ORIGINAL ARTICLES

Spanish Medical Center Collaboration on Smoking Research From 1999 Through 2003 According to the Science Citation Index

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OBJECTIVE: To analyze the network structure of collaboration between medical centers sharing authorship of scientific articles on smoking.

MATERIAL AND METHODS: Articles reporting smoking research by authors from 2 or more Spanish medical centers between 1999 and the end of 2003 were identified through the Science Citation Index. The network of collaboration behind the research was analyzed and the most important measures of centrality were compared. To display the data, scientometric maps were constructed using UCINET and NETDRAW network analysis tools.

RESULTS: Thirty-five Spanish medical centers (29 hospitals and 6 health care clinics) in 8 autonomous communities were involved in 21 collaborative research projects. Hospital de La Princesa was the network core institution with the highest degrees of nodal (16), closeness (88.66), and betweenness (39) centrality. Other core nodes in the network were the following hospitals: de Cruces, San Pedro de Alcántara, La Paz, Vall d'Hebron, and General Yagüe. The autonomous communities of Castile and Leon, Madrid, and Catalonia were assigned positions at the core of the intercommunity collaborative network based on coauthorship of scientific papers shared among their medical centers.

CONCLUSIONS: Network analysis helps identify the most influential institutions in a scientific community that generates coauthored articles in the field of smoking research. Hospital de la Princesa had the highest measures of centrality. The autonomous communities of Castile and Leon, Madrid, and Catalonia form a highly connected, cohesive subgroup within the network.

Key words: *Spain. Smoking. Scientific publications. Coauthorship. Collaboration*

Análisis de la red de colaboración científica sobre tabaquismo entre centros sanitarios españoles a través del Science Citation Index (1999-2003)

OBJETIVO: Analizar la red de colaboración científica que genera la coautoría de artículos científicos entre centros sanitarios españoles en el área de tabaquismo.

MATERIAL Y MÉTODOS: Se seleccionaron los artículos sobre tabaquismo aparecidos en Science Citation Index entre los años 1999 a 2003, en cuya autoría participaron 2 o más centros sanitarios españoles. Se analizó la red de colaboración subyacente, comparando las medidas más importantes de centralidad y elaborando mapas bibliométricos que permiten su visualización. Se emplearon las herramientas informáticas para el análisis de redes UCINET® y NETDRAW®.

RESULTADOS: Treinta y cinco centros sanitarios españoles (29 hospitales y 6 centros de salud), pertenecientes a 8 comunidades autónomas distintas, intervinieron en 21 trabajos de colaboración nacional interinstitucional entre centros sanitarios. El Hospital de La Princesa obtiene los valores más altos de grado nodal (16), grado de proximidad normalizado (86,66) y grado de intermediación (39), y forma parte del núcleo de la red, junto con los Hospitales de Cruces, San Pedro de Alcántara, La Paz, Vall d'Hebron y General Yagüe. Las comunidades autónomas de Castilla y León, Madrid y Cataluña son asignadas al núcleo de la red de colaboración intercomunitaria basada en la coautoría de trabajos científicos entre centros sanitarios.

CONCLUSIONES: El análisis de redes permite identificar las instituciones más influyentes en la red de colaboración científica que genera la coautoría de artículos científicos en el área de tabaquismo. El Hospital de la Princesa destaca en todas las medidas de centralidad. Las comunidades autónomas de Castilla y León, Madrid y Cataluña configuran un subgrupo de la red altamente interconectado y cohesionado.

