For each article, the number of citations received in the year of publication and the next two years was retrieved from Scopus (observed citation). The journal where the article was published was looked up in the SJR, and the expected citation was retrieved for the year of publication. Citation Reports calculate the expected citation for each journal as the average citation of all the articles published in the journal in the same year and consider the citations received in the year of publication and the next two years. For each article, the relative citation was calculated as the ratio of observed citation/expected citation. A value above 1.0 represents higher than average citation, and a value below 1.0 represents lower than average citation. For each country, considering all the articles in Q1 and Q2 journals, the mean of the values for observed citation, expected citation, and relative citation were calculated.

3.4. Statistical analysis

Statistical analysis was carried out using R (R Development Core Team (2008), http://www.R-project.org).

Statistically significant differences were considered when $p < 0.05$.

4. Results and discussion

4.1. Production of immunology articles in Latin America

4.1.1. Yearly publications output

We found a constant yearly increase in the total production of immunology articles. In the year 2000, 437 articles were published, and in the year 2017, this number went up to 1500, a 3.4-fold increase (Figure 1). This finding agrees with other studies that found that Latin America is a region that has steadily increased its contribution to the world’s scientific and technical publications during the last decades. The proportional change in the number of publications from 1990 to 2000 has grown much more rapidly in Latin America than in the United States or Canada (Holmgren and Schnitzer 2004). Latin America contributed 1.8% of all the world’s scientific publications in the period 1991–1995, while almost doubling this contribution to 3.4% in the period 1999–2003 (Hermes-Lima et al. 2007). The studies mentioned above considered publications in most of the scientific disciplines. Chinchilla-Rodríguez, Benavent-Pérez, and Moya-Anegón (2012) carried out a work focused on medical research in Latin America covering the period 1996–2008. Although they concluded that the medical research area is growing in the region, they found that the production of articles declined from 1996 to 2004, then started to grow to reach, in 2008, levels similar to those in 1996. Our findings, which overlap from the year 2000 to the year 2008 with the previously
mentioned study, showed a constant increase of immunology publications up to the year 2017. This suggests that a finding for a broad area—biomedical sciences in this case—cannot be generalized for all the fields of the area—immunology in our case.

4.1.2. Publications in journals at the top and bottom 50% of quality
When the articles are disaggregated by journals ranking, it becomes clear that the growth in total publications was due mainly to articles in Q1 and Q2 journals. Articles in Q1 and Q2 journals had a 3.8 fold increase in the study period, followed by articles in Q3 and Q4 journals that showed a 3.4 fold increase. The production of articles in LATAM journals had a 2.4 fold increase, notably lower than the increase in the other journals (Figure 1). By disaggregating the journals by quartile ranking, we found that for all the years of our study, the proportion of immunology articles published by Latin American countries in Q1 and Q2 journals was higher than the proportion of articles published in Q3 and Q4 journals. In the year 2000, 61.7% of the production was in Q1 and Q2 journals, while in 2017, it was 68.7%. For the same years, the proportion of articles in Q3 and Q4 journals remained practically the same (14.4% vs. 14.3%). There seems to be a tendency to increase the proportion of immunology articles in the top 50% quality journals. The quality standards required to publish in Q1 and Q2 journals are considered higher than those for Q3 and Q4 journals. Most of the bibliometric analyses do not disaggregate the publications analyzed by the journals’ rankings, so when an increase in publications is found, it is impossible to know if the increase is the same or not in the journals with different rankings. Based on our finding of a steady growth of publications in Q1 and Q2 journals, we propose that this is empirical evidence that in Latin America, not only the immunology publications output seems to be increasing, but it seems that also the scientific quality of immunology research.

Figure 1. Number of immunology articles published by Latin American countries in the period 2000–2017. Total refers to articles in all kinds of journals analyzed in this study where there was at least one author from a Latin American institution. Q1Q2 and Q3Q4 refer to articles published in journals classified in the indicated quartiles. LATAM refers to articles published in journals edited by Latin American countries that were classified as Q3 and Q4.
4.1.3. Role of Latin American journals

In this study, we were also interested in looking at the role of LATAM journals in the publication of immunology articles. We found two LATAM journals not totally dedicated to immunology, but that published a substantial number of immunology articles. Both were Q2 and were considered in the journals listed in Supplemental Material Table S3. Three LATAM journals had in their title a word relating them to immunology, were Q4, and were considered in the journals listed in Supplemental Material Table S2. On the other hand, we found 151 LATAM journals that published some immunological articles and that their title did not indicate a direct relation to immunology. The production of immunology articles in these last journals is that shown in Figure 1. They were mainly biomedical or veterinarian journals and mostly Q3 or Q4. Nevertheless, one of these journals was Q1, and ten were Q2. The finding of journals published by Latin American countries that are Q1 or Q2 could result from the actions that have taken some Latin American countries to increase the quality of their journals (Vessuri 1995). We think that the proportion of biomedical and veterinary LATAM journals that have reached the top 50% of quality is still very low. Figure 1 shows that immunology articles published in LATAM journals grew at a slower pace than in other journals. Based on the evidence that the growth in immunology articles is due mainly to articles in Q1 and Q2 journals, we think that the region’s productivity could support a good quality LATAM journal dedicated to immunology.

