# A decade-long innovative collaboration network between hospitals and the biomedical industry in China: A social network analysis

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**Research Article**

**Keywords:** social network analysis, collaboration, hospital, industry, innovation

**Posted Date:** May 4th, 2022

**DOI:** https://doi.org/10.21203/rs.3.rs-1563398/v1

# Abstract

**Background:** Innovative collaboration between hospitals and biomedical enterprises is crucial for ensuring breakthroughs in their development. The aim of this study is to explore the characteristics and examine the main roles of the associated key actors of an innovative collaboration between hospitals and biomedical enterprises in China.

**Methods:** Using the patent data owned jointly by these two key actors within the country's healthcare industry, a decade-long innovative collaboration network between hospitals and biomedical enterprises in China was established and analyzed through social network analysis. Patent data from the IncoPat global patent database, which is based on the International Patent Classification system, were extracted.

**Results:** Findings show that innovative collaboration resulted in enhanced development within economically developed regions. Hospitals occupied a dominant position in the innovative collaboration network, whereas a biomedical enterprise located in Shenzhen had the highest degree, betweenness, and closeness centralities.

**Conclusions:** Innovative collaboration between hospitals and biomedical enterprises in China is still low. Policy support and economic investments should be encouraged, especially in less-developed regions to enhance innovative collaboration between hospitals and the biomedical industry in China and other similar countries or regions.


# Background

The significance of innovative collaboration in the fields of healthcare and medicine has been well demonstrated[1]. Innovative collaboration brings about many advantages to various actors. Such advantages include the sharing and exchange of knowledge and resources, market value expansion, innovation acceleration, and productivity maximization[1−3]. Innovative collaboration between hospitals and the biomedical industry is also crucial because it allows for patients to be served better, improves health outcomes, and promotes the development of diagnosis and treatment approaches[4−6]. Innovative collaboration between hospitals and the biomedical industry is both an individual and professional relationship, which involves hospitals and biomedical enterprises seeking to enhance professional evolution and innovation[7].

In China, the rapid development of hospitals over the recent years has resulted in the high demand for innovation in the field of clinical research, advancements in diagnosis and treatment approaches, and the transformation of medical fields. Moreover, the biomedical industry has entered a critical period of equal emphasis on research and development, transformation, and manufacturing. In 2010 and 2011, the Chinese government proposed policies pointing out that innovative collaboration between hospitals and biomedical enterprises is vital for ensuring high-level hospital reforms and breakthroughs in the biomedical industry[8, 9]. Therefore, since 2011, hospitals and biomedical enterprises in China have been experiencing rapid development and facing new opportunities as well as challenges. Therefore, it is imperative to deeply explore the innovative collaboration network between hospitals and the biomedical industry.

Social network analysis (SNA) should be considered to ensure a deep understanding of innovative collaboration between hospitals and the biomedical industry. SNA is an effective tool for analyzing and evaluating complex collaboration networks by studying the relationships and interactions between various social actors in a group[10]. SNA is also a powerful tool for evaluating collaboration trends and identifying leading actors in collaboration networks, such as those closely associated with ensuring innovative collaboration between hospitals and the biomedical industry[11]. Therefore, various studies exploring innovative collaboration between hospitals and the biomedical industry have been conducted using SNA[7]. Most of these studies involve analyzing and evaluating levels of innovative collaboration based on metrics of publications and grants, which provide data for assessing the effectiveness of innovative collaboration[12, 13]. However, considering the transformation of medical fields is one of the essential aims of innovative collaboration. Additionally, patents jointly owned by hospitals and biomedical enterprises are more appropriate for measurement than publications and grants, which are more suitable for evaluation in the preliminary stage[14].

# Methods

**Aim.** Through SNA and the metrics obtained from jointly owned patents, this study aims to explore the structure of and relationships in the innovative collaboration network between hospitals and the biomedical industry in China over the past decade and examines the roles of the social actors involved. This study also aims to provide quantitative evidence for advancing innovative collaboration between hospitals and the biomedical industry in China and similar countries or regions.