Palabras clave: *España. Tabaquismo. Publicaciones científicas. Análisis de coautorías. Redes de colaboración.*

Introduction

Smoking is the greatest single cause of death, disease, and early preventable disability in industrialized countries such as Spain,[1] where the prevalence of smoking was 31% of the population over the age of 16 years in 2003.[2] The purpose of smoking addiction research is to serve in the

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struggle against this pandemic and to support the effort to curb its impact on health. In many fields, scientific and technological collaboration is considered a useful approach to research,[3] as it facilitates the flow of information and debate, increases the technical resources at investigators' disposal, and makes cost sharing possible and scientific activity more efficient. Whereas international collaboration is common in certain areas, such as mathematics, national networks predominate in clinical medicine.[4]

As coauthorship of research papers is one of the most tangible forms of scientific collaboration, bibliometric indicators have provided the basis for its quantification.[5] The tracking of scientific networks has a long history in bibliometry, which has focused extensively on the networks formed by citation patterns. The contributions of Crane[6] on "invisible colleges" underscored the role of scientific networks in explaining the growth in knowledge in the second-phase logistic growth curve proposed by de Solla Price.[7]

Coauthorship of journal articles affords useful information about the structure of a scientific community composed of "collaboration networks," in which nodes represent authors (in groups, institutions, countries, etc). Two authors or institutions are connected if they have jointly signed one or more articles. The structure of such networks reveals important characteristics of a specific scientific community.[8]

Tracking collaboration through coauthorship of papers is a relatively recent approach, the study of citations being more common. Collaboration networks differ substantially from citation networks: in the first, nodes are authors and links denote coauthorship, whereas in the second, nodes are articles and the links are citations.

Since the 1990s various authors have taken an interest in the potential utility of tracking networks of authors or institutions that publish together.[9,10] These are genuine networks of affiliation in which the actors are linked because they are coauthors. They are social networks in the strictest sense, as authors who write an article together maintain a scientific or academic relationship.

Out of author or institutional collaboration emerges a pattern of relationships that can shed light on the scientific output of groups and help us manage and predict it. The efficiency with which a network reaches its objectives can be assessed and the effects on the network of a variety of approaches and interventions (joint projects, exchange of researchers, sharing of facilities and equipment, etc) can be measured.

Social network analysis is concerned with the links between individuals or institutions, defines the position they occupy in the network, and looks at the overall pattern of the network and its clusters, the flow of knowledge and information and the mutual influences generated.[11] Such analysis also uses standard algorithms to facilitate the formal representation of relationships. A collaboration network can be displayed graphically and numerical indices can objectively define some of the network's properties, as well as the relative position of authors and institutions. The visual display of a network's structure is a key part of the analysis. The map of a collaboration network helps us understand relationships between members easily and it gives a clear, visual impression of its structure, components, the related and isolated clusters, and more.

A high number of connections means that the institutions are exposed to more information of greater variety. Well-connected institutions can better mobilize their resources and they are privy to different points of view on problem solving. Links in collaboration networks affect access to resources, facilitate the transmission of both information and learning, and create areas of influence. These relationships can help us understand the diffusion, distribution, and homogeneity or heterogeneity of scientific output in a country or region. Molina and Muñoz[12] investigated the coauthorship networks that have emerged in Spanish science. More recently, González Alcaide et al[13] looked at the collaboration network of Spanish biomedical centers studying drug addiction.

The objective of the present study was to describe the network of scientific collaboration between Spanish medical centers publishing research on smoking, according to coauthorship of articles listed in the Science Citation Index (SCI) for the period 1999 through 2003. Specifically, the aim was to depict the network graphically and calculate measures of cohesion, centrality, and reachability using modern network analysis tools.

Material and Methods

Database

The SCI, accessed through the platform of the Institute for Scientific Information (ISI-Thompson), was the database used for this study. The SCI Expanded is a multidisciplinary database that compiles scientific publications with the greatest international diffusion (mainstream science). It includes the institutional affiliation of authors and thus facilitates the study of multicenter collaboration, an aspect that cannot be assessed using other bibliographic indexes.

Search Strategy

The search for the period 1999 through 2003 was carried out on November 25, 2004. The descriptors previously defined for the area of smoking addiction by our research group[14] were entered into the title field on the SCI search engine. Limits were set to retrieve only entries for original and review articles. All articles recovered were checked manually to guarantee their relevance to the topic of investigation.

Consistency of Retrievals

The retrievals were processed in a Microsoft Access database after manual checking for consistency in the SCI's designation of institutional affiliation. The purpose was to avoid a single institution being named in 2 or more different ways.

