International Collaboration in Medical Research in Latin America and the Caribbean (2003–2007)

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Bibliometric techniques and social network analysis are used to define the patterns of international medical research in Latin America and the Caribbean based on information available in the Scopus database. The objective was to ascertain countries’ capacity to establish intra- and extraregional scientific collaboration. The results show that increased output and citations in medical research have heightened the region’s presence and participation in the international scientific arena. These findings may be partly influenced by the inclusion of new journals in the database and regional initiatives that may have enhanced collaboration and knowledge transfer in science. The overall rise in partnering rates is slightly greater intra- than extraregionally. The possible effect of geographic, idiomatic, and cultural proximity is likewise identified. The “scientific dependence” of small or developing countries would explain their high collaboration rates and impact. The evidence shows that the most productive countries draw from knowledge generated domestically or by their neighbors, which would explain why impact is so highly concentrated in the regions with the greatest output. The need to incentivize intraregional relationships must be stressed, although international initiatives should also be supported.

Introduction

The growing intensity of scientific collaboration is one of the most visible features of the transformation taking place in science. Ever since the 1960s (Price, 1965), collaboration has been the rule rather than the exception. The growth in the size of research teams in most scientific disciplines is an indication of a move toward greater efficiency in the use of available resources, as well as toward increased productivity and higher prestige and visibility. In short, the growing pace of scientific progress has been at least partly driven by intense partnering between scientists and research groups in different countries (Beaver, 2001; Glänzel, 2001). The earliest sociological studies on scientific collaboration were conducted in the 1960s, but it was not until the 1990s that the use of data and methodologies for their analysis began to grow and diversify (Yamashita & Okubo, 2006; Sonnenwald, 2007). Although scientometric studies themselves cannot fully explain the dynamics of scientific collaboration (Wang, Wu, Pan, Ma, & Rousseau, 2005; Heinze & Kuhlmann, 2008), coauthorship constitutes one of the most obvious and best-documented types of evidence of the existence of relationships among researchers and, consequently, among the institutions and countries funding or conducting R&D (Glänzel & Schubert, 2004). Coauthors are, then, an indication of collaboration through which possible knowledge networks can be identified, at least approximately (Bordons & Gómez, 2000; Anuradha & Urs, 2007; Velden, Haque, & Lagoze, 2010).

One of the objectives pursued in many developed countries is to encourage collaboration at all levels and across all disciplines through incentives and other scientific policy measures. These incentives are geared to furthering the interrelationships developed in scientific research for essentially three reasons. Academically, partnering establishes positive feedback from the scientific system via the import of new knowledge and the integration of that knowledge into institutions and research processes. Economically, it enhances the ability to use the available resources cost-effectively. Politically, it aids in the translation of research efforts into innovation (e.g., Framework Programme or EUREKA in Europe). Moreover, partnering encourages the use of assessment and structural tools and the reinforcement of project assessment and monitoring, primarily on the grounds of the results of scientific activity and the application of indicators that reflect international scientific criteria (Commission of the European Community, 2003; Ministerio de Ciencia y Tecnología, 2004).
The preponderant role played by collaboration in the advancement of science was highlighted in 2003 at a meeting of Organisation for Economic Co-operation and Development (OECD) science and technology ministers and reiterated at a workshop held in 2007. On both occasions, all levels of scientific and technological collaboration were declared to be of utmost importance for the furtherance of sustainable development as a basis for social and economic independence in developing countries, as well as to favor researcher mobility and add to participants’ cultural and scientific assets (OECD, 2003, 2007).

Initiatives to promote and support research adopt different forms from one region to the next, and may include technical assistance, local training, and support for the development of specific institutions, institutional partnering, or intercountry agreements. Analysis of collaboration in Latin American and Caribbean countries is of particular significance, because initiatives were often the result of “research-for-aid” arrangements, which are generally based on North–South asymmetries (Bonfiglioli, 2000). Over the years, however, collaboration for mutual benefit and excellence has gained increasing acceptance, with “partner” selection progressively becoming a strategic priority to enhance one’s own production (Velho, 2002). In this context, a key prerequisite for the design of regional collaboration policies is the determination of how Latin American partners attain higher research potential (more and better results).

The presence of Latin American science in international databases has risen substantially. Regional output in the Web of Science (WoS) grew by 140% from 1991 to 2002, with 65% of the papers published in that timeframe involving collaboration (Sancho, Morillo, Filippo, Gómez, & Fernández, 2006). These numbers reflect the strong trend toward regional collaboration and integration into the international scientific mainstream.

Some of these initiatives grew out of CYTED (Programa Iberoamericano de Cooperación en Ciencia y Tecnología para el Desarrollo: Ibero-American Cooperation for Scientific and Technological Development Programme), a project sponsored by the Latin American and Caribbean countries, Portugal, and Spain to further cooperation among research teams in the member countries.

The Ibero-American Research Area (Espacio Iberoamericano del Conocimiento [EIC]; CYTED, 2010) is another regional initiative that fosters ongoing cooperation in higher education and academic and researcher mobility in pursuit of regional integration and effective cooperation in Latin America. In a context in which knowledge is regarded as the basis for social, economic, and cultural development (Organización de Estados Iberoamericanos para la Educación, la Ciencia y la Cultura [OEI], 2005), the EIC is defined as the “scope in which to further regional integration and strengthen and foster interaction and cooperation as a means of generating, circulating and transferring knowledge for mutual and complementary benefit, improving the quality and enhancing the relevance of higher education, scientific research and innovation on which to base the region’s sustainable development.” This idea is no different from the premise underlying the Commission of the European Union’s Lisbon Strategy, which identified knowledge as the grounds for economic competitiveness.

