Coauthorship networks and institutional collaboration patterns in reproductive biology

Gregorio González-Alcaide, B.Inf.Sci., Rafael Aleixandre-Benavent, M.D., Carolina Navarro-Molina, B.Inf.Sci., and Juan Carlos Valderrama-Zurián, M.D.

Instituto de Historia de la Ciencia y Documentación López Piñero, Universitat de València-CSIC, Valencia, Spain

Objective: Reproductive biology is a highly productive area. By analyzing papers published in the major journals in the period 2003–2005, the collaborative patterns were characterized.
Design: Original research papers published in 2004 in the journals included in the first quartile of the category "Reproductive Biology" of the *Journal Citation Reports* (2005) were selected. A bibliometric analysis was carried out with the information obtained, thus building up the networks of coauthorship and institutional collaboration.
Result(s): A total of 4,702 papers were analyzed, 96.75% signed in collaboration by two or more authors, the authors per paper index being 5.24; 73.73% of the papers were collaborations between institutions. The U.S.A. and the U.K. headed the absolute productivity ranking in number of papers, and adapting the data with respect to the population, Israel, Australia, and other European countries, such as Finland, Belgium, Sweden, and The Netherlands, had notable contributions.
Conclusion(s): We identified the networks of authors who publish in the journals with the greatest impact factor. Only some of the most productive institutions have consolidated collaborative relationships with other institutions. We identified the scientific "isolation" of some countries which, although their productivity is high, have a small number of international collaborations. (Fertil Steril® 2008;90:941–56. ©2008 by American Society for Reproductive Medicine.)

Key Words: Analysis of social networks, reproductive biology, scientific collaboration, scientific publications

Reproductive biology is a biomedical research field with a great productivity, and there are important research groups in different parts of the world. It is a field that has been constantly growing over the last few decades. In 1991, it was given the status of a category by itself in the classification of disciplines in the *Journal Citation Reports* (JCR) under the name "Reproductive Systems," and the current name, "Reproductive Biology," was adopted in 1996. Since the creation of this category, the number of journals included in the field has grown continually, from 14 journals in 1991 to 24 in 2005. Before 1991, the main journals dealing with Reproductive Biology were included in the category "Obstetrics & Gynecology."

Important milestones that encouraged research in the field of Reproductive Biology (1), from the point of view of research organisms and scientific publications, include the creation in 1876 of the American Gynecological Society and in 1888 of the American Association of Obstetricians and Gynecologists, organisms that made their scientific programs known through the publication *American Journal of Obstetrics*, which from 1920 onward has been called the *American Journal of Obstetrics and Gynecology* (2). In 1902 the Carnegie Institution of Washington was created to develop scientific research. From 1913 onward, it has had a department of embryology that has edited, from 1915 onward, the journal *Contributions to Embryology*, which included numerous pioneering works in the field (3). Other important later creations were the American Society for Reproductive Medicine, a society founded in 1944 in Chicago by a group of experts in fertility who, from 1950 onwards, edited the journal *Fertility and Sterility* (4), and the Society for the Study of Reproduction, created in 1967, the organization responsible for the publication of *Biology of Reproduction* (5). The European Society of Human Reproduction and Embryology was created in 1984 and edits *Human Reproduction* (6).

In this context, bibliometric studies provide indicators of great use in evaluating the scientific activity and importance of authors, institutions, scientific journals, countries, or disciplines (7), studies which can be complemented by structural analyses that offer tools to accurately analyze the social relationships established between the agents responsible for scientific activity. These analyses, applied to the study of coauthorship and collaborative relationships between institutions for scientific publications, allow the existing relations between the social agents responsible for the publications to be identified and represented graphically, setting out the number of members in the network, the intensity of the relationships existing between them and who the most relevant members are with respect to a wide range of measures or indicators (8).

Received May 24, 2007; revised and accepted July 25, 2007.
Supported by the I3P Program, cofinanced by the European Social Found and the CSIC (Consejo Superior de Investigaciones Científicas).
Reprint requests: Gregorio González-Alcaide, B.Inf.Sci., Instituto de Historia de la Ciencia y Documentación López Piñero (Universitat de València-CSIC), Facultad de Medicina. Av. Blasco Ibáñez, 15, Valencia, 46010, Spain (FAX: 0034963613975; E-mail: gregorio.gonzalez@uv.es).

0015-0282/08/$34.00
doi:10.1016/j.fertnstert.2007.07.1378

The aim of the present paper is to carry out a bibliometric analysis to quantify the scientific production of the main authors and institutions in the field of reproductive biology over the period 2003–2005, an analysis complemented by applying techniques, originally from social network analysis, to characterize scientific collaboration and information flow with much greater accuracy.

MATERIALS AND METHODS

Identification and Selection of Papers

All the papers published in the journals in the first quartile of the category "Reproductive Biology" ordered by impact factor (2004) of the JCR were selected to identify the research front of the field. The search was limited to the period 2003–2005 and to the documental typology "articles," so that only original research papers would be analyzed. The information obtained from the selected bibliographic registers was introduced into a database using Bibliométricos software, which we developed ourselves and which allows us to create databases in Microsoft Access from the bibliographic information of the registers downloaded from catalogues or databases.

Standardization of Authors and Institutions

A process of standardization was carried out to bring together the various different names of a particular author or institution. The criterion followed in the case of the authors was the occurrence of the institutional signature associated with the variations of names and surnames. In the case of institutions, besides standardizing the different variants, it is important to point out that, in many bibliographic registers, two or more institutions are included under the same institutional address (mainly in the cases of research institutes and hospitals attached to universities). In such cases, so as not to lose information, such institutions were kept apart, giving each bibliographic register as many institutional signatures as macroinstitutions can be identified.

Calculating Bibliometric Indicators and Social Network Analysis

A series of global bibliometric indicators, with respect to the total number of papers studied, was obtained: number of papers with coauthors or institutional collaboration, collaboration index (or authors per paper index), which is the mean number of signatories per paper, and transience index, which is the percentage of authors who signed only one paper. The number of papers published per journal and the mean number of papers per issue were recorded.

The bibliometric description of the scientific production and the degree of collaboration between authors and institutions was carried out using the calculation of the following measurements or indicators: number of papers published, number of signatures, collaboration index, and the number of coauthorships or institutional collaborations.

Author clusters were also carried out. We identified all of the possible combinations of pairs of authors in each paper, which is directly related to the number of signatories in each paper, because it is equal to the number of possible combinations of m different elements (number of signatories) that can be obtained by grouping them in n by n (in this case 2 by 2 because we are identifying coauthors), a value that can be calculated by applying the formula:

$$C_n^m = \binom{m}{n} = \frac{m!}{(m-n)!n!}$$

taking into account the condition $(1 < n \leq m)$

Thus, in a paper with only one signature there is no coauthorship, whereas with two signatures we find one relation of coauthorship (A with B), with three signatures there are three relations of coauthorship (A with B, A with C, and B with C), with four signatures there are six (A with B, A with C, A with D, B with C, B with D, and C with D), and so on.

We must also differentiate between the existing number of coauthorships within the set of papers studied and the number of different coauthorships, because many of them will be repeated when analyzing a large collection of documents, some of them signed by the same authors. Once the number of coauthorships has been quantified, that is, the "collaborative intensity," an algorithm is applied which considers the existence of a cluster, when at least two authors are identified as being linked in an equal or greater number of coauthorships fixed a priori and having been carried out successively within a range that can oscillate between three or more and seven or more coauthorships, to analyze the degree of intensity in the collaborations.

The same methodology was applied to analyze and build the institutional collaborative network. In particular, in this analysis, we distinguished between the existence of different types of collaboration: intrainstitutional (type 1), which occurs in papers from the same macroinstitution (for instance, a university or hospital) but signed in collaboration by different departments, services, or units; and interinstitutional (type 2), differentiating in this case between collaborations of different institutions in the same country (type 2a) and those of institutions from two or more different countries (type 2b).