**Study design.** Owing to rapid advancements in the fields of medicine and biomedicine in China over the past decade, the innovative collaboration network between hospitals and the biomedical industry in China was constructed based on patents jointly owned by hospitals and biomedical enterprises from 2011 to 2021. The adjacency matrix of patent applicants was constructed using Excel 16.16.27. The generated matrix was imported into UCINET 6.732 (Harvard: Analytic Technologies) to generate the network topology of the innovative collaboration network and analyze the network's cohesion and centrality metrics[15].

**Data source.** The patent data jointly owned by hospitals and biomedical enterprises were collected from the IncoPat scientific and technological innovation intelligence platform (BEIJING INCOPAT CO., LTD.). Patents with biomedical-related codes were extracted according to the International Patent Classification (IPC) system. The extraction process was also based on keywords obtained from existing studies to ensure comprehensiveness.

The inclusion criteria involved the following aspects: (1) patents were jointly owned by hospitals and biomedical enterprises; (2) the application should be in mainland China; (3) the patent type is a valid patent for invention; (4) the search time was from January 1, 2011 to December 31, 2021; (5) IPC codes of A61P (special therapeutic activity of chemical compounds or medicinal preparations), A61K (preparations for medical, dental, or toilet purposes), C07K (peptides), C07H (sugars; derivatives thereof; nucleosides; nucleotides; nucleic acids), C12N (microorganisms or enzymes; compositions thereof; propagating, preserving, or maintaining microorganisms; mutation or genetic engineering; culture media), C12M (apparatus for enzymology or microbiology), C12P (fermentation or enzyme-using processes to synthesize a desired chemical compound or composition or separate optical isomers from a racemic mixture), C12Q (measuring or testing processes involving enzymes, nucleic acids or microorganisms; compositions or test papers thereof; processes for preparing such compositions; condition-responsive control in microbiological or enzymological processes), and G01N (investigating or analyzing materials by determining their chemical or physical properties); (6) keywords, including cell, gene, interferon, interleukin, hormone, recombination, protein, enzyme, antibody, monoclonal antibody, antigen, receptor, fermentation, nucleic acid, amino acids, nucleotides, peptides, serum, coagulants, diagnostic reagents, inhibitors, cross-linking agents, vaccines, vitamins, traditional Chinese medicine, and equipment; (7) including the first two applicants if there are three or more applicants for a patent. The exclusion criteria included: (1) repeatedly applied patents; (2) patents not related to the field of biomedicine; (3) patents applied by organizations and individuals from other countries; (4) patents owned by individuals.

**Network visualization and metrics.** The analysis of the innovative collaboration network includes visualization and quantitative metrics. In terms of visualization, the actor in the network is usually represented as a circle or square, and its size in this network reflects the number of patents. The lines between two actors represent the innovative collaboration between them.

Quantitative metrics can be divided into metrics at the network and individual levels. Metrics at the network level include the number of nodes, the number of edges, average distance, and density. The number of nodes refers to the number of all patent application institutions included in the network. The number of edges refers to the number of connections between nodes, which is the total number of cooperative relationships between patent applicants. Average distance refers to the average value of the shortest path between every two nodes in the network. Network density is an index for evaluating the internal information connectivity of the network, which reveals the closeness between the innovative collaboration network and the collaborative relationship of biomedicine in China[16].

In terms of metrics at the individual level, centrality measures are the most common in SNA. Degree centrality is used to measure the degree of communication between a node and other nodes in a network. If a node has a high number of links, it is in a highly important and central position in a network[17]. Betweenness centrality refers to the extent to which a node can be located on the path of other nodes and the role of the intermediary bridge and brokerage in a network. It is an index for evaluating the degree of the control of network members over that of the resources. Closeness centrality reflects the proximity between a node and other nodes in a network. It is used to determine whether a member can be “controlled” by other members in a network[18].

# Results

**Quantitative characteristics of innovative collaborations.** The number of patents in the field of biomedicine increased gradually and steadily from 2011 to 2020, after which it decreased in 2021. A similar trend was observed in patents jointly owned by hospitals and biomedical enterprises. However, as shown in Table 1, the total number of such patents accounted for a significantly small proportion of all biomedical patents.