Against that backdrop and from a perspective aligned with scientific policy, analysis of collaboration is justified as a way to strike an approximate balance between what is expected and what is obtained, between the effects of programs and measures, and their implementation over time. Such an analysis furnishes information useful for decision making with respect to areas such as avant-garde research, the formation of research teams, mobility program planning, and strategic alliances respecting future collaboration. It also contributes to avoiding the duplication of effort by maximizing both human and material resources, among many other advantages. At the same time, academically speaking, it compares cooperation trends (up, down, flat) in countries or areas of knowledge and identifies where partnering is more or less active and visible (Chinchilla & Moya, 2007).

An analysis by discipline shows that more papers are published on medicine than any other subject. Medical research accounted for around 30% of world output between 1996 and 1999. Thereafter, its prevalence declined due primarily to the relative increase in the number of papers published on other subjects, such as engineering, technology, and social science (Scopus, 2011). Depending on the country, this increase may have been a result of the database effect, policies on subject coverage, or the characteristics of specialization in each region. Medical research patterns in Latin America and the Caribbean countries differed from the above in terms of volume, trends, and degree of international collaboration.

Objectives

The characterization of international collaboration in medical research in Latin America and the Caribbean and each country in the region is broached in this context of general public interest, with a view to addressing its strengths and weaknesses from two standpoints. The first is countries’ capacity to engage in scientific collaboration both intra- and extraregionally. The second is the identification of publishing patterns from which to appraise the effects of partnering networks on scientific production and impact, using bibliometric indicators such as output, degree of specialization, visibility, and popularity. The aim is to furnish information with which to interpret countries’ networking potential as a vehicle for reaching the levels of scientific productivity and competence pursued by their governments. Two of the specific objectives sought in connection with the comparison of intra- and extraregional collaboration are

- to identify the countries that hold central or strategic positions in collaboration networks in medical research
- to determine the countries benefiting most from their relationship dynamics in terms of area productivity in medical research
The study also proposes new methodology that combines indicators for use as a decision-making tool able to characterize production and the effect of intra- and extraregional collaboration on the productivity of the region’s main science producers.

Material

The source used in this article was the open-access portal ScImago Journal & Country Rank (SJR), developed by the ScImago Group from the information contained in Elsevier’s Scopus database (ScImago, 2007). Since the period analyzed was 2003–2007, the baseline for the citations received was the scientific output in 2003 involving international collaboration. This assured that most of the citations received by the papers published in 2003 would be included in the impact factor calculations.

Justification of the Source of Data

Some authors have reservations about using international class databases such as WoS or Scopus for analyzing geographically peripheral regions (Sancho, 1992; Whitney, 1992; Garfield, 1997; Herrero & Moya, 1999). Their indisputable contention is that a substantial amount of local and regional knowledge is left out of such databases (Gómez, Sancho, Moreno, & Fernández, 1999), due as much to the strategies adopted by the researchers in these regions with respect to the production and transfer of scientific knowledge as to database publishers’ editorial criteria. Since, moreover, English has traditionally been the predominant language in these sources, the difficulty entailed in assessing the research conducted in non-English-speaking countries has constrained coverage. Similarly, these countries’ presence on the international science arena appears to be more a result of the specific situation of each subject area (Spagnolo, 1990) or the connections of certain lines of research with world science (Shrum, 1997) than of regional behavior. For the reasons set out below, however, the information used in this study overcomes some of these objections and affords other advantages. With respect to other multidisciplinary sources such as the WoS, the journals listed in the Scopus (Elsevier) database provide wider geographic and subject area coverage (Moya et al., 2007), with a higher proportion of peripheral countries and a broader variety of languages (Arencibia & Moya, 2010).

For medical research, LILACS (Literatura Latinoamericana y del Caribe en Ciencias de la Salud, Latin American and Caribbean Health Science Literature) and MEDLINE are among the recommended sources for studying Latin American literature. However, these bases include the first author’s affiliation only, which is a major obstacle to their use in collaboration studies, particularly compared to WoS or Scopus, which furnish all authors’ affiliations. Scopus lists all the journals contained in MEDLINE, affording an additional advantage over WoS. For all the foregoing, Scopus was used as the source of information for this study, given its greater suitability over other international databases for analyzing medical research collaboration among countries in the target region.

Methods

The methodology used in this study combines bibliometric techniques and network analysis, an approach that has proven to be useful to determine aggregate behavior based on a study of structurally established social relationships (Chinchilla, Moya, Vargas, Corera, & González, 2008; Kejzar, Cerne, & Batagelj, 2010; Vargas, Minguillo, Chinchilla, & Moya, 2010; Perianes, Olmeda, Ovalle, Chinchilla, & Moya, 2011). The units of analysis were the 36 countries located in the target area. Collaboration analysis was preceded by the calculation of bibliometric indicators on production volume and citations to position medical research in the regional and international context. The following indicators were used: ndoc, the number of papers published by each country; % ndoc, the percentage of each country’s output over the regional (% ndoc R) or world (% ndoc M) total; Ncit, the number of citations received by each country along with, as with output, the respective percentages of the total for the region (% Ncit R) and the world (% Ncit M); ia, the activity or specialization index, reflecting the relative activity in a given subject area in terms of the degree of specialization, understood to mean the relative effort devoted to that area; and ai, the attractiveness index, which characterizes visibility based on the relative number of citations received by a given scientific unit.