Finally, the productivity and patterns of collaboration by country were analyzed: number of papers, number of collaborating countries, and number of collaborations. In this case, standardized indicators of each country's productivity with respect to the population and the Gross Domestic Product (GDP) are also provided, obtained from reports of the World Health Organization.

Several indicators were also calculated that have a long tradition of use in studies concerning social networks and which are extremely useful in complementing the analysis of clusters. To find the degree of interconnection between nodes (institutions or countries) and the position the major institutions and countries occupy in the network as a whole, these are: "degree of centrality," a term that refers to the number of nodes with which an institution or country is connected, that is, the number of different institutions or countries it has collaborated with; "betweenness," which indicates the frequency with which a node appears in the shortest route joining another two nodes, that is, a measure that quantifies whether an institution or country acts as an intermediary, permitting a connection with others, forming a bridge between both and thus evaluating its prestige and accessibility and its control over the flow of information; and "closeness," which refers to the capacity and proximity of a node to reach the rest of the nodes that make up the network. It is calculated as the inverse of the sum of the distances from the agent in question to the rest of the agents it is connected to, thus allowing an agent's speed of interaction with the other agents in the network to be evaluated (9).

The Bibliométricos software was used to calculate the bibliometric indicators, and, in the case of the social network indicators and the graphic representations, the Pajek program for analyzing and visualizing networks was used (10).

RESULTS

A total of 4,702 papers were considered, of which 96.75% were signed in collaboration by two or more authors; 24,635 signatures were identified, for an authors per paper index of 5.24, and 14,629 different authors, the transience index being 70.28%. The author network was built through the identification and later quantification and analysis of the 65,958 coauthorship relationships in the papers under study.

Fertility and Sterility is the journal that published the greatest number of papers (n = 1,491), followed by *Human Reproduction* (n = 1,400) and *Biology of Reproduction* (n = 1,322). With much smaller contributions, we have *Molecular Human Reproduction* (n = 339), *Journal of Reproductive Immunology* (n = 131), and *Human Reproduction Update* (n = 19). *Human Reproduction* is the journal with the highest average number of papers per issue (38.89), followed by *Biology of Reproduction* (33.9) and *Fertility and Sterility* (28.67; Table 1).

We identified 106 authors who published more than 9 papers. Table 2 shows the ranking of the most productive authors (n ≥ 15) and their collaborative patterns. The most productive authors were Van Steirteghem and Devroey with 48 and 46 papers, respectively. Following them were Diamond with 34 and Pellicer with 30 papers. There were another nine authors with over 20 papers: Ho with 26; Yeung, Tournaye, and Agarwal with 25 each; Simon and Frydman with 24 each; Andersen with 23; Ng with 22; and Remohí with 21.

TABLE 1

Distribution of papers published in journals included in the first quartile of the "Reproductive Biology" category of Journal Citation Reports (2004).

Journal	2003	2004	2005	Total
Fertility and Sterility				
Papers	493	537	461	1,491
Issues	18	18	16	52
Papers per issue	27.39	29.83	29.81	28.67
Human Reproduction				
Papers	421	464	515	1,400
Issues	12	12	12	36
Papers per issue	35.08	38.67	42.92	38.89
Biology of Reproduction				
Papers	532	472	318	1,322
Issues	13	13	13	39
Papers per issue	40.92	36.31	24.46	33.9
Molecular Human Reproduction				
Papers	97	118	124	339
Issues	12	12	12	36
Papers per issue	8.08	9.83	10.33	9.42
Journal of Reproductive Immunology				
Papers	37	52	42	131
Issues	6	6	6	18
Papers per issue	6.17	8.67	7	7.28
Human Reproduction Update				
Papers	11	6	2	19
Issues	3	1	2	6
Papers per issue	3.67	6	1	3.17

González-Alcaide. Research networks in reproductive biology. Fertil Steril 2008.

Applying a threshold or intensity of collaboration of six or more papers signed in coauthorship, we identified 68 clusters or groups of authors made up of 232 researchers, the largest group consisting of 19 authors. Figures 1 and 2 represent graphically the groups with four or more members. Applying a threshold of three or more papers signed in

TABLE 2

Ranking of most productive authors (≥15 papers) and their collaborative patterns.

Author	Papers	Signatures[a]	Authors/ paper index	Collaborators[a]	Distinct authors/ paper[b]	Coauthorships[a]	Main collaborator (Coauthorship papers, author[s])
1. Van Steirteghem A	48	340	7.08	84	1.75	292	36, Devroey P
2. Devroey P	46	324	7.04	66	1.43	278	36, Van Steirteghem A
3. Diamond MP	34	169	4.97	81	2.38	137	12, Saed GM
4. Pellicer A	30	201	6.7	72	2.4	171	23, Simon C
5. Ho PC	26	127	4.88	36	1.38	101	20, Ng EHY
6. Yeung WSB	25	141	5.64	47	1.88	116	16, Ho PC
7. Tournaye H	25	168	6.72	37	1.48	143	23, Van Steirteghem A
8. Agarwal A	25	152	6.08	65	2.6	127	15, Sharma RK
9. Simon C	24	164	6.83	58	2.42	140	23, Pellicer A
10. Frydman R	24	161	6.71	76	3.17	137	11, Fanchin R
11. Andersen AN	23	136	5.91	57	2.48	113	10, Loft A
12. Ng EHY	22	122	5.54	35	1.59	100	20, Ho PC
13. Remohi J	21	140	6.67	50	2.38	119	20, Pellicer A
14. Van der Veen F	20	124	6.2	39	1.95	104	12, Bossuyt PMM
15. Spencer TE	19	89	4.68	30	1.58	70	11, Bazer FW
16. Rosenwaks Z	19	90	4.74	37	1.95	71	9, Spandorfer SD
17. Liebaers I	19	146	7.68	38	2	127	19, Van Steirteghem A
18. Habbema JDF	18	123	6.83	36	2	105	8, Eijkemans MJC/Te Velde ER
19. Lambalk CB	17	87	5.12	34	2	70	7, Schats R
20. Camus M	16	115	7.19	28	1.75	99	16, Van Steirteghem A/ Devroey P
21. Sharma RK	15	97	6.47	36	2.4	82	15, Agarwal A
22. Mol BWJ	15	93	6.2	35	2.33	78	6, Van der Veen F/Van der Steeg JW
23. Loft A	15	108	7.2	53	3.53	93	10, Andersen AN
24. Haines CJ	15	94	6.27	33	2.2	79	11, Briton-Jones CM
25. Evers JLH	15	107	7.13	49	3.27	92	6, Dumoulin JCM
26. Cohen J	15	111	7.4	58	3.87	96	7, Tarlatzis B
27. Chan CCW	15	74	4.93	11	0.73	59	15, Ho PC
28. Arici A	15	85	5.67	39	2.6	70	7, Kayisli UA

[a] In papers where the author has participated.
[b] Average of different authors by paper (indicating the size of an author collaborators' team).

González-Alcaide. Research networks in reproductive biology. Fertil Steril 2008.