Construction of the Collaboration Network

Once data had been checked for consistency and reviewed, articles with authors coming from at least 2 different Spanish medical centers (hospitals or health care clinics) were selected. With the resulting list of centers, single-mode adjacency matrices were constructed. A link was defined between centers and between Spanish autonomous communities as "collaboration, or coauthorship, of the same scientific paper."

Matrices of bibliometric transactions are square matrices of statistical data relating units (journals, institutions, countries, etc) or elements (articles, books, etc). They were first analyzed by de Solla Price[15] en 1981. Instances of coauthorship can be considered bibliometric transactions.[16]

Statistical Analysis

Data were subject to descriptive analysis, with calculation of 95% confidence intervals.

Visual Display and Structural Analysis of the Collaboration Network

The graphic representation of the results of bibliometric transaction matrix analysis is called "mapping."[16] A map gives a clear, easy-to-understand picture of the links between elements in a complex bibliometric network and it facilitates its analysis. A map of a network is the only tool available that allows its structure to be analyzed.

For this study we used the program UCINET,[17] considered the standard tool. It includes the program NETDRAW for mapping the relationships and producing graphic outputs.

We also studied the principle measures of centrality, the basic concepts of which deserve clarification:

– Density, the most widely applied concept in graph theory, describes the overall relationship between nodes in a network. Density is high if many actors, or nodes, are connected. In a network of scientific collaboration, density measures the extent to which existing collaborations approach the total number of possible ones. It estimates the intensity of collaboration in the network overall, excluding subsequent or repeated publications.

– The distance between 2 points in a network is the length (number of links) on the shortest (geodesic) route connecting them. Two nodes connected to each other by a line form an adjacent pair. In a network of scientific collaboration, a distance of 1 indicates direct collaboration (adjacency). If the distance is 2, the authors or institutions are not directly connected, but each collaborates with a third one, and so on. Distance estimates the "effort" an institution must make to gain access to another one.

– Reachability expresses reciprocal connection by way of 1 or more links of 2 actors in a network. This concept expresses the ability of actors to make contact with each other through a limited number of intermediate relationships and to share ideas and resources. A medical center in the network is reachable if there is a line of collaboration that connects them. If many institutions are unconnected or little connected, the network is weak and lacks cohesion. Subclusters tend to appear.

– The degree of a node, or the range of an actor in a network, is a numerical measure of the number of other actors with which a direct or adjacency relationship has been established. In a network of scientific collaboration, degree expresses how many connections an institution has and estimates its influence. In our case, degree counts the number of collaborations each medical center has had. As a reflection of level of activity, it identifies the most prestigious institutions, the ones that are points of reference for others in the network. Range is usually considered a measure of how reachable information circulating in a network is to an actor.

– Degree of mediation (betweenness) is another measure of centrality. It expresses the degree to which an actor can mediate between others in a network. An actor with a relatively low node degree may still play an important mediating role. Betweenness distinguishes actors who play the role of mediator, broker, or gatekeeper in a network. It is associated with control of optimal communication, pointing to the actors who are most influential in controlling flow of information. If actors with a high degree of betweenness are eliminated from networks, the distance between others will increase considerably. In our study, betweenness quantifies the frequency with which an institution appears in the shortest geodesic route connecting 2 other institutions. This is to say, it reveals that a center mediates between 2 others who do not collaborate directly with each other. Put in other words, this measure shows how often a medical center serves as a bridge.

– Measures of centrality are indicators of prestige or influence, as they assess an actor's chances of influencing or being influenced by other actors. Those with the highest centrality scores comprise the core of a network, whereas those with lower scores are on its edges. Positions are assigned by models that use mathematical procedures to classify actors in one part of a network or another.

Results

A total of 3484 titles on smoking addiction were retrieved from the SCI for the period 1999 through 2003 (Table 1). Spanish medical centers participated in writing 94 papers, 21 (22.34%) of them having 2 or more centers named among the coauthors. A total of 35 other medical centers (29 hospitals and 6 health care clinics) were involved. Of the 99 Spanish institutions that published a paper on smoking addiction during the study period, 63 (63.6%) were medical centers.