Table 1
Number of biomedical patents in China from 2011 to 2021.

| Year | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 | 2019 | 2020 | 2021 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Number of all biomedical patents | 8794 | 11977 | 15508 | 16658 | 19294 | 20932 | 23078 | 25757 | 27162 | 30815 | 15559 |
| Number of biomedical patents applied by hospitals and biomedical enterprises | 45 | 48 | 74 | 90 | 87 | 99 | 89 | 108 | 100 | 130 | 43 |

**Regional characteristics of innovative collaborations.** The national biomedical patent network comprised 30 regions, which could be divided into three levels. Approximately 60% of the patents were jointly applied by hospitals and biomedical enterprises in the most economically developed regions, including Beijing, Shanghai, and Guangdong. Provinces, such as Zhejiang, Sichuan, Shandong, and Fujian followed, with the number of patent applications in each of these regions being more than 50. As shown in Fig. 1, patent applications in the western regions of China, such as Xinjiang, were significantly fewer, with the number of jointly owned patents being far less than 50 in each region.

**Professional field characteristics of innovative collaborations.** The top five classifications of biomedical patents jointly owned by hospitals and biomedical enterprises in China were G01N, C12N, A61K, A61P, and C12Q according to IPC numbers. Patent applications for C12M, C07K, C12R, C12P, and C07D were significantly fewer, as shown in Fig. 2.

**Overall network analysis.** The innovative collaboration network between hospitals and biomedical enterprises has a large scale and a complex structure. It has 341 nodes, which include 144 hospitals, 197 biomedical enterprises, and 460 edges between these nodes (Fig. 3). The overall network density is 0.004, thereby indicating that the network relationship is at a low concentration level, the overall network structure is sparse, the connectivity is relatively weak, and the degree of resource sharing is not high. Most nodes at the edge of the network only have one connection, and the overall network is still in the low-frequency collaborative stage. The average distance of the network is 5.094, with a standard deviation of 2.769, which indicates that each institution can communicate with other institutions in the network through an average of five intermediaries.

**Centrality analysis.** Degree centrality indicates the most crucial institutions in the innovative collaboration network. The analysis result shows that the top two most central institutions are Shenzhen Huada Gene Technology Co., Ltd. and the Beijing Union Medical College Hospital of the Chinese Academy of Medical Sciences, with 11 and 10 partners, respectively. Furthermore, among the top ten institutions with the highest-ranking calculated through degree centrality analysis, seven are hospitals, meaning that hospitals play an essential leading role in this innovative collaboration network and have stronger initiatives throughout the collaboration process.

The top three institutions with the highest betweenness centrality are Shenzhen Huada Gene Technology Co., Ltd. (accounting for 2.808%), the General Hospital of the Chinese people's Liberation Army (accounting for 1.875%), and Xiangya Hospital of Central South University (accounting for 1.589%). Compared to other hospitals or enterprises, the institutions mentioned above have higher intermediary centrality, stronger resource control ability, and stronger information load as well as transmission ability.

There is little difference in the values of closeness centrality among all hospitals or biomedical enterprises, thereby indicating that an obvious core actor is yet to emerge in this network, and the levels of connectivity and communication between the nodes remain low (Table 2).

Table 2
Top ten rankings of centrality metrics.