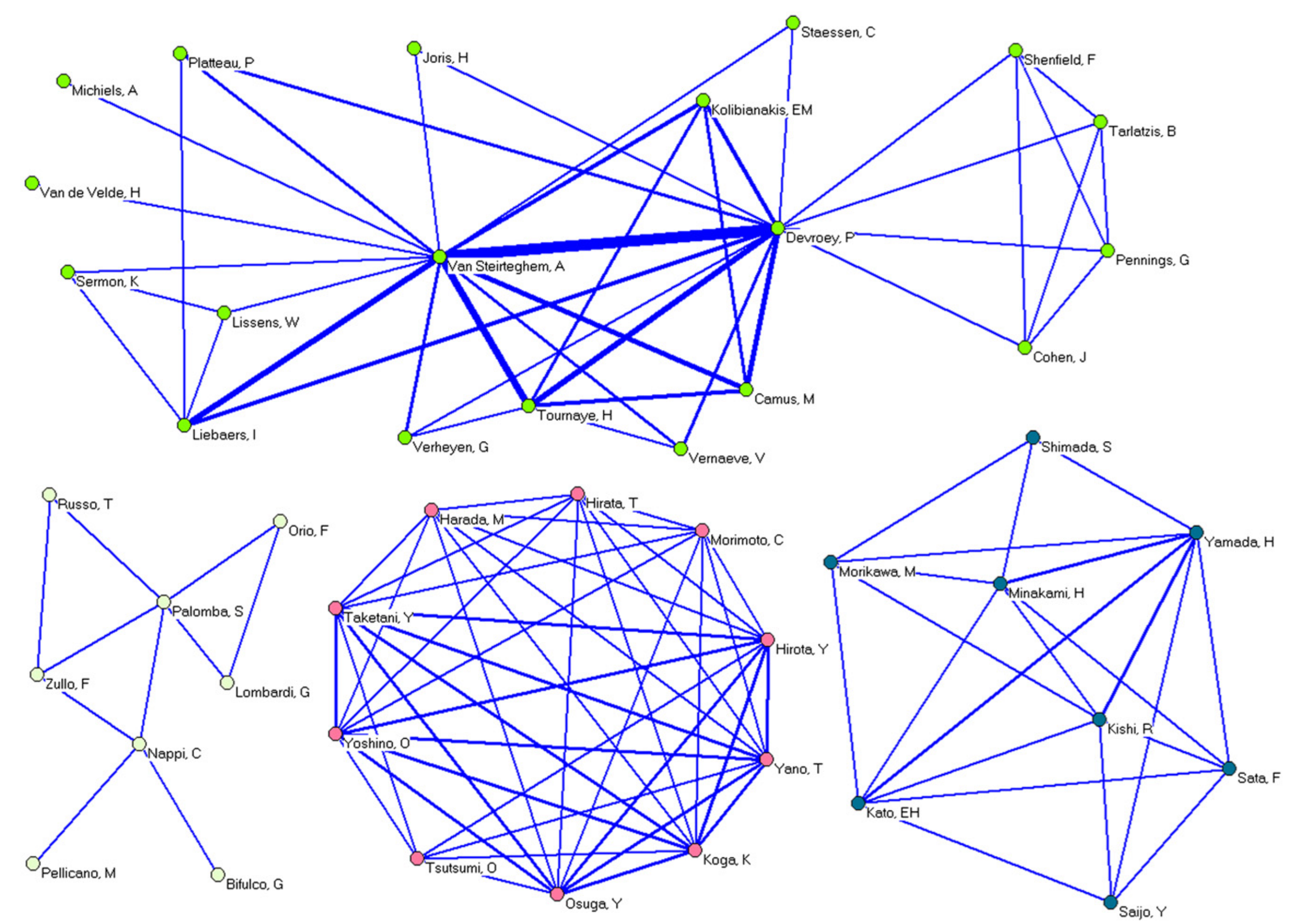
coauthorship, we identified 340 clusters or groups of authors made up of 1,510 researchers, the largest group consisting of 58 authors.

Of the 4,702 papers studied, 2,927 (62.25%) were interinstitutional collaborations; the figure which reached 3,467 (73.73%) when intrainstitutional collaborations are taken into account; 3,076 macroinstitutions were identified, totalling 10,632 signatures, putting the interinstitutional signatures per paper at 2.26. The institution network was built through the 12,095 interinstitutional collaborative relationships identified. Quantifying the number of collaborations grouped by type of collaboration, interinstitutional collaboration between institutions in the same country (type 2a) predominated, totaling 52.12% of the collaborations (n = 2,720). The intrainstitutional collaboration (type 1) was next, representing 32.84% (n = 1,714), and finally interinstitutional collaboration between institutions from different countries (type 2b), which totaled 15.04% of the collaborations (n = 785). In the diachronic breakdown of types of collaboration per year, we can see a noticeable increase in the number of collaborations, rising from 31.54% in 2003 to 34.37% in 2005.

Institutional productivity (Table 3) was headed by the Institut National de la Santé et de la Recherche Médicale with 94 papers. Next came the University of Texas and Dutch Speaking Brussels Free University with 65 and 64 papers, respectively, followed by Harvard University with 59 papers, Tel Aviv University and the Centre National de la Recherche Scientifique with 55 each, Copenhagen University Hospital with 54, Yale University with 53, McGill University with 50, and Monash University with 49. These last three institutions, together with the Institut National de la Santé et de la Recherche Médicale and the Institute of Reproductive Medicine of the University of Münster were the ones with the highest number of international collaborative relationships.

FIGURE 1

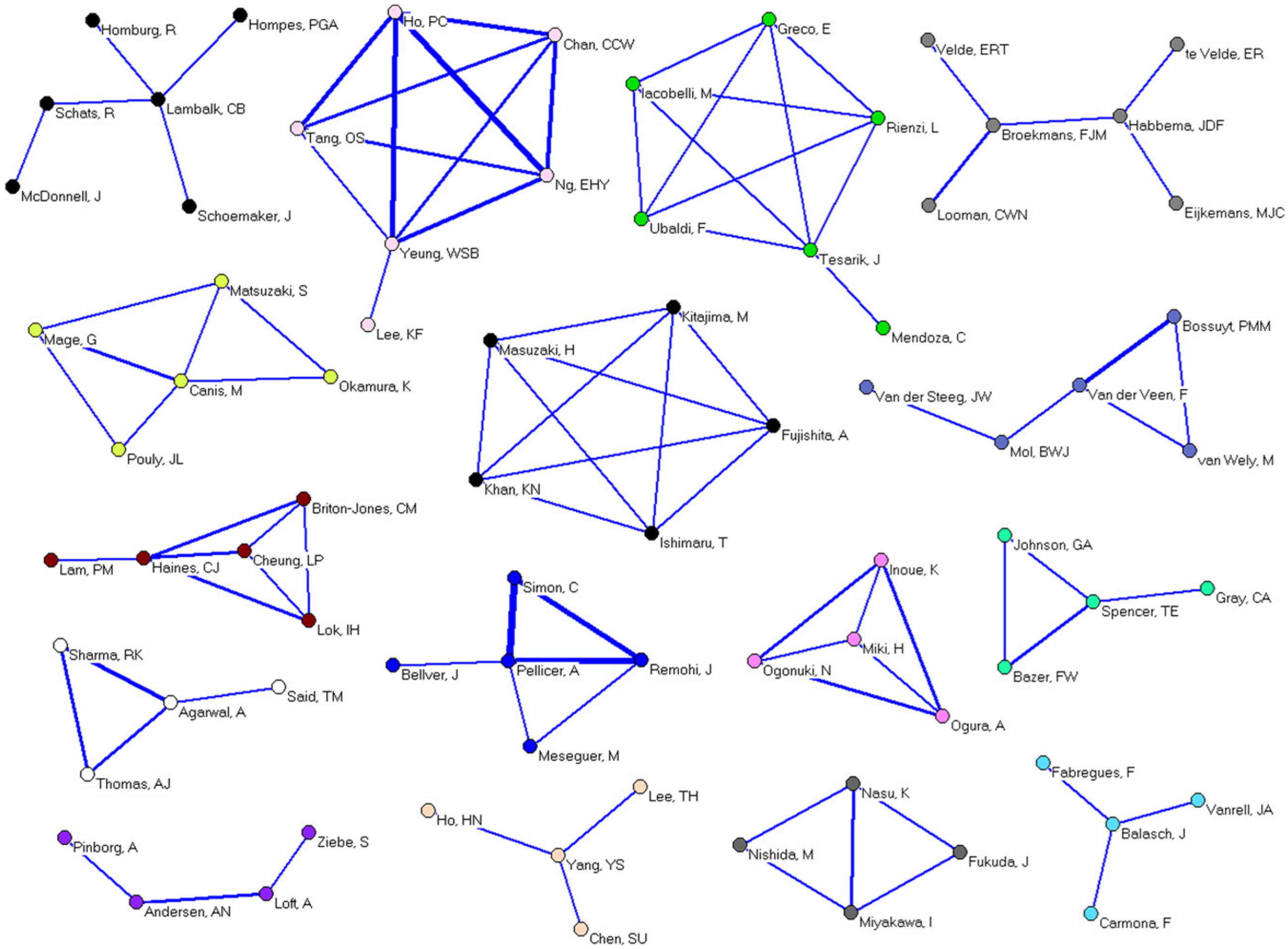
Clusters of authors (>6 members), applying a threshold of six or more papers signed in coauthorship.