Bibliometric Indicators for Collaboration and Matrix Generation

Another indicator was ncol or the number of papers involving international collaboration, subsequently broken down in the relationship study into papers written in collaboration with extraregional authors and papers written in collaboration with authors from countries within the region.

The findings on the number of coauthored papers were used to build symmetrical matrices for the years 2003 to 2007. A matrix was built for 2003 with two partitions, shown and analyzed in this article by way of example. The first partition provides information on collaboration with all the countries with which the 36 target countries collaborated. All the countries in the region were considered, from Brazil to Saint Vincent and the Grenadines, even though output from the latter in the period amounted to less than 20 papers, for the study aimed to define a comprehensive network, including the characteristics of such “satellite” countries. The second is a subset of the first, showing information only on collaboration among the target countries themselves. Taken together, the two identify each country’s role in its intra- and extraregional relations, facilitating subsequent comparisons of network indicators. Two intercountry similarity networks were generated for the same year. In the first, the Pajek software D1 index was used, which factors in the number of
first-degree neighbors shared by two nodes, irrespective of the number of instances of collaboration among them. In the second, a similarity network was generated based on the number of instances of mutual collaboration among countries. Finally, a list of neighbors was drawn up to generate a heliocentric network showing each country’s relationships with all the others. This was based on the information on the number of internationally coauthored papers produced by the country in question and the citations per paper received for the papers published with each partner.

Relationship Indicators and Structural Analysis

The following relationship indicators were also calculated. The nodal degree is the number of nodes (countries) to which each network node is directly related. This measure depends on the size of the network, for it represents the total number of relationships in a node with respect to the maximum number possible. It is the simplest indicator for estimating social capital. The existence of many relationships is no proof of their quality, however, nor does it reflect the intensity of internodal associations (Mrvar, 2000; Hanneman & Riddle, 2005). Betweenness furnishes information on countries’ capacity to serve as bridges between other nodes and provides insight into the control exerted by a given node over other nodes’ communications. (A node with a low nodal degree but a high level of betweenness may carry substantial weight, for if it disappeared from the network, the nodes connected by it would not exhibit the same degree of interrelationships [Mrvar, 2000].) Node closeness is its capacity to connect to other nodes in the network and indicates the number of stops it takes to reach another vertex. A high degree of proximity means being well positioned, which in turn facilitates access to resources that contribute positively to node activities. The clustering coefficient indicates the density of the relationships among a given node’s circle of partners. It is equal to the ratio between the number of links between a node and its neighbors and the total number of links among all nodes in the network. This indicator is normalized because it takes into account not only the number of each node’s neighboring links and the total in the network, but also the maximum nodal degree in the network (Watts & Strogatz, 1998). Values close to one denote a high rate of collaboration with partners, but also among these partners. Figures close to zero, by contrast, mean that the node is the sole interpartner link (Barabási, 2002). The popularity indicator proposed by Perianes et al. (2009) was also calculated. This hybrid indicator is the result of an innovative combination of two known indicators, one structural and the other bibliometric: a node’s clustering coefficient and its scientific output. The expression used for these calculations is shown below.

\[ \text{Popularity index} \quad CC(v) \times ndoc(v) \]

where \( ndoc(v) \) is the total output of node \( v \) in a given period of time. The clustering coefficient relates the bibliometric popularity indicators (number of papers) to collaboration with this node. A new measure can consequently be obtained to distinguish between two nodes (in this case, countries) with the same output. The more “popular” of the two is the one with a more cohesive network of collaborators. Two variations were used in this study: in the first, the calculation was run for the total number of papers and, in the second, for only the papers involving international collaboration. This approach is designed to determine possible differences between popularity as a country attribute and popularity due to its output as a network component.

Network Visualization

Two types of collaboration networks are shown: socio-centric and heliocentric. The Kamada-Kawai (1989) algorithm was used to position the nodes in both. This method assigns coordinates to the nodes to adjust the distances between them as closely as possible to the theoretical distances (Vargas, 2007). The size of each node represents its output and the lines indicate intercountry relationships. The color (shades of gray) is a measure of intensity. Pajek software (Batagelj & Mrvar, 2003) was used to calculate and display both indicators. For the heliocentric network, the methodology applied was an adaptation of the methodology proposed for international collaboration networks, factoring in collaboration and visibility in terms of citations (Chinchilla, 2005; Chinchilla et al., 2010). The map was charted on the basis of the number of articles coauthored by the country studied with each other country, taking a list of neighbors as the point of departure. The representation occupies the maximum space available and is characterized by a central node (country analyzed) and a number of surrounding nodes (collaborating countries) that orbit around it at a greater or lesser distance, depending on the intensity of their relations with the central node. The size of each sphere represents the number of documents produced in collaboration with the country in question, whereas the color reflects the geographic region where the country is located. The lines denote the citations received for the articles written in collaboration with each country. The networks are depicted on the basis of value similarity, yielding links with identical thicknesses but variable lengths.