The proportion of immunology articles published in LATAM journals by the countries included in our study was 24% (3870 articles). That is a significant amount of the articles that we analyzed. One interesting question is why they are published in these journals, mostly Q3 or Q4, and not in journals with higher quality. One possibility is that they study problems that are of local interest, not attractive to international journals. Another possibility is that articles end up in these journals after failed attempts to publish them in journals with higher rankings, which would tend to perpetuate their low rankings. The first possibility could be a good reason to promote and support LATAM journals. However, it would be important to avoid the second reason to increase LATAM journals’ rankings. Similar considerations have been thoroughly discussed by Vessuri (1995).

4.1.4. Production of immunology articles by country

For each country and the period 2000–2017, we examined the number of immunology articles published in Q1Q2, Q3Q4, and LATAM journals. Brazil, with over 8000 total articles, was the country with the highest production. Mexico and Argentina followed with an output of about one-third of this. These three countries were the major contributors to the region. Together, they published 77.3% of the total immunology articles of the region. Colombia, Chile, and Cuba could be classified as the next group of article-producing countries. They had a similar production of near 1000 articles, which together represent 15.4% of the regional output. These six countries are shown in Figure 2(a). They had between 60% to 67% of their production in Q1 and Q2 journals, except for Cuba with only 46%. Their output in Q3 and Q4 journals was between 8% to 19%, except for Cuba with 32%. Although Cuba had good results in other indicators (see below), compared to the other five countries, a relatively high proportion of its production was in Q3 and Q4 journals. In a study also focused on immunology but covering only 31 research
groups from Brazil and Colombia, Roa-Atkinson and Velho (2005) also found an increase in immunology publications in 1990–1999. Nevertheless, they report that 70% of Brazilian articles were published in low-impact journals, while we found that 63% of the Brazilian immunology articles were published in Q1 and Q2 journals. We think that the fact that Roa-Atkinson’s data set was obtained in a different way to us and included other years might explain why our results are different.

There are some variations in the proportion of articles that these six counties published in LATAM journals. Mexico had the lowest proportion (14%) and Chile the highest (32%), with the other countries in between. Still, a constant feature was that the journals published by a particular country publish a very high proportion of articles from local researchers (data not shown). It seems that, in general, LATAM journals do not contribute

Figure 2. Number of immunology articles published by each Latin American country in the period 2000–2017, in all kinds of journals analyzed in this study. The number of articles published in Q1Q2, Q3Q4, and Latin American (LATAM) journals is indicated for each column. (a) shows the six countries with the highest total production, and (b) shows the rest of the countries.
much to the dissemination of knowledge generated in other countries of the region, at least for the case of immunology.

The rest of the countries had total article production below 400 and are shown in Figure 2(b). In this group, Venezuela, Peru, Uruguay, and Costa Rica had more than 100 publications. They had a high proportion of their limited production in Q1 and Q2 journals (around 80%), except for Venezuela, which had 45%. Venezuela had the highest proportion of its publications in LATAM journals (41%), followed by Peru with 23%. Uruguay and Costa Rica published less than 10% of their total production in LATAM journals. We found no journals published by these last two countries with immunology articles. That might explain why these two countries do not publish many immunology articles in LATAM journals. As mentioned above, LATAM journals publish articles mainly from local scientists.

The rest of the countries in Figure 2(b) published less than 100 articles, so it is not possible to draw meaningful conclusions from these numbers. Nevertheless, it is relevant to say that they had a high proportion of their smaller production in Q1 and Q2 journals, a point that will be discussed later on.

Our results concur with other studies. Glänzel, Leta, and Thijs (2006) and Hermes-Lima et al. (2007), looking at all scientific areas, which have identified Brazil, Mexico, and Argentina as the Latin American countries with the highest output of scientific articles, with the other countries shown in Figure 2(a) and Venezuela, Peru and Uruguay lagging behind. In a study on medical research articles, Brazil, Mexico, and Argentina were also the countries with the highest production, followed by Chile, Venezuela, Colombia, and Cuba (Zacca-González, Chinchilla-Rodríguez, and Vargas-Quesada 2018). While in a study that looked at the scientific output in public health, the three countries with the highest production were Brazil, Mexico, and Cuba, followed by Colombia with Argentina in fifth place (Zacca-González et al. 2014) or in sixth place (Chinchilla-Rodríguez et al. 2015). As one would expect, there might be some variations in the productivity ranking of countries when specific fields are analyzed. Nevertheless, the six countries we identified as the more productive in immunology are, in general, the most productive in other scientific areas or fields.