| Ranking | Patent Applicant | Degree Centrality | Patent Applicant | Betweenness Centrality | Patent Applicant | Closeness Centrality |
|---|---|---|---|---|---|---|
| 1 | Shenzhen Huada Gene Technology Co., Ltd | 11.000 | Shenzhen Huada Gene Technology Co., Ltd | 1618.000 | Shenzhen Huada Gene Technology Co., Ltd | 92632.000 |
| 2 | PLA General Hospital | 10.000 | PLA General Hospital | 1080.500 | PLA General Hospital | 92660.000 |
| 3 | Peking Union Medical College Hospital, Chinese Academy of Medical Sciences | 8.000 | Xiangya Hospital of Central South University | 915.500 | Xiangya Hospital of Central South University | 92664.000 |
| 4 | Bo'ao biological Group Co., Ltd | 6.000 | Tianhao Biomedical Technology Co., Ltd | 824.000 | West China Hospital of Sichuan University | 92670.000 |
| 5 | Zhongshan Hospital Affiliated to Fudan University | 5.000 | West China Hospital of Sichuan University | 751.500 | The First Affiliated Hospital of China Medical University | 92690.000 |
| 6 | The 302 Hospital of the Chinese people's Liberation Army | 5.000 | Ruijin Hospital Affiliated to Medical College of Shanghai Jiaotong University | 751.000 | Shenzhen Huada gene Co., Ltd | 92692.000 |
| 7 | Beijing Yangshen biological information technology Co., Ltd | 4.000 | Bo'ao biological Group Co., Ltd | 682.500 | Shanghai Changhai Hospital | 92696.000 |
| 8 | West China Hospital of Sichuan University | 4.000 | Beijing Yangshen biological information technology Co., Ltd | 607.000 | Shenzhen Second People's Hospital | 92698.000 |
| 9 | Ruijin Hospital Affiliated to Medical College of Shanghai Jiaotong University | 4.000 | Shanghai Fuyuan Biotechnology Co., Ltd | 590.000 | Xiangya Third Hospital of Central South University | 92700.000 |
| 10 | Xiangya Hospital of Central South University | 4.000 | The First Affiliated Hospital of Sun Yat sen University | 560.000 | The first hospital of Peking University | 92700.000 |

## Discussion

The innovative collaboration network from 2011 to 2021 based on jointly owned patents in China included 144 hospitals and 197 biomedical enterprises, and it involved 460 connections. Patents jointly owned by hospitals and biomedical enterprises were few, especially in less-developed regions. Patents related to the G01N, C12N, and A61K classifications were the most popular for ensuring innovative collaboration. The overall levels of network density, collaborative frequency, and network cohesion were significantly low. Hospitals are in a leading position and have stronger initiatives pertaining to ensuring innovative collaboration. A biomedical enterprise in Shenzhen has the highest degree, betweenness, and closeness centralities. In China, there is no obvious core actor in the innovative collaboration network between hospitals and the biomedical industry.

Although the level of innovative collaboration between hospitals and the biomedical industry in China remains low, the attention paid to innovative collaboration keeps increasing. Additionally, the overall quantitative tendency of patents keeps increasing. However, it dropped in 2021, and this aspect may be attributed to the incomplete data resulting from the delayed publication of some patents[19]. Nonetheless, jointly applied patents were far fewer than the total in the field of biomedicine owing to the following reasons. First, in China, there is a large gap in innovative collaboration between hospitals and the biomedical industry between various regions with different levels of economic development. The evidence indicates that the number of patents might be correlated with the level of regional economic development[20]. Therefore, investments or policy support should be encouraged in less-developed regions to ensure innovative collaboration between hospitals and the biomedical industry, thereby promoting development in such regions. Second, research statistics suggest that the transformation rate of hospitals, even in developed regions of China, such as Shanghai, is only 3%, which is extremely lower than the international transformation rate of approximately 30–50%[21]. Furthermore, low transformation rates are associated with low densities and frequencies of innovative collaboration networks between hospitals and the biomedical industry[21]. Third, evidence showed that in China, there are only 5% primary drugs among all the approved biological drugs[22]. Investments from biomedical enterprises aiming to fund innovative research are significantly low, and this attribute hinders the actualization of an innovative collaboration between hospitals and the biomedical industry. However, such investments must satisfy the requirements associated with both the scale and capital strength of biomedical enterprises. According to a study conducted in the United States, the median research and development investment for a new drug was $985.3 million, and the mean investment was $1.336 billion[23]. Moreover, over the recent years, the levels of investment required to ensure innovative research from both public and private sources keep increasing[24], thereby suggesting the potential for creating innovative collaboration networks between hospitals and biomedical enterprises.