The partnering countries orbit around the central node at a greater or lesser distance and their relationship is represented by a line whose length is inversely proportional to visibility. This type of graphic has been used to quickly identify the countries with which a country publishes most (highest volume) and with which it is more visible (closer to the center). This analysis shows the main geographic axes and to what extent and how these relationships impact visibility, depending on the type of collaboration. Moreover, two concentric circles give the average number of citations per paper for the country’s overall production (dashed line) and the average for papers involving international collaboration (solid line). This information can be used to draw comparisons between the visibility of the associations with...
different countries. Countries can therefore be classified in terms of their position in a peripheral circle (less visible) and whether or not they lie above the average impact for each type of scientific partnering (Chinchilla, 2005; Chinchilla & Moya, 2007; Olmeda, Perianes, Ovalle, & Moya, 2008; Chinchilla, Vargas, Hassan, González, & Moya, 2010). It can also be used for both static and dynamic descriptions of an institution, region, country, or scientific discipline. An analysis of the variations in these relationships provides insight into their stability, expandability, and visibility, enabling anyone concerned to monitor joint projects and strategic alliances, among others.

Results and Discussion
World and Regional Medical Research Output: Countries’ Role

Medical research accounted for around 30% of world output between 1996 and 1999. Medical research patterns in Latin America and the Caribbean countries differed from the above, both volume- and trend-wise. First, even at its highest, the percentage never exceeded 24%. Second, while research in this discipline declined steadily until 2004, it turned upward from then on, climbing back to the values recorded at the beginning of the period (Figure 1). These developments narrowed the earlier 6-point gap with respect to the rest of the world, bringing the region into line with general global trends.

Note the high correlation between output volume and citations received (Moya et al., 2009) and the relative uniformity in the pattern of variation in the world and regional domains. Nonetheless, the citation rate grew more rapidly in Latin America than in the world at large, narrowing the gap at an even faster pace than observed for output. While this might be initially believed to be related to an improvement in publication patterns in the region and greater visibility, the proven fact that the inclusion of journals in international citation indices leads to a decline in visibility (Zitt, Ramanana, & Bassecoulard, 2003; López, Moya, & Moed, 2008) clashes with that assumption.

The target region accounted for 2.88% of world output in the period studied, with a mean increase of 14% (taking 2003 as the baseline), while its contribution to worldwide medical research was slightly lower, at 2.45%. The 10 major producers in the region in all fields were Brazil, Mexico, Argentina, Chile, Venezuela, Colombia, Cuba, Puerto Rico, Uruguay, and Peru. Country by country, the percentage contribution was very irregular, particularly at the lower end of the classification. Brazil grew at a higher rate than the world overall, climbing to nearly 1.51% of the global total, compared to 0.58, 0.39, and 0.23% for Mexico, Argentina, and Chile, respectively, and 0.1, 0.09, and 0.08% for Venezuela, Colombia, and Cuba. These findings concur with the results reported by Glänzel, Leta, and Thjis (2006).

The country output classification was the same for medical research. Brazil accounted for nearly 60% of the regional total, followed by Mexico and Argentina with much more modest values, 16 and 12%, respectively. The gap was even wider with Chile (7.5%), Venezuela and Colombia (4.5% each), Cuba (3%), Puerto Rico and Uruguay (1.5% each), and Peru (1.1%). None of the remaining countries accounted for even 1% of the regional total (Figure 2). Some countries’ percentage of the world total changed. Output declined in Argentina and rose in Venezuela, for instance. Finally, overall medical research output grew in all these
countries, giving the region a greater presence worldwide, as shown in the subgraph on the right in Figure 2.

**Specialization, Attractivity Index, and Output**

Figure 3 is a multivariate graph positioning the 20 countries with the highest output in the region from 2003 to 2007 by area of specialization and attractivity index (compared to the regional mean). The importance of medical research against overall scientific production can be visualized on this graph. Each country’s output is shown by the size of the sphere, which ranges from Brazil’s 57,370 scientific articles to Guadeloupe’s 170 papers. A reference sphere representing 250 papers is shown in the upper left quadrant. The

![Specialization, Attractivity Index, and Output](image)

**FIG. 2.** Medical research output for the 10 major Latin American producers: variations in the percentage of total world production.

**FIG. 3.** Specialization, attractivity index, and output.
specialization or activity index is graphed on the x-axis and the attractivity index on the y-axis. The countries positioned in the upper right quadrant had higher than the regional average values for both variables; those in the lower right quadrant had higher than the regional mean values for specialization only. The countries with higher than the average regional number of citations are positioned in the upper left quadrant; and the lower left quadrant contains the countries that failed to reach the regional standard in either of the two variables. A country’s output reflects not only activity in the field and its capacity to generate knowledge, but also its specialization by subject area. The two, moreover, need not follow the same pattern. This is the case of the countries in the lower left quadrant, where some of the most productive nations, such as Argentina, Mexico, and Chile, are positioned. Venezuela, Costa Rica, and Puerto Rico are positioned in the upper right quadrant, with a high attractivity index but very modest production volumes. This may be related to their participation in international projects, due to which scientific collaboration would play an important role in the position attained, as discussed below.

The highest performers in the upper right quadrant, Guatemala, Barbados, Nicaragua, Peru, Trinidad & Tobago, and Guadeloupe, have fairly small outputs. While the focus in the present analysis is on the impact of production (measured by citations and specialization), these data must be interpreted with caution. The results for countries in this quadrant with a substantial production such as Cuba, Colombia, Peru, and Jamaica are actually far more significant. The most prominent finding, however, is Brazil’s position, for despite its high output, both its specialization and citation figures exceeded the regional means. This represents added value, for it is more difficult to place a large than a more modest volume of papers in the highest citation and specialization positions.