González-Alcaide. Research networks in reproductive biology. Fertil Steril 2008.

FIGURE 2

Clusters of authors (4–6 members), applying a threshold of six or more papers signed in coauthorship.



González-Alcaide. Research networks in reproductive biology. Fertil Steril 2008.

Applying a threshold or intensity of collaboration of four or more papers signed with interinstitutional collaboration, we identified 92 clusters or groups consisting of a total of 310 institutions. Figures 3–5 show the main interinstitutional collaborative relationships (clusters made up of five or more institutions that collaborated on at least four papers).

The productivity ranking for countries with respect to the number of papers (Table 4) was headed by the U.S.A., which was responsible for 27.32% of the papers (n = 1,541). After the U.S.A. came the U.K. (n = 436), Japan (n = 394), Italy (n = 300), France (n = 273), Canada (n = 252), Germany (n = 236), The Netherlands (n = 218), and Australia (n = 205). Above 100 papers we also had China (n = 163), Spain (n = 159), Belgium (n = 156), Israel (n = 140), Sweden (n = 121), and Denmark (n = 109). Another 25 countries had between 10 and 100 papers, and 30 countries published fewer than 10 papers. The U.S.A. also headed the list of the number of different countries it had collaborated with (a total of 45 countries) as well as the total number of collaborations, representing 17.29% of the total number of collaborations between countries. In addition, the U.S.A. was the principal collaborator with 28 of the 40 most productive countries. Second in this list was the U.K., which collaborated with 38 different countries, representing 8.85% of all collaborations. The 21 most productive European countries accounted for 43.49% of papers and 55.95% of the collaborations.

When we considered the number of papers per million of inhabitants (Table 4), Israel and Denmark took the first two places (20.82 and 20.07 papers, respectively). They were followed by Belgium, Finland, Sweden, The Netherlands, and Australia, with the average number of papers per million of population between 14.97 and 10.17. Another eight countries had more than five papers per million of population (New Zealand, Canada, the U.K., Austria, Switzerland, Greece, the U.S.A., and Italy). When we considered the number of papers with respect to the GNP per capita, the U.S.A. came at the top of the list, followed by China, India, the U.K., Japan, Turkey, and Italy, all with figures above 10 when the

TABLE 3

Ranking of most productive institutions (≥31 papers) and their collaborative patterns.

Institution	Papers/papers in collaboration (%)[a]	Type 1	Type 2a	Type 2b	Signatures[b]	Collaborations[b]	Collaborators[b]	Main institutional collaborator (papers, institution)
1. Institut National de la Santé et de la Recherche Médicale (France)	94/92 (97.87%)	48	92	27	411	317	161	18, Centre National de la Recherche Scientifique (France)
2. University of Texas (U.S.A.)	65/50 (76.92%)	19	41	9	158	93	69	4, Baylor College of Medicine (U.S.A.)
3. Dutch-Speaking Brussels Free University (Belgium)	64/44 (68.75%)	17	31	13	139	75	43	18, University Hospital of Brussels (Belgium)
4. Harvard University (U.S.A.)	59/55 (93.22%)	16	55	11	190	131	58	24, Brigham & Womens Hospital (U.S.A.)
5. Tel Aviv University (Israel)	55/54 (98.18%)	24	54	11	171	116	44	19, Rabin Medical Center (Israel)
6. Centre National de la Recherche Scientifique (France)	55/54 (98.18%)	25	53	17	225	170	84	24, Institut National de la Recherche Agronomique (France)
7. Copenhagen University Hospital (Denmark)	54 48 (88.89%)	13	37	16	190	136	59	21, University of Copenhagen (Denmark)
8. Yale University (U.S.A.)	53/43 (81.13%)	19	18	28	139	86	58	6, Akdeniz University (Turkey)
9. McGill University (Canada)	50/42 (84%)	22	33	20	133	83	46	18, Royal Victoria Hospital (Canada)
10. Monash University (Australia)	49/45 (91.84%)	17	43	19	165	116	57	16, Prince Henrys Institute for Medical Research (Australia)
11. University of Pennsylvania (U.S.A.)	46/37 (80.43%)				127	81	61	4, National Institute of Child Health and Human Development (U.S.A.)

González-Alcaide. Research networks in reproductive biology. Fertil Steril 2008.

TABLE 3

Continued.

Institution	Papers/papers in collaboration (%)[a] Type 1	Type 2a	Type 2b	Signatures[b]	Collaborations[b]	Collaborators[b]	Main institutional collaborator (papers, institution)
	23	30	6				
12. University		46/40 (86.96%)		103	57	24	24, Queen Mary Hospital
of Hong Kong (China)	16	31	11				(China)
13. Universiteit Utrecht		43/39 (90.7%)		140	97	66	6, Erasmus Universiteit
(Netherlands)	24	34	17				Rotterdam (Netherlands)
14. Institut National		43/40 (93.02%)		160	117	56	24, Centre National de la
de la Recherche	16	35	12				Recherche Scientifique
Agronomique (France)							(France)
15. Università degli		41/35 (85.36%)		120	79	41	9, Istituto “Luigi
Studi di Milano (Italy)	8	32	6				Mangiagalli” (Italy)
16. Cornell University		39/18 (46.15%)		84	44	36	5, Cornell Institute for
(U.S.A.)	7	14	6				Reproductive Medicine
							(U.S.A.)
17. University of Adelaide		36/28 (77.78%)		92	56	42	10, Queen Elizabeth
(Australia)	12	21	11				Hospital (Australia)
18. Wayne State University		35/29 (82.86%)		103	68	41	9, Hutzel Hospital (U.S.A.)
(U.S.A.)	15	22	3				
19. University of		35/34 (97.14%)		107	72	35	16, Royal Hospital for
Melbourne (Australia)	12	33	9				Women (Australia)
20. Erasmus MC		34/31 (91.18%)		124	90	42	11, Universitair Medish
(Netherlands)	17	26	10				Centrum (Netherlands)
21. Chinese Academy		34/34 (100%)		106	72	34	28, Institute of Zoology
of Sciences (Peoples	12	33	14				(China)
RChina)							
22. University of		33/33 (100%)		140	107	46	21, Copenhagen University
Copenhagen	15	30	9				Hospital (Denmark)
(Denmark)							
23. Stanford University		33/16 (48.48%)		77	44	31	5, Wayne State University
(U.S.A.)	7	13	3				(U.S.A.)
24. Università degli		32/27 (84.37%)		74	42	35	2, Università degli Studi di
Studi di Roma “La							Napoli “Federico II”
Sapienza” (Italy)							(Italy)

González-Alcaide. Research networks in reproductive biology. Fertil Steril 2008.

TABLE 3

Continued.