To consider the variability in population size between the Latin American countries, we calculated, for each country, the number of articles per million population (APMP). Population data for 2017 was retrieved from the World Bank (https://data.worldbank.org/indicator/SP.pop.TOTL). We calculated the APMP for total article production and for articles in Q1Q2 journals. This indicator gave a different ranking of countries, compared to total article production. Figure 3(a) shows that Cuba, Argentina, Chile, Uruguay, and Brazil are now the top five countries with APMP values for total articles of around 50, with Cuba reaching 70. They were followed by Costa Rica, Mexico, and Colombia, with APMP values of around 20. When considering APMP for Q1Q2 articles, the same countries are also in the top five, but now Uruguay is number one with an APMP value of 41. The other four countries are in the range of 25–34. Costa Rica, Mexico, and Colombia followed with APMP values for Q1Q2 articles of 21, 15, and 12, respectively. The rest of the countries had APMP values below 14 for total articles and below 10 for Q1Q2 articles, as shown in Figure 3(b).

The normalization of article production by population allows making more even comparisons between countries. For example, countries that had a relatively low number of total articles moved up in the ranking. It is notorious for Uruguay that it went up from
the ninth to fourth place when considering total publications and was first for Q1Q2 APMP. On the other hand, Costa Rica moved from the 10th to 6th place when considering total publications. According to these results, we think that Uruguay and Costa Rica could be regarded as part of the Latin American countries with a considerable presence in immunology in relation to their population. With this consideration, Cuba became the first country in APMP for total publications and the third in Q1Q2 articles.

4.1.5. Growth of publications by country
To analyze how the production of articles per country is changing over time, we compared the number of articles published during the first five years of the study (2000–2004) to the number published in the last five years (2013–2017), both for total and for Q1Q2 articles. We did not include countries with less than ten publications in the first five years for this analysis. Table 1 shows that Peru, Colombia, and Chile had the
highest increases in total publications and, except for Colombia, also in Q1 and Q2 publications. Chile and Peru showed an impressive growth in Q1 and Q2 publication with around a 7.5 fold-increase. Colombia and Uruguay also showed a 4.0 fold increase in Q1Q2 publications. The rest of the countries showed several fold-increases from 1.2 to 3.6 in their total or Q1Q2 publications. Peru, which was not highly ranked either by total production or by APMP, is increasing its output at paces above most other countries. If this pace continues, it might be on its way to improve its presence significantly in Latin American immunology. Chile is another country that will be interesting to follow. It was fourth in total production, third in APMP, and it showed the highest increase in Q1 and Q2 publications. It could be on its way to displace Argentina from second place in APMP (Figure 2(a)).

4.1.6. Scientific leadership by country

The number of articles in Q1 and Q2 journals could be considered, by international standards, an indicator of the amount of high-quality and internationally competitive immunology research carried out in a country. Nevertheless, this indicator alone is not informative on how much of this research could be considered independent or national and how much is the result of collaboration with developed countries where the Latin American country might be playing a somewhat secondary role. When all the authors are from the same country, the research can obviously be ascribed to the scientific capability of that country. For internationally collaborative articles involving two or more countries, we used the corresponding author address to identify the country to which the research leadership can be assigned, as in Chinchilla-Rodríguez, Sugimoto, and Larivière (2019). We focused on Q1Q2 articles only to calculate the percent leadership for each country in their Q1 and Q2 articles. Table 2 shows the results for countries that had more than 100 total Q1 and Q2 articles. Three groups of countries could be identified. One group of four countries had leaderships above 70%. It included the three countries with the highest production in total articles (Brazil, Mexico, and Argentina) and the first country in APMC (Cuba). Leadership was associated, in general, with high total publication output or with high APMP output. The second group comprises three countries, Venezuela, Uruguay, and Colombia, with leaderships around 53%. For this group, there was no clear relation either to total publications nor APMP output. Chile was somewhat between these two groups. The last group comprises Costa Rica and Peru, with 30% and 20% leaderships, respectively. Costa Rica was 6th in APMP, and Peru showed the second-highest growth in Q1Q2 articles (Table 1). Nevertheless, these good rankings did not result in high leadership. Their Q1Q2 article production was highly dependent on international collaboration (see below). Chinchilla-Rodríguez, Sugimoto, and Larivière (2019) found leadership values lower than ours in a study that included all scientific areas. Their values for Brazil, Mexico, and Argentina were around 45% compared to more than 70% in our results. For Cuba, the difference was greater. They reported 35% compared to 72% in our results. Interestingly, in a study focused on a more specific field (nanoscience and nanotechnology), Chinchilla-Rodríguez et al. (2018) found leadership values very similar to our results for Brazil, Mexico, and Argentina. The conclusion is that one might expect variations in this and other indicators when different scientific areas and fields are analyzed.
4.2. International collaboration