Figure 1 shows ties of scientific collaboration between Spanish medical centers as reflected by coauthorship of articles on smoking included in the SCI from 1999 through 2003. Circles represent hospitals or primary health care centers and lines indicate collaboration. The thickness of a line shows the number of papers that 2 institutions have coauthored. The thickest line corresponds to 4 joint publications and the thinnest to a single paper. Some hospitals can be seen to be more connected than others and the network is fragmented into several subclusters. Thus, the 35 hospitals form a reticular structure that is not fully connected but rather composed of 8 unconnected subclusters.

Seven of the 17 Spanish autonomous communities are fully networked, whereas the remaining 10 are completely unconnected (Figure 2). That is to say, they have not collaborated with institutions in other communities on smoking research in the 5-year period studied. Cohesion in this network is low and centralization high.

The mean density of the network is 0.0958 (Table 2), meaning that 9.58% of the possible collaborations between institutions actually took place. The SD measures the observed variation in number of collaborations. In this case, the SD of 0.29 is much larger than the mean, indicating that there was great variation as to the number of collaborations different centers undertook.

The mean geodesic distances (shortest paths) between accessible pairs of hospitals in this collaboration network is 1.61. That distance is fairly short, approximating adjacent or direct collaboration.

The most important measures of centrality (range, closeness, the mediation index of betweenness, and overall centrality) are presented in Table 3. They reveal that Hospital de La Princesa is the most connected and central.

TABLE 1
Indicators of Productivity and Scientific Collaboration Between Spanish Medical Centers Publishing Articles on Smoking According to the Science Citation Index, 1999–2003

No. of articles on smoking in the Science Citation Index, 1999-2003	3484
No. of articles from Spanish medical centers	94
No. of articles with coauthors from different Spanish medical centers	21
No. of Spanish medical centers collaborating with other Spanish centers	35
No. of Spanish medical centers producing a publication on smoking addiction	63
No. of collaborations between different pairs of medical centers	114
No. of different collaborations between pairs of medical centers	150
No. of subsequent or repeated collaborations between pairs of medical centers	36
No. of Spanish institutions producing a publication on smoking addiction	99
No. of medical centers per coauthored publication	0.5
No. of publications per medical center	1.77
No. of collaborations per medical center	4.28

TABLE 2
Density of the Network of Scientific Collaboration Between Spanish Medical Centers Publishing Articles on Smoking According to the Science Citation Index, 1999–2003

Density, mean	0.0958
Standard Deviation	0.2943
Variance	0.087
No. of different collaborations	114
No. of possible collaborations	1190
Distance between connected pairs	1.61

The hospitals with the highest degree of mediation (betweenness) are La Princesa, La Paz, and Gómez Ulla. The bibliometric map also reveals their importance as mediators, or brokers, between Madrid and other autonomous communities.

Models constructed to reflect the positions of medical centers (Figure 3) and autonomous communities (Figure 4) at the center or on the periphery of collaboration show that the core of the network is composed of 7 highly