Collaboration

The literature (Melin & Persson, 1996; Melin, 1999; Chinchilla, 2005) has shown that for aggregates of whatever sort, output is inversely proportional to the rate of international collaboration. The smallest countries exhibit the highest rates of international collaboration, as Figure 4 shows, although surprisingly, Jamaica and Trinidad & Tobago have rates similar to the values observed for countries with much larger outputs. Four areas are differentiated on the graph in Figure 4 for reader visualization. From the top down, the countries where the rate of international collaboration is less than 30% are listed first (Brazil only); the second area lists countries where the rate is 30–50% (Mexico, Argentina, Chile, Venezuela, Colombia, Jamaica, and Trinidad & Tobago); in the third, the rate is 50–70% (Cuba, Puerto Rico, Uruguay, Ecuador, Panama, and Guadeloupe); and finally, the fourth shows the countries whose medical research output is practically a satellite activity, with international collaboration accounting for over two thirds of the total (Peru, Costa Rica, Bolivia, Guatemala, and Nicaragua).

Figure 4 also compares international collaboration in medicine (broken line) to international collaboration in all areas (solid line). In most countries the collaboration rates are slightly lower in medicine than in all subject areas, but this is especially the case in Ecuador and Uruguay. In Cuba, Puerto Rico, Costa Rica, Barbados, and Guadeloupe,
however, the percentages are the same, an indication that nearly all research conducted in collaboration with other countries is associated with medicine. This information should be taken into account, together with the specialization and attractivity indices, to ascertain how open or dependent a country is with regard to foreign influence. The countries where international collaboration is highest would be the so-called “satellites,” with similar percentages of international collaboration in their overall and medical research outputs.

Finally, all the countries in the region have tended toward greater internationalization. The trend was strongest in Ecuador, where the rate trebled, and Mexico, where it nearly doubled, followed by Uruguay, Panama, Chile, Argentina, and Peru (Figure 5). Although the rise in the percentage for Ecuador may be explained by the low initial figure, this was not the case in Mexico, where further analysis would be required to determine the reasons for such a leap. The overall pattern, which is the general rule in the international context, had a few exceptions in the region studied: Cuba, Jamaica, Bolivia, Barbados, Nicaragua, and, to a lesser extent, Venezuela and Colombia.

Intra- Versus Extraregional International Collaboration

This distinction makes it possible to determine whether intraregional collaboration is growing and how it impacts consolidation both in the Ibero-American Research Area (Espacio Iberoamericano de Investigación) and internationally. By combining the values for the battery of indicators designed for this study, information can also be gleaned on the variations in the number of participating countries, the number of papers involved, and the effects of these associations.

Table 1 gives the variation in the number of countries involved in international collaboration by region. Two rows are shown for Latin America, one for intra- and the other for extraregional collaboration. The bottom rows give the percentage of papers by type of collaboration.

An upward trend can be observed in the number of papers coauthored both intra- and extraregionally, as well as in the number of regional partners, which grew by 25% (first row for Latin America), bringing intraregional collaboration to 73%, while collaboration with other countries grew by only 6%. The increase was also much higher for the number of intra- than for the number of extraregional papers (48.74% vs. 25%).

The number of countries from other regions grew by 23% (from 110 countries in 2003 to 135 in 2007), and the nations involved were located in a wide variety of regions. Eastern Europe, the Near East, Western Europe, and Asia accounted for the largest number of partners, with 75, 66.7, 60, and 54.5%, respectively, although proportionally more Asian than European countries were new to the list. Depending on the area, the participation of Southern African countries grew substantially. Relations with the Pacific region, while scant, held steady throughout the 5-year period.

Collaboration Patterns in Latin American Countries

The network depicted below reflects the relationships among countries by their choice of partners for medical research. The distance between nodes and the intensity of the lines are determined by the affinity between countries in
terms of the number of neighbors concurring on the same
two nodes, regardless of the frequency. The size of the nodes
is proportional to medical research output and the colors
distinguish three groups by their collaboration rates. Coun-
tries with international collaboration rates of under 30% are
shown in black; gray denotes rates of 30–50%, and white
rates of 50–100% (Figure 6).

Here the analysis is positional, that is, associated with the
place occupied by each country on the network, in which
possible intercountry similarities in terms of collaborative
behavior in the region are identified. The countries clustered
on the right, for instance, partner only with countries outside
the region; in the present context, this group is disconnected
from the rest of the network. These are, moreover, satellite

### TABLE 1. Variation in the number of countries collaborating in medical research.

<table>
<thead>
<tr>
<th>Region</th>
<th>2003</th>
<th>2004</th>
<th>2005</th>
<th>2006</th>
<th>2007</th>
<th>Growth Rate</th>
<th>Number of partner countries per region</th>
<th>% of partner countries per region</th>
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<td>17</td>
<td>18</td>
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<td>12</td>
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<td>45.8</td>
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<td>84</td>
<td>82</td>
<td>92</td>
<td>100</td>
<td>21.95</td>
<td>242</td>
<td>41.3</td>
</tr>
<tr>
<td>Percentage of partners</td>
<td>33.88</td>
<td>34.71</td>
<td>33.88</td>
<td>38.02</td>
<td>41.32</td>
<td></td>
<td></td>
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</tr>
<tr>
<td>% intraregional collab</td>
<td>16.51</td>
<td>20.41</td>
<td>21.42</td>
<td>22.09</td>
<td>24.55</td>
<td></td>
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<td>48.74</td>
</tr>
<tr>
<td>% extraregional collab</td>
<td>58.33</td>
<td>60.42</td>
<td>58.33</td>
<td>64.58</td>
<td>72.92</td>
<td></td>
<td></td>
<td>25.00</td>
</tr>
</tbody>
</table>