According to IPC analysis, the most jointly owned biomedical patents in China are those involving the G01N (investigating or analyzing materials by determining their chemical or physical properties), C12N (microorganisms or enzymes; compositions thereof; propagating, preserving, or maintaining microorganisms; mutation or genetic engineering; culture media), A61K (preparations for medical, dental, or toilet purposes), A61P (specific therapeutic activity of chemical compounds or medicinal preparations), and C12Q (measuring or testing processes involving enzymes, nucleic acids or microorganisms; compositions or test papers thereof; processes of preparing such compositions; condition-responsive control in microbiological or enzymological processes) classifications. These types of patents are generally in accordance with popular trends reported in other studies[25], and this suggests the future professional direction of innovative collaboration in China.

Considering that most of the top ten actors with the highest degrees of centrality, betweenness centrality, and closeness centrality are hospitals, hospitals are dominant, with higher centralities regarding the actualization of an innovative collaboration network between them and the biomedical industry. This aspect may be related to the gap in the development stages of hospitals and biomedical enterprises. Owing to the concepts and practices employed in research hospitals[26], hospitals in China have experienced rapid development over the past two decades[27], and this has been a national medium and long-term development plan[28]. As the main task of research hospitals is conducting innovative research and collaborative translation[29], hospitals have stronger initiatives for seeking and actualizing innovative collaboration[30]. However, similar practices and policy directions were not proposed in the field of biomedicine until a decade ago[9]. This attribute explains the delayed development in innovative collaboration of biomedical enterprises compared with hospitals. Furthermore, there has not been an obvious core actor in such a network, thereby indicating that the innovative collaboration capabilities of both hospitals and biomedical enterprises are very weak and far from facilitating the development of an innovative collaboration network for breaking through the current elementary stage[31]. Additionally, although hospitals account for the majority of the top ten actors in terms of centrality, a biomedical enterprise, *Shenzhen Huada Gene Technology Co., Ltd*, is always the actor with the highest degree centrality, betweenness centrality, and closeness centrality, thereby indicating that this actor has the greatest power in this innovative collaboration network, is the most important bridge for collaboration among all other actors, and has the most direct connections with other actors.

There are several limitations associated with this study. First, considering the scope of the IPC in the field of biomedicine varies across different studies, the biomedical patents included in this study are based on a broader range, which can be made highly accurate in future studies. Second, patent data were obtained from only IncoPat. The sources of patent data should be increased in future studies. Third, we selected the first two applicants if there are three or more applicants, thereby neglecting some actors who made small contributions to the innovative collaboration network and some new relationships. Fourth, although it is reasonable to evaluate the levels of innovative collaboration using the metric of patents jointly owned by hospitals and biomedical enterprises, a comprehensive measurement metric including aspects other than patents can be used to better reflect innovative collaboration levels in future studies.

# Conclusions

This study describes and analyzes a decade-long innovative collaboration network between hospitals and the biomedical industry based on patent applications. Policy support and increased investment should be encouraged to improve innovative collaboration density and frequency between hospitals and the biomedical industry in China, especially in less-developed regions. Hospitals should further play their role as leaders and come up with stronger initiatives for enhancing innovative collaboration between them and the biomedical industry. The Chinese government could consider the potential of a biomedical enterprise in Shenzhen to develop a core actor in the innovative collaboration network between hospitals and the biomedical industry by taking advantage of the institution with the highest centrality.

# Abbreviations

SNA: Social network analysis

IPC: International Patent Classification

# Declarations

## Acknowledgments

Not applicable.

## Author Contributions

W.Y. and Z.W. conceived the project. J.T. and Z.C. collected the data. H.C. and M.L. performed the network analyses. Y.L. and Q.C. performed all the numerical calculations. W.Y., H.C., and X.L. wrote the manuscript. All authors reviewed and edited the manuscript.