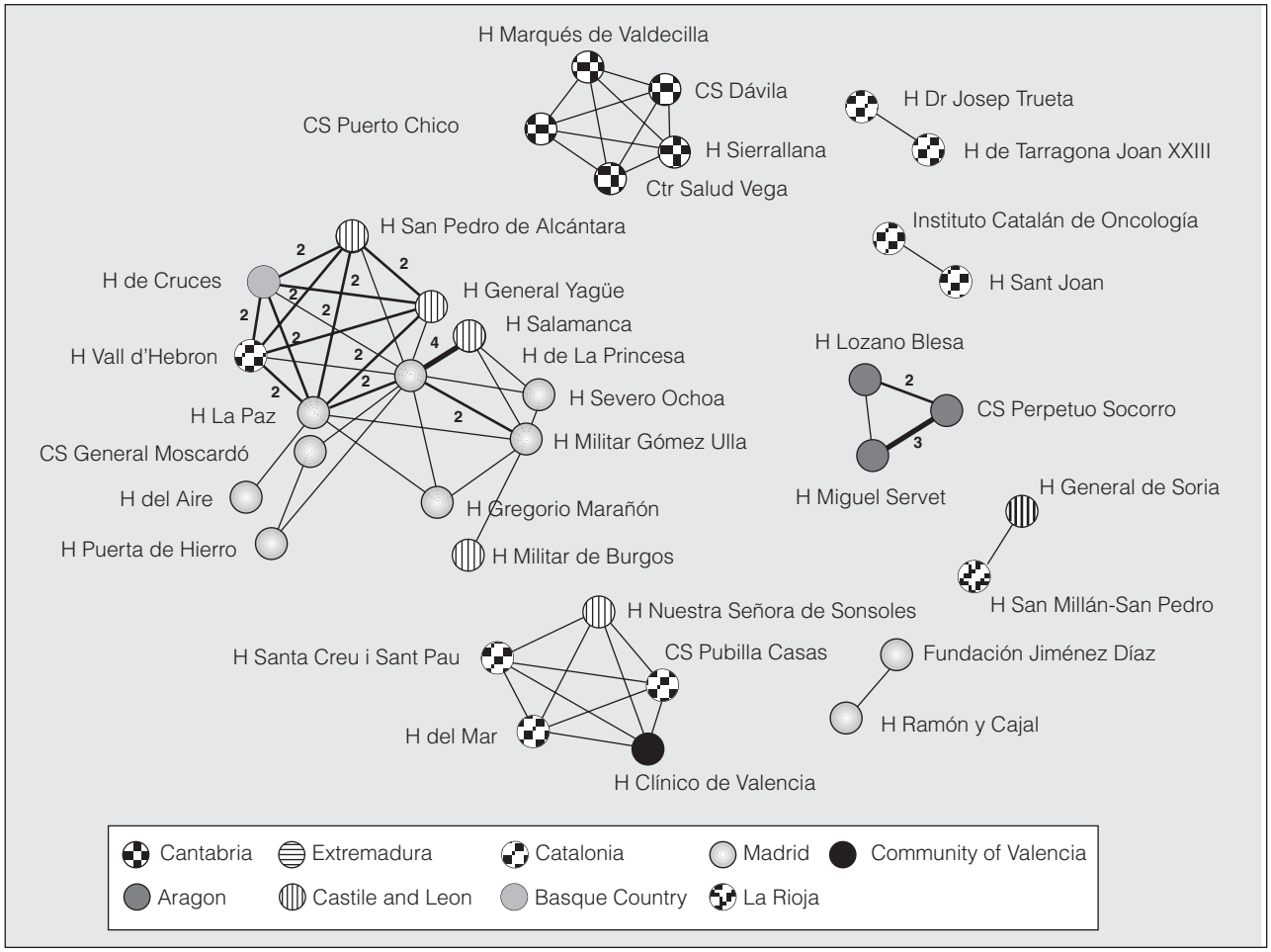

Figure 1. Network of scientific collaboration between Spanish medical centers publishing smoking addiction research, according to the Science Citation Index, 1999–2003

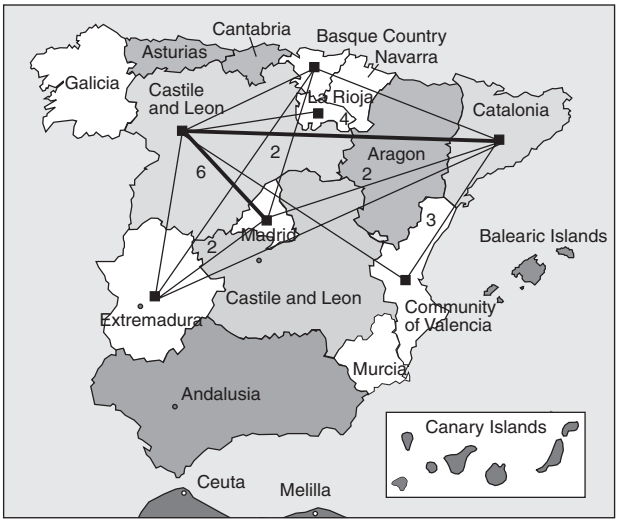

Figure 2. Network of scientific collaboration between Spanish autonomous communities publishing smoking addiction research, according to the Science Citation Index, 1999–2003