*Includes only countries partnering with countries in the region. *Includes all Central and South American countries engaging in international collaboration. *Includes only non-Central and South American countries.

countries with small outputs and a high collaboration rate, partnering essentially with the world’s major producers (North America and the most scientifically significant European countries). The center of the network is occupied by three trios forming a nearly vertical line: Colombia, Cuba, and Guatemala; Chile, Brazil, and Argentina; and Mexico, Peru, and Venezuela. These clusters comprise the region’s main producers, as observed from the size of the spheres and relatively low collaboration rates.

Another cluster, including some of the Caribbean islands and the Guianas, can be identified left of center. This group is characterized by intense partnering with countries outside the region and with Latin American countries of a similar size. One of the factors possibly contributing to these connections is linguistic affinity, inasmuch as English is the official language in most of these countries. Geography and subject area are other possible influences, the former for reasons of proximity and the latter because the groupings may be a result of specialization in each country.

Figure 7 shows partnering among the countries in the region in 2003. The sphere size and color scheme are as in Figure 6. In this case, the distance between the actors reflects the total number of joint projects. Unlike the preceding figure, this image contains a list of countries on the lower right that were included in the general analysis but which are disconnected from the rest of the network because they engage only in extraregional collaboration.

The central part of the map revolves around Brazil as the strategic partner for the rest of the countries. Brazil and Chile are the only countries that collaborate with the English-speaking satellite nations positioned in the upper right corner of the network. The rest of the network is positioned around the most productive countries, forming clusters which, as in the preceding case, are geographically oriented. The Central American countries are clustered at the lower part of the map and at the lower left: the Caribbean countries, on the one hand, and Bolivia, Ecuador, and Paraguay, on the other.

Comparison of Intra- and Interregional Networks: Indicators of Centrality, Cohesion, and Popularity

Generally speaking, Brazil exhibits the highest intra- and extraregional centrality values, followed by Argentina. Chile, in turn, exhibits indisputable potential with regard to intraregional centrality and proximity, greater than observed for Mexico. In the broader extraregional context, however, Chile ranks higher than Mexico only in betweenness. The map is a clear indication of these four countries’ capacity in these two contexts. It confirms Brazil and Argentina as central pillars, followed by Chile and Mexico due to their good strategic positioning and large number of relationships. Moreover, not all countries perform better extra- than intraregionally: Examples are Guatemala, Honduras, and Peru. This may be explained by the implementation of collaboration policies geared more to the regional than the extraregional sphere, probably due to a focus on local subjects or induced by geographical proximity.
Countries’ strategic position in terms of betweenness is generally higher in the international than the regional arena. The strongest countries in terms of other indicators, namely Brazil, Argentina, and Mexico, are located even more advantageously as international intermediaries, while Trinidad & Tobago stands out clearly as a regional hub. Curiously, the importance of the Central American countries (Guatemala, Honduras, and Nicaragua) and Barbados as intermediaries is lower in the extra- than the intraregional context.

The proximity indicator reveals the importance of being positioned in broad networks. All countries’ communication potential rose, improving their positions in terms of ease of establishing contacts. Greater partnering capacity led to greater access to material and social resources, which ultimately translates into more highly developed scientific activity. In this case, the smaller countries (Antigua and Barbuda, Grenada, Bermuda, Dominica, Haiti, and Martinique among others) benefited most from international collaboration. This would confirm Persson’s (2010) hypothesis mentioned earlier.

By contrast, cohesion, in terms of the intensity of relationships, was found to be weaker when the countries were placed in a broader context. In other words, intraregional relationships are stronger than the extraregional variety. The most notable examples in this regard are Colombia, Ecuador, El Salvador, and Puerto Rico. Guadeloupe, Honduras, and Trinidad & Tobago, with the highest coefficient in the extraregional network, stand at the other extreme, an indication that they may have pursued greater international visibility by partnering with countries outside the region.

The popularity indicator analyzes the benefit in terms of productivity deriving from the collaboration strategy implemented by examining the values obtained from two standpoints. The first is the relationship between the two types of popularity in the intra- and extraregional spheres. The second focuses on the significant differences in each version of the indicator by comparing intra- and extraregional collaboration. In both cases, the index combines a country’s total output or total output involving international collaboration with the implications of the number of associations established, the density of the resulting relationships, and the degree of betweenness acquired. In the intraregional context, the scientific majors rank highest in total and international collaboration-related popularity, in the following order: Brazil, Mexico, Argentina, Chile, Colombia, and Venezuela. Although these countries’ total popularity is more or less similar, minor differences are observed in popularity linked to international collaboration, particularly for Cuba, Puerto Rico, and Venezuela. In the extraregional domain, popularity follows similar patterns. The strongest countries rank highest. In terms of total popularity, Cuba ranks very high, ahead of Venezuela, which is followed by Puerto Rico. Cuba’s popularity slides while Peru’s rises substantially when popularity is viewed from the standpoint of international collaboration.

Comparing the popularity index from the intra-/extraregional standpoint shows that while Cuba’s popularity is higher outside the region, Colombia ranks better within it. Analyzed from this perspective, but in terms of output involving international collaboration, Colombia plays a significant role intraregionally whereas Peru is prominent extraregionally.