4.2.1. International collaborative articles

Another aspect of interest was to identify articles that were published in collaboration with other countries. We focused only on articles published in Q1 and Q2 journals. For each country, we identified those articles with at least one co-author from a different country. Countries with less than one hundred Q1 and Q2 articles were not considered for this analysis. For the total production of Q1 and Q2 articles and for Q1 and Q2 articles where the corresponding author is from the country, we calculated the percent of articles involving collaboration with developed countries. Results are shown in Figure 4. We observed that the countries could be grouped into two. One group, the first six countries in Figure 4, had more than 50% of their total Q1 and Q2 articles involving international collaboration with developed countries. For Peru, Costa Rica, and Uruguay, these values were 96.6%, 85.8%, and 80.7%. These countries were heavily dependent on international collaboration to publish immunology articles in Q1 and Q2 journals. Colombia, Venezuela, and Chile were less dependent, but still, between 60% to 75% of their Q1 and Q2 articles involved international collaboration. Argentina, Mexico, Cuba, and Brazil conformed the second group with 40% to 50% of their Q1Q2 articles involving international collaboration. The production of articles in leadership (corresponding author) must be analyzed under two considerations. One is the proportion of total Q1 and Q2 articles where the country assumed the leadership (Table 2), and the other is the proportion of these articles that involved international collaboration. For Peru, in only 20%
of their total Q1 and Q2 articles, the country was the scientific leader (Table 2). Figure 4 shows that 80% of these articles involved international collaboration. So, Peru is heavily dependent on international collaboration, both for their total Q1 and Q2 article production and for their Q1 and Q2 article production as the scientific leader. Costa Rica, although as Peru, was the scientific leader in a relatively low proportion of their Q1 and Q2 articles (30%, Table 2), only 50% of these articles involved international collaboration (Figure 4). We interpret this as an indication that Costa Rica is developing an adequate capacity to carry out international competitive and independent immunology research. Uruguay, Colombia, Venezuela, and Chile showed similar results among them. The proportion of their total Q1 and Q2 articles where the country assumed the scientific leadership was around 50% to 60% (Table 2). Between 32% and 50% of these articles involved international collaboration. These countries showed a certain capacity to carry out competitive and independent research in immunology, although international collaboration still played an important role. The last four countries in Figure 4 were composed of the three top countries in total article production (Figure 2(a)) and the top country in APMP production (Figure 3(a)). The proportion of their total Q1 and Q2 articles where the country assumed the leadership was high, with values between 70% and 80% (Table 2), and only around 25% of these articles involved international collaboration. It is clear that by this and other indicators, these countries have developed a solid capacity to carry out internationally competitive and independent immunology research.

The nine countries with the lowest article production shown in Figure 2(b) had, in relation to its production, a high proportion of articles in Q1 and Q2 journals. However, that production was almost entirely dependent on international collaboration with developed countries.

Overall, our results concur with what Chinchilla-Rodríguez, Sugimoto, and Larivière (2019) reported. They found that countries with the greater outputs of scientific articles, which generally means that they have a consolidated scientific system, tend to have lower amounts of articles in international collaboration.

Chinchilla-Rodríguez et al. (2018) analyzed leadership and collaboration in nanoscience and nanotechnology in emerging countries, including Latin American countries with some degree of scientific development. One of their conclusions is that collaboration with developed countries improved impact and visibility with or without the leadership of a Latin American country. Nevertheless, the improvement for articles with Latin American leadership was lower. It would be interesting to carry out a similar analysis for immunology publications.

International collaboration may have different roles in the development of science for different countries, and this role could be related to the stage of development of their scientific capabilities. Although the achievement of independent and good quality scientific research is a desirable goal for all countries, science is by definition an international enterprise. A country cannot have a developed science without international collaboration. The question is, what is a healthy balance between independent and collaborative science. Leta and Chaimovich (2002) found that Brazil, the Latin American country with the highest contribution to the world’s scientific publications, increased its publications with international collaboration from 18% to 30% from 1981 to 1992 and stayed around 30% from 1992 to 2000 while its total publications constantly grew in this period. It is possible that international collaboration helped Brazil to increase the
number of publications during the first years of this study. Still, for the last years, international collaboration was not solely responsible for the observed increase. Feld and Kreimer (2019) have shown that for Latin American countries, considering all scientific documents in the Web of Science, the countries with the higher scientific output tend to have a lower production of articles with international co-authorship, with values between 30% and 38%. Roa-Atkinson and Velho (2005) found that for Brazil, domestic articles contributed significantly to the increase of immunology articles published in indexed journals, while for Colombia, a country with a less developed scientific system, international collaboration was more relevant to increase the same kind of articles. Those results concur, in general, with what we found with the difference that we focused on articles in Q1 and Q2 journals and that we provide information for all articles and for articles where the country is the scientific leader. Our results show that in the period 2000–2017, for Q1 and Q2 immunology articles, the four most productive countries had around 45% of their total articles and 25% of their articles where they were the scientific leaders, in collaboration with developed countries. We consider that this level of collaboration with developed countries allows these countries to benefit in terms of increasing their presence in Q1 and Q2 journals while at the same time increasing their capacity to publish independently in the same kind of journals.