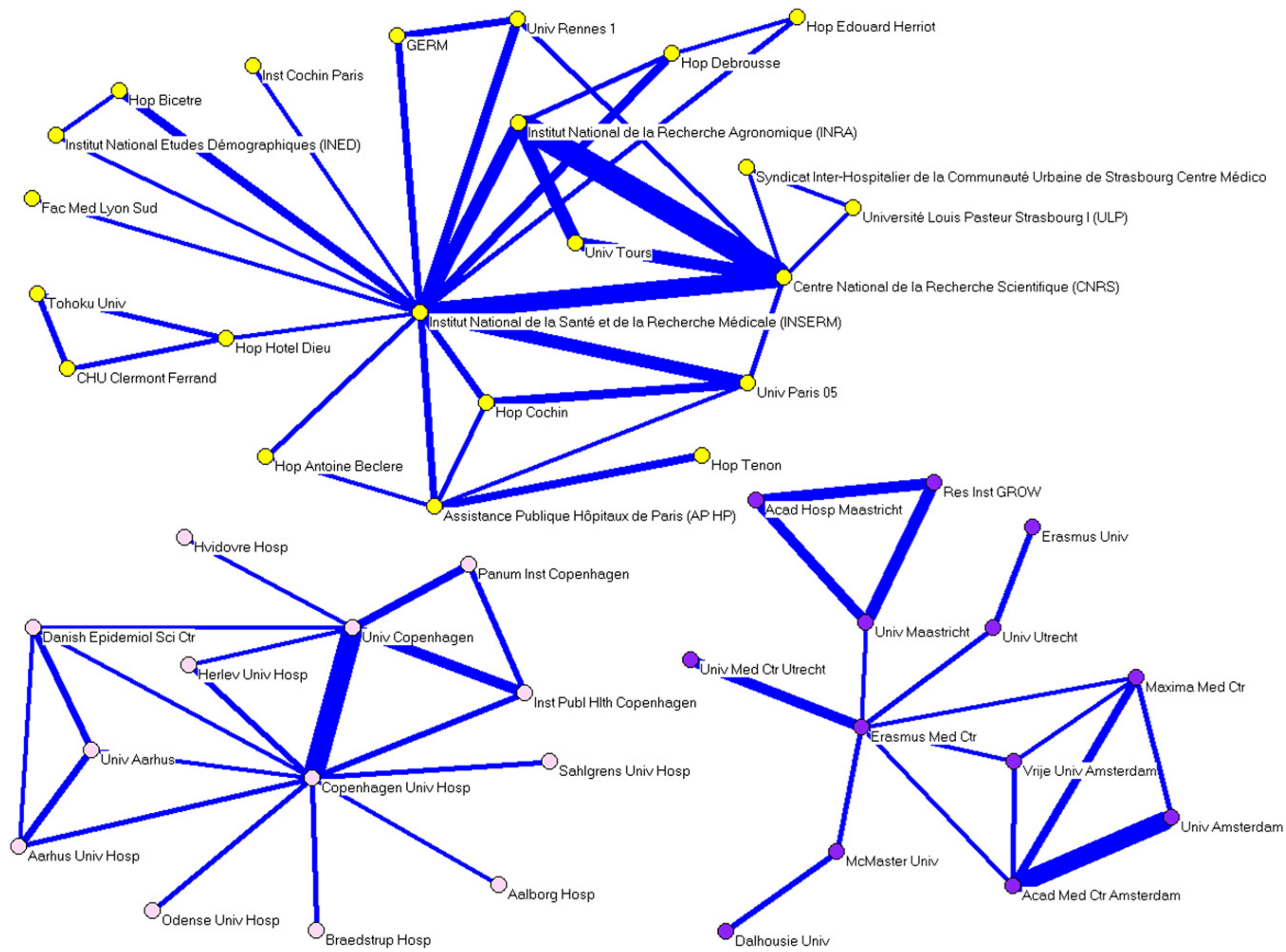
Institution	Papers/papers in collaboration (%)[a] Type 1	Type 2a	Type 2b	Signatures[b]	Collaborations[b]	Collaborators[b]	Main institutional collaborator (papers, institution)
20	21	1					
25. Chinese University of		32/23 (71.87%)		58	26	7	17, Prince of Wales
Hong Kong (China)	3	22	2				Hospital (China)
26. Baylor College of		32/25 (78.12%)		90	58	50	4, University of Texas
Medicine (U.S.A.)	17	16	9				(U.S.A.)
27. Vrije Universiteit		31/17 (54.84%)		74	43	29	5, Academic Medical
Amsterdam (Netherlands)	12	14	1				Center Amsterdam (Netherlands)
28. University of		31/29 (93.55%)		78	47	36	4, Temple University
Wisconsin (U.S.A.)	17	25	8				(U.S.A.)
29. University of Tokyo		31/18 (58.06%)		69	38	32	2, Kyushu University
(Japan)	5	16	5				(Japan)
30. University of Illinois		31/28 (90.32%)		91	60	45	3, Wayne State University
(U.S.A.)	16	21	8				(U.S.A.)
31. Kyoto University		31/25 (80.64%)		61	30	19	5, Rikagaku Kenkyusho
(Japan)	17	16	1				(RIKEN) (Japan)
32. Instituto Valenciano		31/23 (74.19%)		73	42	17	17, Universitat de
de Infertilidad (Spain)	14	18	8				València (Spain)
33. Institute of		31/31 (100%)		117	86	49	26, University of Munster
Reproductive Medicine of the University of Munster (Germany)	9	30	19				(Germany)
34. Cleveland Clinical		31/27 (87.1%)		77	46	19	23, Glickman Urological
Foundation (U.S.A.)	17	27	11				Institute (U.S.A.)

Note: Type 1 = intrainstitutional collaboration; type 2a = interinstitutional collaboration in same country; type 2b = interinstitutional collaboration from different countries.
[a] Number of papers with some type of collaboration, intra- or interinstitutional (the total amount does not coincide with the total number of papers because some papers have more than one collaboration type).
[b] Values obtained considering interinstitutional collaborations.

González-Alcaide. Research networks in reproductive biology. Fertil Steril 2008.

FIGURE 3

Clusters of institutions (13–22 members), applying a threshold of four or more papers signed in institutional collaboration.



González-Alcaide. Research networks in reproductive biology. Fertil Steril 2008.

number of papers was divided by the per capita income corresponding to 2004 in international dollars.