International Collaboration: Heliocentric Network

Another aspect of interest, in addition to the description of collaboration in terms of frequency and similarities in publication patterns, is the number of citations received per internationally coauthored medical research paper for each of the countries studied. The baseline for the citations received in the period 2003–2007 was the scientific output in 2003 involving international collaboration, as represented in the preceding networks. An example of the results of collaboration in terms of visibility and impact on the international scientific community are shown in Figure 8, which depicts the heliocentric network for Cuba’s internationally coauthored output in medicine.

The partnering countries orbit around the central node at a greater or lesser distance and their relationship is represented by a line whose length is inversely proportional to visibility measured as citations per paper. This type of graphic has been used to quickly detect the countries with which coauthoring volume is largest and which afford the greatest visibility (closest to the center), as well as to identify the main axes (Chinchilla, 2005; Chinchilla & Moya, 2007; Chinchilla et al., 2008, 2010).

Interestingly, the map shows that although international collaboration enhances visibility, not all countries are equally effective in this regard and consequently not all benefit from collaboration to the same degree. The countries located in the central orbit (citations per paper received by internationally coauthored papers) are the countries with which the largest number of citations is recorded, although substantial differences in size can be observed. Hence, while the citation rate is somewhat lower with countries such as Italy, United Kingdom, France, Germany, and The Netherlands, a higher volume of studies is conducted in collaboration with these nations. Higher citation rates are attained with countries closer to the center, such as Poland, Turkey, and Hungary, but the number of papers involved is fairly small. Despite Spain’s predominance in terms of the number of papers written in collaboration, that production is among the least visible, along with the output with all the countries positioned outside the orbit representing the mean number of citations per paper received by Cuban production overall (broken line).

Conclusions

The recent increase in Latin American medical research production and citations has raised the region’s presence and participation in the international scientific arena. Although this growth is partly associated with the inclusion of new journals in the Scopus database and regional initiatives such
as Mercosur, which may have enhanced the figures (Narváez, Russell, & Velho, 1999), the rise in the number of medical research papers has doubled the overall increase. Medicine is, then, a high-growth area in the region as well as a sphere with enormous worldwide potential in terms of output, citations, and collaboration.

When output is broken down by intra- and extraregional collaboration, the growth rate proves to be slightly higher for the former (25%) than the latter (23%). Although the increase in absolute terms is small, the fact that both values rise at nearly the same rate is an indication of cohesion and similar trends in scientific research across the region. In other words, the policies designed to further regional collaboration may be bearing fruit. An earlier study on collaboration between Argentina and the European Union showed no apparent relationship between coauthorship of scientific papers and the partnering that stems from intercountry scientific cooperation agreements, whose purpose seems to be primarily formal (Miguel & Ugartemendía, 2010). Consequently, the motivation for partnering should be sought in strategic alliances associated with programs and projects in which collaboration with certain countries is requisite, such as in the EU’s framework programs, the CYTED program, and others.

All the countries in the region are improving their position and productivity from the standpoint of visibility and specialization. Visibility values are high for Brazil, as well as for Cuba and Colombia. Brazil’s performance is particularly significant, for its attractivity index (a measure of citations) is high, despite the fact that its domestic journals are listed in the Scopus database. This is striking, for as a rule the inclusion of such journals paradoxically leads to a decline in a country’s mean impact. Here, however, the presence of these journals in the SCielo database, which covers medical research very thoroughly, may have contributed to raising the country’s visibility. The BIREME, a specialized center under the auspices of the Pan-American Health Organization, which sponsored this regional initiative, is headquartered in Brazil. Future studies will include in-depth research on the effect of SCielo on participating countries’ visibility.

As might be expected, the smaller countries exhibit the highest international collaboration rates, an indication of their capacity to establish international relationships. Most of the countries with significant values in this regard are small: Jamaica, Guatemala, Barbados, Nicaragua, Trinidad & Tobago, Guadeloupe, and Ecuador. In some cases, size is almost incidental, for the position attained is explained by specialization or the fact that collaboration favors visibility, particularly in countries that publish a very small number of papers. The countries with the largest outputs have low international collaboration rates. Collaboration would not appear to affect production in such countries, in contrast to the situation in smaller nations.
These patterns have been widely discussed in the literature, which has identified a negative correlation between the size of any geographic domain and the percentage of internationally coauthored articles (Katz, 1994). This correlation may be explained by the fact that most researchers in smaller regions seek out colleagues from abroad, for their only hope of networking in a given research community is by working with national or foreign partners (Narin, Stevens, & Whitlow, 1991; Melin, 1999). This gives rise to a series of considerations. The first is that, in Latin America, smaller countries collaborate extraregionally to offset the size factor. The second is that since larger communities have more personnel, the percentage of domestic or intraregional collaboration is necessarily greater. The third consideration is that, according to the center-periphery model, small communities depend more heavily on national and international networks; and, lastly, according to that same model, small communities are more dependent on national collaboration to establish international contacts. All these assertions explain the higher proportion of collaboration in smaller communities (Melin & Persson, 1996).