The total number of articles in collaboration shown in Figure 4 is 5358. In 54.3% of them, the country or one of the collaborating countries was the United States, followed by France (13.9%), the United Kingdom (13.4%), Spain (11%), and Germany (10.4%). There are other developed collaborating countries, but they were in proportions below 4%. The top five countries with which Latin American countries are collaborating are among the ten top countries producing scientific and technical journal articles per year (OECD 2016). This international collaboration may be one factor that has driven the growth we observed in our study of immunology publications in Q1 and Q2 journals. It also might have contributed to the maturation of several countries, which allows them to publish independently in Q1Q2 journals. Many Latin American scientists have spent part of their training in elite laboratories located in the above-mentioned developed countries. This likely explains why collaboration is more frequent with these countries (Kreimer and Meyer 2008).

4.2.2. Collaboration among Latin American countries

Figure 4 splits collaboration among Latin American countries in two modalities. One is where a Latin American country collaborated with at least one developed country plus at least one Latin American country. The other is articles where there was a collaboration with at least another Latin American country. Both modalities of collaboration are very low for the four countries with the top production indicators, going from 0.8% for Brazil to 4.1% for Argentina. The rest of the countries show slightly higher collaboration levels in one or the other modalities, except for Uruguay, with 24% of their Q1Q2 articles collaborating with other Latin American countries, mainly Brazil and Argentina. We don’t have an explanation for this last finding. Roa-Atkinson and Velho (2005) also found that for immunology articles, Brazil had a very low collaboration with Latin American countries in the period 1990–1999. Our results show that this situation remained the same 18 years later. This information might be relevant to policy-makers and national and international organizations interested in designing programs to promote Latin American collaboration.
in immunology. One relevant piece of information to encourage this regional collaboration was made by Leta and Chaimovich (2002). They found that collaborative articles between Brazil, Argentina, and Chile had impacts comparable to collaborative articles between Brazil and developed countries.

4.2.3. Impact of articles with international collaboration versus domestic articles

International collaboration in science has notoriously increased since the last part of the past century (Katz and Martin 1997). It is motivated by different factors. Latin American scientists have recognized that international collaboration allows them to learn new techniques, publish in high-impact journals, and access equipment not available in their countries, among other benefits (Gaillard, Gaillard, and Arvanitis 2010). In the case of biomedical sciences, there are other benefits such as access to genetically manipulated strains of animals, cell lines, or microorganisms, for example. It is considered, in general, that articles that were the result of international collaboration with developed countries increase their citation impacts. That has been demonstrated for chemistry (Glänzel and Schubert 2001); for scientific publications of Brazil (Leta and Chaimovich 2002), and for medical research in Latin America (Chinchilla-Rodríguez, Benavent-Pérez, and Moya-Anegón 2012).

With our data set, we investigated if this was the case for immunology. The three studies mentioned above assigned a collaborative article to a country if there was at least one author from that country. That means that the same collaborative article is assigned at least to two countries, regardless of the type of collaboration between them (as equals or as one country as a secondary collaborator). We wanted to study if the immunological topics of interest to the Latin American immunologists increase their impact by international collaboration. For this reason, we analyzed only the articles where the CA is from a Latin American country. As argued before, we consider that these articles represent the country’s national capability and research agenda.

For the Q1Q2 articles of the six most productive countries (Figure 2(a)), we calculated the mean observed, expected, and relative citation rate, as described in data and methodology, for the domestic and international collaborative articles published in the period 2013–2015. Review articles were not considered for this analysis. The results are shown in Table 5. The relative citation rates compare the citations received by the articles to the expected citations (see materials and methods). A value above 1.0 indicates that the articles had an impact above the average, and values below 1.0 indicate the opposite. According to our results, all domestic articles from the six countries in Table 5 had mean relative citation rates (MRCR) values from 1.20 to 1.81. That is evidence that Latin America publishes domestic immunology articles with impacts above the average of immunology articles published by other countries in the same journals. Table 5 includes 1125 domestic articles published in 111 different journals, including some of the top ten immunology journals, according to Google Scholar, such as Frontiers in Immunology, The Journal of Immunology, or Journal of Allergy and Clinical Immunology.