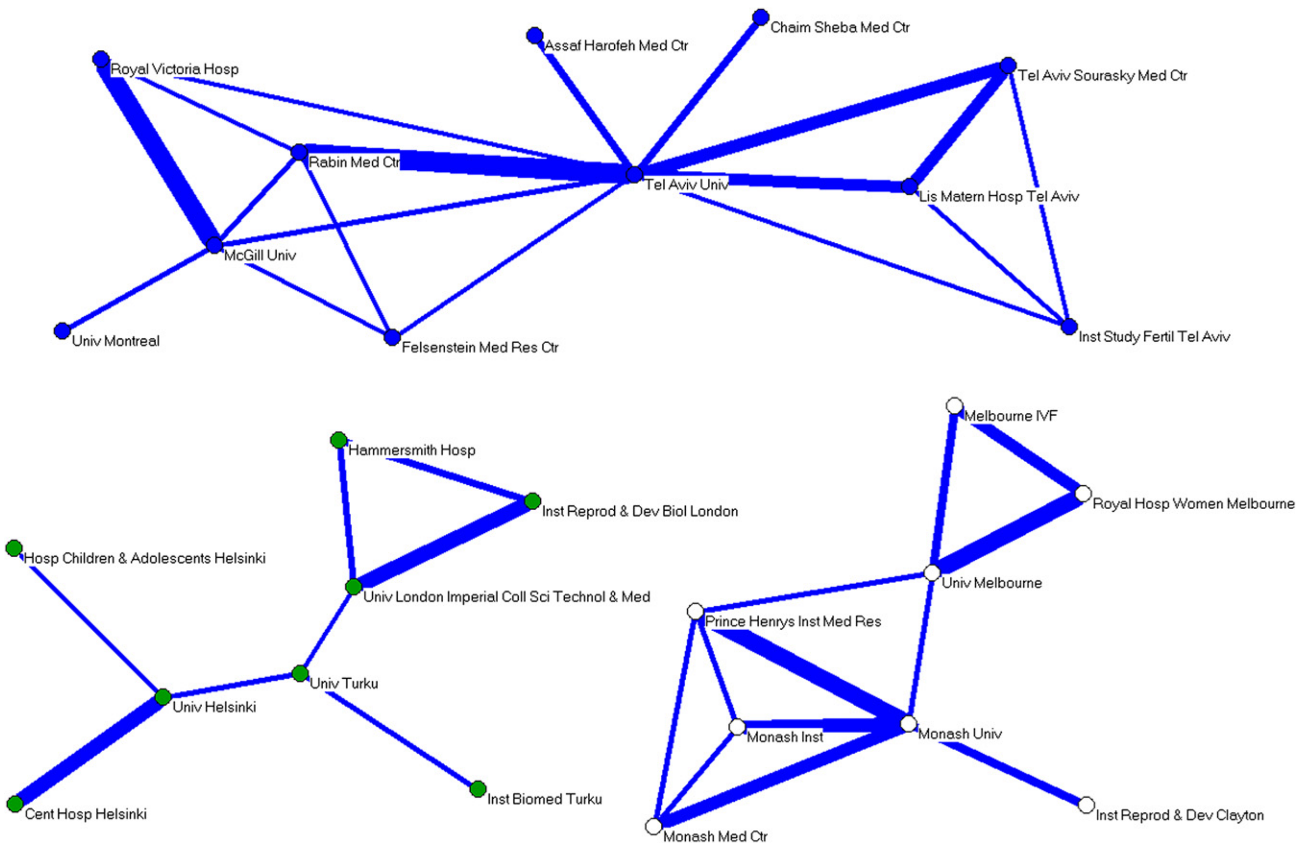
The U.S.A. and the U.K. occupied first and second place, respectively, in all of the measures of centrality by country (degree 45 and 38, betweenness 1,594 and 1,456, closeness 7,059 and 651, respectively). However, there was not always a correspondence between the productivity ranking and the measures of centrality, because countries such as Croatia, the Czech Republic, and Mexico played an important role of centrality in the country network, even though they did not occupy the top places in the productivity ranking. Other countries, such as Sweden, Finland, Switzerland, and Ireland had noticeably higher levels of centrality compared with their productivity ranking. On the other hand, countries with a high productivity index, such as China, Turkey, Taiwan, Greece, Israel, or South Korea, all among the 20 most productive countries, had only a peripheral role in the network of countries. Figure 6 shows a visual representation of the collaborative network between countries, in which we can see the relationships of some with respect to others and the position each occupies in the network as a whole.

DISCUSSION

The applied methodology allowed us to identify the most productive authors and institutions, as well as the make-up of the clusters or groups of authors with intense collaboration and the relationships established between the institutions that have published papers in the main journals of reproductive biology through the period 2003–2005 and which can therefore be considered the elite of the field, that is, the people in the vanguard of scientific development within the discipline, because they are the authors who publish in the journals with the greatest impact factor (11).

FIGURE 4

Cluster sof institutions (8–11 members), applying a threshold of four or more papers signed in institutional collaboration.



González-Alcaide. Research networks in reproductive biology. Fertil Steril 2008.

Nevertheless, the following limitations of this study must be pointed out:

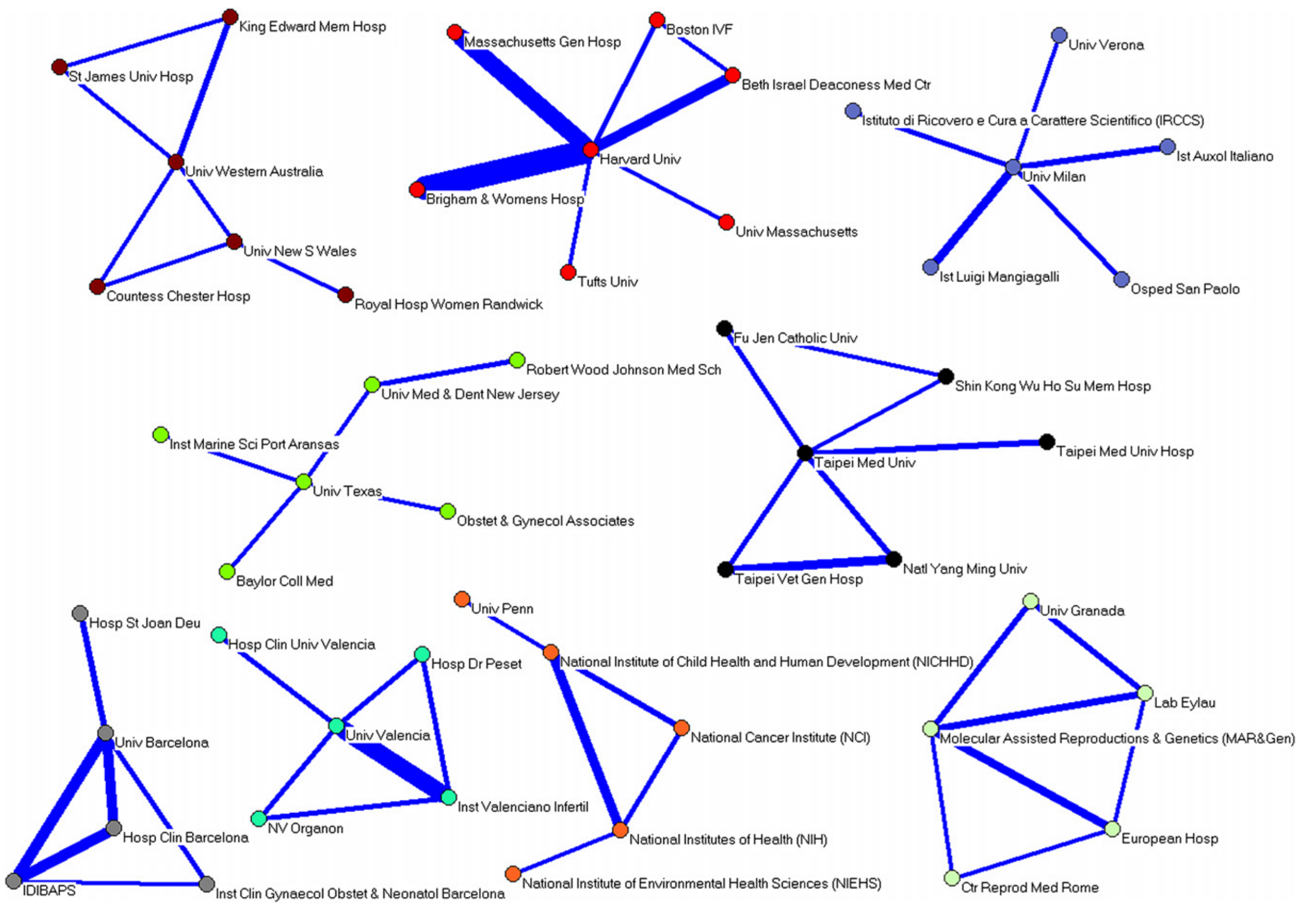
1) The data source: There are often problems of quality in the bibliographic data from databases such as the one used here, and these problems are especially important when analyzing authorship, either because the authors themselves do not always sign their papers in the same way, or because of errors at the time of processing the information. To minimize this problem, a careful manual check was carried out to unify different variations in the names of particular authors or institutions.

   In the case of authors, the criterion followed with two or more variants of a name or surname was to check the coincidence of the different variants with the workplace. This procedure does not assure complete certainty, because in the database there is no correspondence between the author and institutional signature, because the latter refer to the group of authors who sign the paper without discriminating between which authors are related to each one of the mentioned institutions in such cases where there is more than one. This procedure does not, however, take into account possible changes in the authors' workplace, nor does it avoid the problem where the same bibliographic name refers to the scientific production of two or more authors, although the fact that a single field and a short chronologic period were being analyzed helped to minimize this kind of error.