connected hospitals: Cruces, La Princesa, San Pedro de Alcántara, Gomez Ulla, Vall d'Hebron, General Yagüe, and La Paz. The density of 0.81 of the matrix that includes only core hospitals means that these are the ones that account for 81% of all possible collaborations. Hospitals assigned to the periphery are relatively unconnected to each other (density, 0.077) or to the core (density, 0.056). Analyzing by autonomous communities reveals that Castile and Leon, Madrid, and Catalonia occupy core positions.

The core–periphery matrices show the connectedness of outlying hospitals and autonomous communities both with each other and with the core institutions.

Discussion

The scientometric map of scientific collaboration between Spanish medical centers according to SCI entries reveals fragmentation into 8 subclusters during the period studied. From the perspective of network analysis, the

TABLE 3
Measures of Centrality of the Network of Scientific Collaboration Between Spanish Medical Centers Publishing Articles on Smoking According to the Science Citation Index, 1999–2003

	Range (Degree)	Closeness†	Mediation (Betweenness)
CS Dávila	4	–	0
CS General Moscardó	2	50.00	0
CS Perpetuo Socorro	5	–	0
CS Pubilla Casas	4	–	0
CS Puerto Chico	4	–	0
CS Vega	4	–	0
Fundación Jiménez Díaz	1	–	0
H Clínico de Valencia	4	–	0
H de Cruces	9	59.09	0
H del Aire	1	43.33	0
H del Mar	4	–	0
H Dr Josep Trueta	1	–	0
H General de Soria	1	–	0
H General Yagüe	9	59.09	0
H Gregorio Marañón	3	56.52	0
H La Paz	13	72.22	18
H Lozano Blesa	3	–	0
H Marqués de Valdecilla	4	–	0
H Miguel Servet	4	–	0
H Militar de Burgos	1	40.62	0
H Militar Gómez Ulla	7	65.00	15
H Nuestra Señora de Sonsoles	4	–	0
H de La Princesa	16	86.66	39
H Puerta de Hierro	2	50.00	0
H Ramón y Cajal	1	–	0
H de Salamanca	6	54.16	0
H San Millán-San Pedro	1	–	0
H San Pedro de Alcántara	9	59.09	0
H de la Santa Creu i de Sant Pau	4	–	0
H Severo Ochoa	3	54.16	0
H Sierrallana	4	–	0
H Sant Joan	1	–	0
H de Tarragona Joan XXIII	1	–	0
H Vall d'Hebron	9	59.09	0
Instituto Catalán de Oncología	1	–	0
Mean	3.25	57.79	2.06
SD	2.18	11.19	7.41
Variance	4.76	125.26	54.91
Maximum	11	86.66	39.00
Minimum	1	40.62	0

*CS indicates a primary health care center *(centro de salud)*; H, hospital.
†Calculated for large clusters.