To study the effect of international collaboration on the citation impact, we compared the MRCR of the domestic articles to the MRCR of the collaborative articles for each country in Table 5. For all the countries in Table 5, the MRCR of the collaborative articles was higher than the MRCR of the domestic articles. We found that for Brazil, Mexico, and Argentina, the MRCR for collaborative articles was statistically significantly higher than for domestic
articles. For Chile, Colombia, and Cuba, although the increment in MRCR for collaborative articles was similar to that for Brazil, Mexico, and Argentina, it was not statistically significant. That could be because fewer articles were analyzed. In any case, these countries show a tendency to have higher MRCR for collaborative articles than for domestic articles.

The general conclusion is that immunology articles published by Latin American immunologists, which had already impacts above average, benefited from international collaboration in their citation impacts. The fact that some countries (in our study Chile and Cuba) seem not to benefit from the international collaboration was also found by Chinchilla-Rodríguez, Benavent-Pérez, and Moya-Anegón (2012) for the medical research area.

Although one limitation of our study is that we do not make comparisons with developed countries, in this part of our results, we are in fact comparing the impact of the articles from the Latin American countries shown in Table 5, with the impact of the articles published by other countries in the same journals. As the journals are Q1 and Q2, it is expected that developed countries have a substantial amount of publications in these journals.

4.3. Immunological areas of the articles published by Latin American countries

Our final question asks which are the immunological areas being studied by the Latin American immunologists. We focused on articles published in Q1 and Q2 journals where a Latin American country assumed the leadership. As discussed above, we think that this is a good reflection of the regional immunology research agenda. The area for each article was identified as described in data and methodology. Results are shown in Table 3. Infectious diseases and vaccines-infectious diseases areas comprised 50% of all articles. This last area refers to articles that had in sight the possibility of developing a new vaccine against a particular infectious disease. The next areas of importance were autoimmunity, basic immunology, vaccines, and allergy, which comprised 23% of the articles. The articles classified in the vaccine area, as a stand-alone topic, deal mainly with studies related to adjuvants, side effects associated with the application of commonly used vaccines, cancer vaccines, etc. The other four immunological areas shown in Table 3 comprised around 7% of the articles. These results give an overview of which areas and in which magnitude the Latin American immunologists are focusing their research interests on. We consider it worth mentioning that the topic of 6.2% of the articles could be classified as basic immunology, i.e. articles that study basic immune response mechanisms without directly focusing on the application thereof. This means that the region also contributes to understanding the fundamental mechanisms that make the immune system work.

As infectious diseases and vaccines-infectious diseases were the most frequent areas of the articles, we identified the microorganism-caused diseases most often addressed by the Latin American immunologists in Q1 and Q2 journals. Table 4 shows ten diseases for which more than 100 articles were found. For Chagas disease, leishmaniasis, and mycobacterial diseases (includes tuberculosis and leprosy), we found more than 400 articles for each one. For the other seven diseases, we found between 119 and 262 articles. All these diseases are a heavy burden for Latin American countries. Chagas disease, leishmaniasis, leprosy (from mycobacterial diseases), schistosomiasis, dengue, and brucellosis, are considered neglected tropical diseases. Although tuberculosis, AIDS (HIV), malaria, and toxoplasmosis are not classified as neglected tropical diseases, they also constitute a heavy burden for Latin American countries (Hotez 2008).
Our study provides evidence that an important proportion of the immunological studies that Latin American immunologists carry out focus on diseases that are very relevant to the region. The number of articles on the ten diseases shown in Table 4 represents 34% of all the articles published in Q1 and Q2 journals where the scientific leadership corresponds to a Latin American researcher. That is particularly important for the so-called neglected diseases as they are not the subject of intensive research in developed countries. Roa-Atkinson and Velho (2005), in a study focused on immunology but limited to Brazil and Colombia, also found that immunology researchers in both countries tend to study regional and local pathologies. Our study extended this observation to all Latin American countries.

There are no vaccines for human use for any of the diseases shown in Table 4, except for tuberculosis. Interestingly, 20% of all the articles in Table 4 are oriented to vaccines. Nevertheless, the development of a licensed vaccine for human use is a process that goes through different development phases that can take 15–20 years to complete (Artaud, Kara, and Launay 2019). A substantial amount of the results reported in the vaccine articles in Table 4 are from the first phases, that is, at the stage of basic research or preclinical tests in animals. So, despite the active and relevant research on these diseases, the possibility of developing a vaccine for human use for one of these diseases seems still far away. Cuba is a country that has demonstrated its capacity to develop new vaccines (World Health Organization 2015). Brazil has well-established programs to support the development and production of vaccines (Homma 2009). Further support is needed from national or international entities in charge of promoting science in Latin American countries for Latin American research groups to reach more advanced stages to develop vaccines against these neglected diseases.