   As for the case of institutional signatures, the main problem is that the same signature frequently applies to two or more institutions, something which is very common among authors who work in institutes or hospitals connected to universities. In such cases, we opted to assign as many signatures as macroinstitutions could be identified. Although this procedure has the problem, in some cases, of multiplying the institutions in the recount, it is necessary to avoid losing information concerning the macroinstitutions in second place or later in the list of signatories. The same criterium of multiplying the signatures was used in the case of the institutes and other research organizations, sometimes administratively dependent on one macroinstitution, the result being that it may be possible to obtain a "fictitious" interinstitutional collaboration. This procedure

FIGURE 5

Clusters of institutions (5–7 members), applying a threshold of four or more papers signed in institutional collaboration.



González-Alcaide. Research networks in reproductive biology. Fertil Steril 2008.

was used because, in many cases, we were dealing with administratively independent organizations, or those who have their own scientific policies, resources, and assigned personnel, despite being dependent on a macroinstitution. There may also exist cases of mixed institutes, in which case it is necessary to individualize and duplicate the institutions to take in the two macroinstitutions on which they depend.

2) The study's coverage: This study does not include all research carried out in the field, because we selected only the journals of the first quartile classified under the category "Reproductive Biology" of the JCR. Papers published in multidisciplinary journals or those included in journals belonging to other categories were not taken into account. Nevertheless, by focusing the analysis on the source journals with the greatest impact and international repercussion, the aim of focusing the analysis on the most relevant authors and institutions in the field is achieved.
3) The characteristics of the coauthorship study: Analyses based on the references and bibliographic quotes in scientific papers have a long tradition in bibliometric studies (12). However, coauthorship analyses with the aim of building up author networks are a more recent object of study (13), and there are still no uniform criteria to identify communities or research groups within previously built networks. This is a problem when faced with interpreting the results obtained, especially as far as the comparison with previous studies which applied other methodologies is concerned.

The U.S.A. and the U.K. still headed the absolute productivity ranking (number of papers) with respect to a previous study analyzing the geographic distribution of the publications in *Fertility and Sterility* and *Human Reproduction* in the 1990s. Of note in the top ten ranking of the most productive countries was the entrance of Canada and China. Adapting the data for the number of inhabitants, Israel was still the most productive country per million of population. Eight of the top ten countries in the ranking maintained their place. The most significant differences can be seen with respect to

TABLE 4

Productivity and patterns of collaboration by countries.

Country	Papers	%	Papers per million inhabitants	Papers per GDP/ capita[a]	Distinct countries of collaborators	Collaborations	%	Main collaborator (papers, country[ies])
1. U.S.A.	1,541	27.32	5.17	38.62	45	455	17.29	48, Canada
2. U.K.	436	7.73	7.31	13.93	38	233	8.85	35, U.S.A.
3. Japan	394	6.98	3.08	13.12	31	112	4.25	39, U.S.A.
4. Italy	300	5.32	5.16	10.73	29	118	4.48	17, U.S.A.
5. France	273	4.84	4.51	9.07	34	157	5.96	20, U.S.A.
6. Canada	252	4.47	7.81	8.03	23	132	5.01	48, U.S.A.
7. Germany	236	4.18	2.85	8.41	33	180	6.84	39, U.S.A.
8. Netherlands	218	3.86	13.37	7	21	102	3.87	12, U.K./Canada
9. Australia	205	3.63	10.17	6.52	26	114	4.33	26, U.S.A.
10. China	163	2.89	0.12	29.21	16	57	2.16	24, U.S.A.
11. Spain	159	2.82	3.69	6.54	25	100	3.8	19, U.S.A.
12. Belgium	156	2.76	14.97	4.95	20	102	3.87	18, U.S.A.
13. Israel	140	2.48	20.82	6.16	15	50	1.9	12, U.S.A.
14. Sweden	121	2.14	13.38	3.99	23	93	3.53	14, Denmark
15. Denmark	109	1.93	20.07	3.44	21	87	3.3	14, Sweden
16. Turkey	97	1.72	1.32	12.62	8	24	0.91	17, U.S.A.
17. Taiwan	89	1.58	—	—	7	16	0.61	9, U.S.A.
18. Finland	75	1.33	14.29	2.46	22	63	2.39	14, U.K.
19. Greece	58	1.03	5.21	2.7	12	35	1.33	7, U.S.A.
20. South Korea	53	0.94	1.11	2.53	5	11	0.42	6, U.S.A.
21. Austria	52	0.92	6.35	1.64	16	32	1.21	10, Germany
22. Brazil	50	0.89	0.27	6.14	16	31	1.18	11, U.S.A.
23. Argentina	48	0.85	1.24	3.6	10	19	0.72	9, U.S.A.
24. India	47	0.83	0.04	25.68	6	9	0.34	2, U.S.A./U.K./Australia
25. Switzerland	42	0.74	5.79	1.23	16	44	1.67	16, U.S.A.
26. New Zealand	36	0.64	8.94	1.46	9	22	0.83	5, U.S.A./U.K./Australia
27. Czech Republic	26	0.46	2.54	1.4	14	28	1.06	4, Sweden
28. Poland	24	0.42	0.62	1.9	3	16	0.61	8, U.S.A.
29. Egypt	21	0.37	0.28	4.91	4	9	0.34	4, U.S.A.
30. Chile	20	0.35	1.23	1.6	6	7	0.26	2, Finland
31. Portugal	17	0.3	1.61	0.87	6	9	0.34	4, U.S.A.
32. Norway	17	0.3	3.68	0.44	10	20	0.76	5, Sweden

González-Alcaide. Research networks in reproductive biology. Fertil Steril 2008.

TABLE 4

Continued.

Country	Papers	%	Papers per million inhabitants	Papers per GDP/capita[a]	Distinct countries of collaborators	Collaborations	%	Main collaborator (papers, country[ies])
33. Hungary	16	0.28	1.58	1.01	5	9	0.34	3, U.S.A./Germany
34. South Africa	14	0.25	0.29	1.64	4	8	0.3	3, U.S.A./Germany
35. Mexico	13	0.23	1.12	1.28	7	10	0.38	4, U.S.A.
36. Iran	13	0.23	0.19	1.55	2	7	0.26	4, Japan
37. Ireland	11	1.95	2.65	0.3	8	14	0.53	3, Spain
38. Thailand	10	1.78	0.15	1.2	9	14	0.53	5, U.S.A.
39. Singapore	10	1.78	2.31	0.35	3	5	0.19	2, U.K./Australia
40. Croatia	10	1.78	2.20	0.88	8	8	0.3	1, U.S.A./U.K.
41. 30 more countries	68	1.2	—	—	56	70	2.66	—

[a] In millions of international dollars, 2004.

González-Alcaide. Research networks in reproductive biology. Fertil Steril 2008.

the GDP, because the U.S.A. was not included in this ranking in the 1990s but now occupies the top position, whereas only one country (the U.K.) maintained a position among the top ten (14).