Nonetheless, forming part of international networks benefits all concerned, for a greater capacity to establish such relationships affords greater visibility. One premise in this regard, generally accepted for several decades, is that the number of citations received is positively correlated with the participation of more than one (individual or institutional) author (Lewison & Cunningham, 1991). The number of citations increases with the number of authors, particularly when the partners are from different countries (Katz & Martin, 1997; Glänzel, 2001), although this trend differs depending on the country, sector, and scientific discipline (Glänzel & Schubert, 2001). In a recent study, however, Persson warned that in the context of citations, international collaboration may vary depending on the units of analysis and aggregation levels used. He contends that international collaboration is a much more important factor in small countries and their institutions than in countries with a substantial output (Persson, 2010). More than 10 years ago, Glänzel, Schubert, and Czerwon (1999) proved that the relationship between international collaboration and citations was more advantageous for less advanced than for more industrialized countries, although the latter also benefitted.

The “scientific dependence” of small or developing countries would explain their high collaboration rates and impact, since their output is essentially marginal and anecdotal: hence the term “satellite countries.” Advanced countries account for most of the world’s output and citations. Assuming that impact (citations per paper) reflects the use made by researchers of previously generated knowledge, the evidence shows that the most productive countries use the knowledge generated domestically or by their neighbors, which would explain why impact is so highly concentrated in the most productive regions. One of the implications is that research institutions’ repute is influenced by their geography, and such prestige is often unattainable for institutions in less productive or less advanced regions or countries. Put another way, a research institution’s neighborhood may limit its global scientific reputation, unless it can reach beyond its neighborhood through interregional alliances with reputed institutions from highly productive regions (SCImago Lab, 2011). Therefore, the position of these small, highly visible countries may be explained by factors such as size, international collaboration rate, area specialization, and the industrial status or stage of emergence of transition economies, while the position of large countries is affected by the environs and the cumulative repute of their institutions.

Structurally speaking and from an intra-/extraregional standpoint, Brazil has consolidated its position as a central pillar. It and the other countries with a high scientific output reach the highest values in these network indicators. Generally speaking, Latin American countries improve their ability to combine forces and communicate in a more international context; here, the smaller countries benefit from collaboration most effectively. However, links appear to be stronger in the regional domain. The region’s major producers also rank highest in terms of popularity, attaining the highest rates both when the domain considered is total regional output and when the context is limited to production involving intra- or extraregional collaboration. A connection can be established between economic and scientific potential and publication patterns. Geographic, idiomatic, and cultural proximity may also contribute to the determination of relationships and collaboration preferences, as suggested in papers by Zitt, Bassecouard, and Okubo (2000), Schubert and Glänzel (2006), and others. The growth of intraregional collaboration would thus appear to be a good starting point for developing the Espacio Iberoamericano de Investigación (Ibero-American Research Area).

The need to incentivize intraregional relationships must, then, be stressed, but without establishing boundaries, that is, international initiatives should also be supported. The reason is simple. The trend observed over the years is toward greater cohesion among countries in the region from the standpoint of productivity and knowledge transfer, along with a more open attitude, involving a larger number of countries in research. These findings concur with the results reported by Lewison and Cunningham (1991), Lewison, Fawcett-Jones, and Kessler (1993), Fernández, Gómez, and Sebastian (1998); San et al. (2006), Russell (1995), Glänzel et al. (2006), and Russell, Ainsworth, Río, Narváez, and Cortés (2007) and may be related to regional initiatives such as Mercosur, which may have had a beneficial influence on intraregional collaboration and knowledge transfer in science (Narváez et al., 1999). These findings also raise new questions, such as whether the increased cohesion among countries in the region translates into more citations among them, or how the citation rate received by countries relates to their intraregional collaboration rates. A recent study on citation flows by type of collaboration and neighborhood
influence concluded that science knows no boundaries. The greater influence of certain countries, regions, or institutions over others is due to the existence of a number of immediate environs and the quality or prestige that entails. Influence or the citation rate is greatest in authors’ most immediate environs, which need not agree with their national surrounds, and wanes with the enlargement of those environs. The bias introduced by self-citation is maximized in smaller circles. Since the greatest domestically oriented bias appears in small and developing countries, boundaries should be avoided when establishing relationships (Lanch, Guerrero, Chinchilla, & Moya, 2011).

Future papers should continue to explore the origin of these relationships and ascertain whether they appear for political reasons, individual scientists’ endeavor, or other social, institutional, or specialization-related factors. The aspects contributing to greater scientific excellence must also be studied further by including indicators able to supplement the impact factor, the sole measure currently in place. Future research is also planned to extend the period to 2008–2011 and to analyze the impact of international relations based on the percentage of papers published by each country in first quartile journals, or the percentage of papers in the top 10 by number of citations. Other input indicators would also have to be included, such as funding, staff size, and so on, to determine which countries are most productive from the standpoint of international collaboration in each area, relating inputs to outputs. This would provide a basis for comparing progress with information on publication, collaboration, and visibility patterns. Such input would be instrumental in analyses of the value and implications of the findings of such studies for the management of countries’ and institutions’ scientific and technological activity.

Combining relationship analysis and bibliometric techniques has proven to be a useful method for investigating the patterns that govern collaboration makeup and dynamics, enlarging on the existing knowledge about researcher (and therefore country, institutional, and sectoral) networking. The new formulas for characterizing scientific activity based on relationship and hybrid indicators are therefore now viewed as valid analytical and assessment tools for broaching the comparison of intra- and extraregional collaboration. This analysis constitutes a more in-depth approach to the study of formalized collaboration. It is likewise a method for positioning each country in terms of output and impact based on heliocentric international collaboration networks.

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