The current COVID-19 pandemic has put enormous pressure on all countries with scientific capacities to develop, as soon as possible, a vaccine against this disease. The Latin American countries that we identified in this study as the more advanced in immunology are taking the lead in the region and reporting vaccines’ developments in different stages. At the time of writing this report, Cuba is probably the more advanced. It has three vaccine candidates in phase III clinical trials, involving tens of thousands of individuals in each trial (de Vacunas 2021). Using a technique developed and licensed by the Mount Sinai Institute of the United States, Brazil has developed a vaccine candidate in phase I clinical trials (Mendoça and Borges 2021). Mexico, also using a technique developed and licensed by

### Table 4. Infectious diseases for which more than 100 articles were found.

| Infectious disease        | Number of articles<sup>a</sup> | Area of classification of the articles |
|---------------------------|-------------------------------|---------------------------------------|
|                           |                               | Infectious diseases | Vaccines<sup>b</sup> | Others |
| Chagas disease            | 571                           | 493                   | 67                  | 11     |
| Leishmaniasis             | 530                           | 427                   | 102                 | 1      |
| Mycobacterial diseases    | 459                           | 370                   | 76                  | 13     |
| AIDS (HIV)                | 262                           | 211                   | 46                  | 5      |
| Malaria                   | 226                           | 148                   | 73                  | 5      |
| Paracoccidioidomycosis    | 154                           | 128                   | 24                  | 2      |
| Schistosomiasis           | 140                           | 103                   | 29                  | 8      |
| Dengue                    | 137                           | 94                    | 43                  | 0      |
| Toxoplasmosis             | 122                           | 98                    | 17                  | 7      |
| Brucellosis               | 119                           | 72                    | 45                  | 2      |

<sup>a</sup>Articles in Q1 and Q2 journals where the corresponding author is from a Latin American country.

<sup>b</sup>Includes vaccines and vaccines-infectious diseases.
| Country   | Domest. articles | Citat. | MOCR | MECR | MRCR | Collab. articles | Citat. | MOCR | MECR | MRCR | p value |
|-----------|-----------------|--------|------|------|------|-----------------|--------|------|------|------|---------|
| Brazil    | 670             | 3261   | 4.87 | 3.30 | 1.48 | 200             | 1522   | 7.61 | 3.75 | 2.12 | 0.0001  |
| Mexico    | 205             | 931    | 4.54 | 3.15 | 1.49 | 71              | 441    | 6.21 | 3.29 | 1.89 | 0.0058  |
| Argentina | 146             | 759    | 5.20 | 3.57 | 1.46 | 65              | 541    | 8.32 | 3.91 | 2.16 | 0.0047  |
| Chile     | 46              | 292    | 6.35 | 3.62 | 1.81 | 40              | 294    | 7.35 | 3.59 | 2.29 | 0.4182  |
| Colombia  | 35              | 158    | 4.51 | 3.28 | 1.34 | 35              | 205    | 5.86 | 3.35 | 1.85 | 0.1049  |
| Cuba      | 23              | 106    | 4.61 | 3.86 | 1.20 | 15              | 80     | 5.33 | 3.32 | 1.65 | 0.5805  |

*a* Articles in Q1 and Q2 journals from the six countries with the highest production where the CA is from the indicated country were analyzed.

*b* Domestic articles: all authors belong to an institution from the indicated country.

*c* Mean Observed Citation Rate: mean observed citations per article.

*d* Mean Expected Citation Rate: The expected citation according to the journal’s impact factor in the year that the article was published. Information retrieved from the Scimago Journal and Country Rank portal (https://www.scimagojr.com/).

*e* Mean Relative Citation Rate: for each article, the relative citation was calculated as OCR/ECR, and the mean is reported. A value above 1.0 indicates that the number of citations is above the expected citations.

*f* Collaborative articles: at least one author is from a developed country.

*g* A Wilcoxon rank-sum test was performed to compare the relative citations rates (RCR) of the domestic articles to the RCR of the collaborative articles. Statistical significances are highlighted in bold.
the Mount Sinai Institute of the United States, has developed a vaccine candidate that is in preclinical trials (CONACYT 2021). Argentina and Chile report efforts to develop a COVID-19 vaccine that is in the initial phases (Gisande 2021; Radio Usach 2021).

4.4. Limitations and future work

With our data set, we were able to reach our objective of gathering information on the status of immunology in Latin America. However, one limitation of our work is that it doesn’t make comparisons with other regions. The contrast of the indicators we used with those for developed or other emerging countries would have provided us with more solid information. That is certainly a topic for future work.