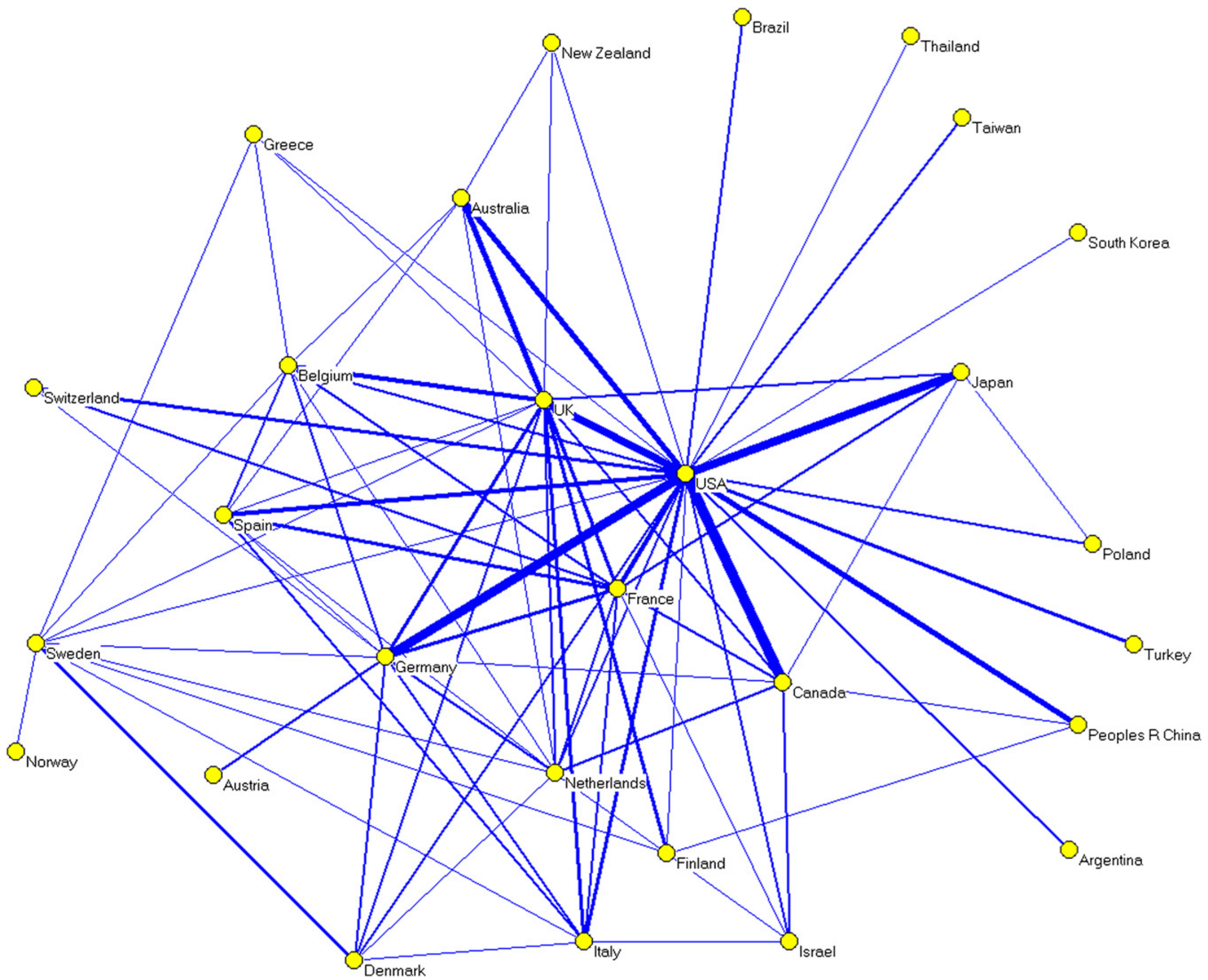
The analysis of the social structure of the established relationships in scientific papers allowed us to determine the existence of the scientific "isolation" of some countries, because, although they published an important number of papers, there was a very small number of collaborators and a reduced number of collaborations. Such countries are mainly in southast Asia with the addition of Turkey and Israel. Some studies have identified poor communications as the reason to explain the small amount of international contact between scientists from different countries (15), thus leading to a small amount of international collaboration.

At the institutional level, we should point out that the collaborations of some institutions are centered on one or very few institutions with which collaborations are carried out in an important number of papers. At the other extreme are the institutions that do not have a stable consolidated nucleus of collaborators, although in some cases they may have many papers in collaboration with other institutions. There are two other aspects of note with respect to the institutional analysis. First, the methodology applied, even though necessary, creates a bias in the results in favor of governmental organizations or research organisms of a national character. Thus, the Institut National de la Santé et de la Recherche Médicale appears in only 36 institutional signatures at the top of the list, the rest corresponding to the process of duplication carried out by us. Second, the diverse nature of the types of institutions studied should be kept in mind as far as policies, personnel, and available economic resources are concerned, because these create a bias in favor of organizations such as universities as opposed to other types of institutions such as hospitals or research institutes. Considering this kind of organization independently, with respect to the number of works published, the following stood out: Copenhagen University Hospital (n = 54), Erasmus Medical Center (n = 34), Chinese Academy of Sciences (n = 34), Baylor College of Medicine (n = 32), Instituto Valenciano de Infertilidad (n = 31), Institute of Reproductive Medicine of the University of Munster (n = 31), and the Cleveland Clinical Foundation (n = 31).

Future work could provide a more in-depth analysis of the scientific production of the identified groups, as well as their scientific impact and repercussions or the scientific quality and excellence of the published papers (16). In addition, given the dynamic nature of science and research groups, it would be interesting to observe their evolution over time to see whether there is an increase in the number of participants, if they remain stable, or if instead they die out and new coalitions arise between authors, institutions, or countries. It would also be useful to analyze the causes of the "black holes" in the networks, that is, the authors, institutions, or

FIGURE 6

Visual representation of the collaborative network between countries, applying a threshold of five or more papers signed in collaboration.



González-Alcaide. Research networks in reproductive biology. Fertil Steril 2008.

countries that remain on the periphery or isolated from the network (17).

REFERENCES

1. Edwards RG. The history of assisted human conception with special reference to endocrinology. Exp Clin Endocrinol Diabetes 1996;104: 183–204.
2. Taylor ES. History of the American Gynecological Society, 1876–1981 and American Association of Obstetricians and Gynecologists, 1888–1981. St. Louis: Mosby, 1985.
3. Trefil J, Hazen MH. Good seeing: a century of science at the Carnegie Institution of Washington. 1902–2002. Washington, DC: Joseph Henry Press, 2002.
4. Keye WR. American Society for Reproductive Medicine: reaching its full potential. Fertil Steril 2004;82:557–8.
5. Dziuk P. The Society for the Study of Reproduction. 25 years in retrospect. Biol Reprod 1993;48:28–32.
6. Diedrich K, Felberbaum R. The European Society of Human Reproduction and Embryology (ESHRE). Gynakologe 2002;35:444–6.
7. López Piñero JM, Terrada ML. Los indicadores bibliométricos y la evaluación de la actividad médico-científica. III. Los indicadores de producción, circulación y dispersión, consumo de información y repercusión. Med Clin (Barc) 1992;98:142–8.
8. Scott JP. Social network analysis: a handbook. London: Sage, 1991.
9. Freeman LC. Centrality in social networks: conceptual clarification. Soc Netw 1978–79;1:215–39.
10. Batagelj V, Mrvar A. Pajek (version 0.70). Program for large network analysis. Ljubljana: University of Ljubljana, 2001.
11. Price DJS. Some remarks on elitism in information and the invisible college phenomenon in science. JASIS 1971;22:74–5.
12. Price DJS. Networks of scientific papers. Science 1965;149:510–5.
13. Newman MEJ. Coauthorship networks and patterns of scientific collaboration. Proc Natl Acad Sci U S A 2004;101:5200–5.

14. Kremer JAM, Braat DDM, Evers JLH. Geographical distribution of publications in *Human Reproduction* and *Fertility and Sterility* in the 1990s. Hum Reprod 2000;15:1653–6.
15. Saegusa A. Survey finds deep insularity among Japanese scientists. Nature 1999;401:314.
16. Van Raan AFJ. Evaluación de la excelencia científica de programas de investigación: un punto primordial en la toma de decisiones. The IPTS Report 1999. Available at: http/www.jrc.es/home/report/spanish/articles/vol40/RTD5S406.htm. Accessed September 7, 2006.
17. Davis M, Wilson CS. Vision Sciences as a collaborative enterprise: issues of multidisciplinarity and work-interest space. Collaboration in science and in technology. In: Proceedings of the Second Berlin Workshop on Scientometrics and Informetrics. Berlin: Freie Universität Berlin, 2000.