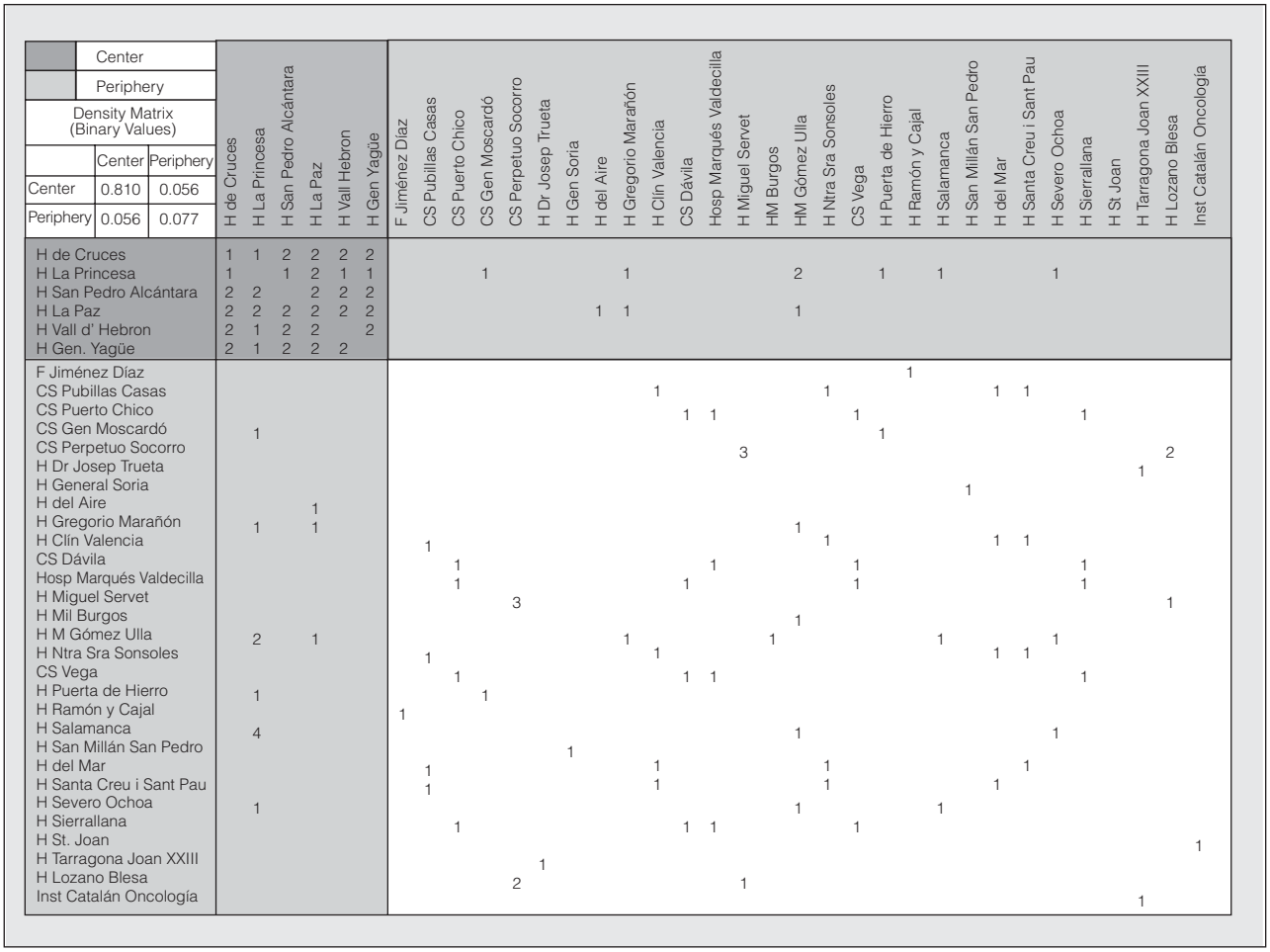

Figure 3. Matrix assigning positions at the center or periphery of the network of scientific collaboration between medical centers publishing on smoking addiction, according to the Science Citation Index, 1999–2003

interpretation of this pattern is that the reachability of information circulating between medical centers is low, making it difficult to exchange information and favoring stratification. The maps of collaboration between medical centers and between autonomous communities displays actors who are brokers, who can help researchers create new collaborations.

Brokers can cause collaboration to be more frequent and intense between hospitals within the same autonomous community (differentiated on the map by different circle fillers). Not all Spanish autonomous communities are present because not all of them had medical centers carrying out research on smoking with other centers and that was published in SCI-listed papers. Some medical centers serve as brokers mediating contact between autonomous communities. The hospitals La Paz and La Princesa connect the medical centers of Madrid with other communities. The centers in Cantabria and Aragon have only collaborated within their own communities. The medical centers of Catalonia have few connections with each other but are present in 4 network clusters, while Madrid has developed research in only 2 clusters.