We are aware that our databases do not include all the immunology articles published in the region, as immunology has become an interdisciplinary field. Articles with an immunological approach are published more and more frequently in biomedical journals which are not focused on immunology. Although we included what we think is a significant sample of immunology articles (603) published in non-immunological journals, other articles were not included that might impact on our findings. Nonetheless, the total Q1 and Q2 immunology sample of 10,315 is, we argue, representative.

The disaggregation of the journals by quartiles provided us with relevant information on the productivity of immunology articles of a certain quality. Nevertheless, we are aware that the quartile rank is only a proxy for quality that is subject to criticism. The publication of a particular article in a Q1 or Q2 journal is not a guarantee of high impact and visibility. In future works, it is desirable to carry out more detailed studies of the impact of the Latin American immunology articles at the level of individual articles. That would prove or disproved our proposition that in Latin America, not only the immunology publications output seems to be increasing, but also its quality.

We provided some very basic and limited information on international collaboration that might be useful as a starting point to further and more profound studies. Chinchilla-Rodríguez et al. (2018) studied to what extent Latin American countries benefit from international collaboration in the field of nanoscience and nanotechnology. Feld and Kreimer (2019) made a profound analysis of the type of collaborations between the European Union and Latin America and their positive and negative effects. These kinds of studies are an important topic for future research focused on immunology.

For collaborative articles, we used the corresponding author’s country to assign the leadership role as in Chinchilla-Rodríguez, Sugimoto, and Larivière (2019). Nevertheless, we are aware that this is subject to certain errors as in some cases, other factors are considered to decide who the corresponding author is. However, we think that in the majority of the cases, the assumption of to which country assign the leadership is correct.

The classification of articles in immunological areas might be subject to question or discussion. As the classification was made mainly from the articles’ title, it is possible that if the article is analyzed more thoroughly, some might argue in favor of changing the classification, especially if there was more than one possible area in which to classify the article. Nevertheless, we think that the information we gathered is helpful in giving an overview of the immunological areas being the subject of research in Latin America.
Finally, at the time of writing this study, the COVID-19 pandemic is in its third wave. Although vaccines are already available and in use, the demand is higher than the production. It would be very important to follow up the efforts to develop a vaccine against COVID-19 that some Latin American countries are making. The question here is if they can develop and produce in time a licensed vaccine that could help control the pandemic in the region.

5. Conclusions

Our bibliometric analysis shows that in the present century, immunology research is growing steadily in Latin America. The growth was more notorious in articles published in journals at the top 50% of quality. We interpret this as an indication that immunology research in Latin America is improving its quality.

By analyzing the production of immunology articles and the international collaboration, we were able to characterize the situation of immunology in each country. Brazil, Mexico, and Argentina were the top article producers, both in total articles and in articles in Q1 and Q2 journals. In a high proportion of their Q1 and Q2 articles, they assumed the leadership, and they are not very dependent on international collaboration with developed countries to have articles in Q1 and Q2 journals. Nevertheless, their Q1 and Q2 articles in collaboration with developed countries had higher impacts than their domestic articles. We consider these indicators as the goals to be reached by the other countries in the region if they want to attain a better immunology research system.

Chile, Colombia, and Cuba are the countries ranked next when considering the indicators mentioned above. These six countries have been recognized as the most productive in publications in other studies. Here we confirm this status for the immunology field.

Other countries showed interesting signs of improving their participation in immunology research. Uruguay and Costa Rica were part of the six top countries as article producers, and Uruguay was the first for articles published in Q1 and Q2 journals when their population size was considered. Peru was the country with the highest increase in total publications. Peru, Uruguay, and Ecuador had a proportion of their Q1 and Q2 articles as scientific leaders with values similar to Chile and Colombia.

The information provided here makes a first diagnosis of the stage of the scientific development of immunology in the region. The data can be considered a useful starting point for policy-makers interested in setting up programs to improve immunology research in Latin America and its countries.

Another important contribution of our study is that Latin American immunologists contribute substantially to the study of diseases that are a heavy health burden to the region. Most of these diseases are, in general, neglected by the scientific systems of developed countries. The work of Feld and Kreimer (2019) analyzes the thematic orientation of the collaboration projects between Latin American countries and the European Union, which tends to concentrate on research topics that they call “universal,” decreasing the research on topics of more interest to the Latin American countries; “local problems,” as they call them. Interestingly, they put as an example a decrease in research on Chagas disease, which we found as the infectious disease with more Q1 and Q2 publications by Latin American immunologists. From these observations and our results, we conclude that the
collaboration strategies of Latin America with developed countries must be studied in greater depth.

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