The analysis of mediation (betweenness) underlines the development of 3 evident brokers: the hospitals La Princesa, La Paz, and Gómez Ulla. The medical centers with the highest degrees of mediation have much higher scores than the others, a phenomenon also observed in other social networks. Collaboration with these hospitals will create short links to large regions of the network that are connected to these influential hospitals, creating an effect called funneling.[18] The largest subcluster in the network we have constructed is a large funnel through which most medical centers established their links to other centers thanks to the 3 highly influential hospitals named. The observation that most short paths to other nodes on a network are generated by collaborating with only a small number of institutions has been seen in other settings and such brokers have been given the name of "sociometric stars."[19]

The degree of closeness indicates an institution's mean distance to others in the network. This index quantifies an institution's ability to reach others and receive and send information. Given that not all medical centers are connected, the closeness between unconnected ones and others cannot be calculated (the distance between 2 totally

Center
Periphery

	Catalonia	Madrid	Castile and Leon	Asturias	Andalucia	Aragon	Castile-La Mancha	Balearic Islands	Canary Islands	Ceuta	Community of Valencia	Extremadura	Galicia	La Rioja	Cantabria	Melilla	Murcia	Navarra	Basque Country
Catalonia		2	4								3	1							1
Madrid	2		6									2							2
Castile and Leon	4	6									1	1							1
Asturias																			
Andalucia																			
Aragon																			
Castile-La Mancha																			
Balearic Islands																			
Canary Islands																			
Ceuta																			
Community of Valencia	3		1																
Extremadura	1	2	1																1
Galicia																			
La Rioja			1																
Cantabria																			
Melilla																			
Murcia																			
Navarra																			
Basque Country	1	2	1									1							

Figure 4. Matrix assigning positions at the center or periphery of the network of scientific collaboration between Spanish autonomous communities from which articles on smoking are published, according to the Science Citation Index, 1999–2003

unconnected hospitals is infinite), although closeness can be calculated for larger units.

Castile and Leon is the autonomous community with the greatest centrality. It is better connected and has a greater ability to broker contact in the network. The most intense collaboration on smoking research in the period under study took place between hospitals in the communities of Castile and Leon, Madrid, and Catalonia. The preeminent positioning of the last 2 communities is closely related to their status as the main generators of scientific articles in Spain in the areas of clinical and biomedical science.[20] The important position of Castile and Leon in the national collaboration network on smoking research is remarkable, given the community's level of clinical research output.

The model assigning positions at the core or outlying areas of a network identifies medical centers that are central and better connected as well as those that are peripheral. The core contains the most important, best-connected actors. A core position, then, is another feature that identifies a network's key actors, stake holders, flagships, key opinion leaders or decision makers, key connections, and consumers of more resources. It is yet another indicator of prestige, power to influence, and ability to reach information.

The matrix reveals intense centralization: only 3 of the 17 communities account for nearly half of all collaborations.

Finally, social network analysis provides appropriate tools for visualizing and studying scientific collaboration that generates publications coauthored by individuals and institutions studying smoking addiction or any other area of medicine. Coauthorship structures can be mapped and measured in order to identify the relative positions of research centers. This type of analysis facilitates the identification of pivotal players who exercise the greatest influence, occupy the core, have the most prestige, are most important and better connected—in other words, the ones who enjoy greater access to information. It also identifies highly cohesive clusters and provides considerable information on the network's structure that can be put to various purposes (to design strategies for research collaboration, allocate and optimize resources, plan sales campaigns, etc).

The highest scores on all measures of centrality (degree, closeness, and betweenness) were earned by Hospital de La Princesa. The autonomous communities of Castile and Leon, Madrid, and Catalonia have cohesive, well-connected clusters and they make up the core of this network of collaboration on smoking research.

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