## Funding

This work was supported by grants from the National Natural Science Foundation of China (72104140, 82101870, 71804128, 71673291, 72004133); the Shanghai Public Health Outstanding Young Personnel Training Program (GWV-10.2-XD07); the Shanghai Pujiang Program (21PJC083, 2020PJC080, 2020PJC081); the Soft Science Project of Shanghai Science and Technology Innovation Action Plan (21692191300, 22692192000); the Natural Science Foundation of Zhejiang Province (LQ21H100001); and the Hangzhou Health Science and Technology Program (B20220431).

**Availability of data and materials**

The data are publicly available at https://www.incopat.com/

**Ethics approval and consent to participate.**

Not applicable.

**Consent for publication.**

Not applicable.

**Competing interests.**

The authors declare no competing interests.

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# Figures

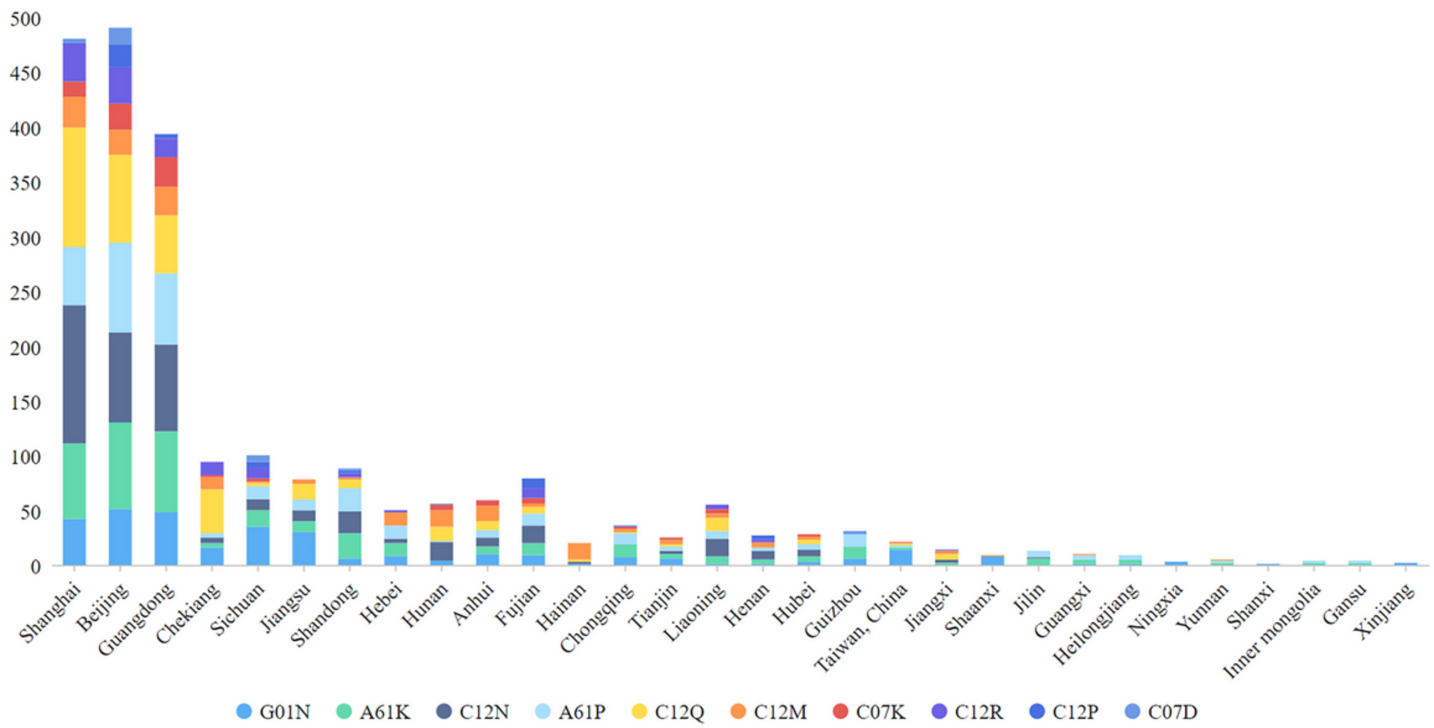


Figure 1

**Regional distribution of biomedical patent applications in China from 2011 to 2021.**

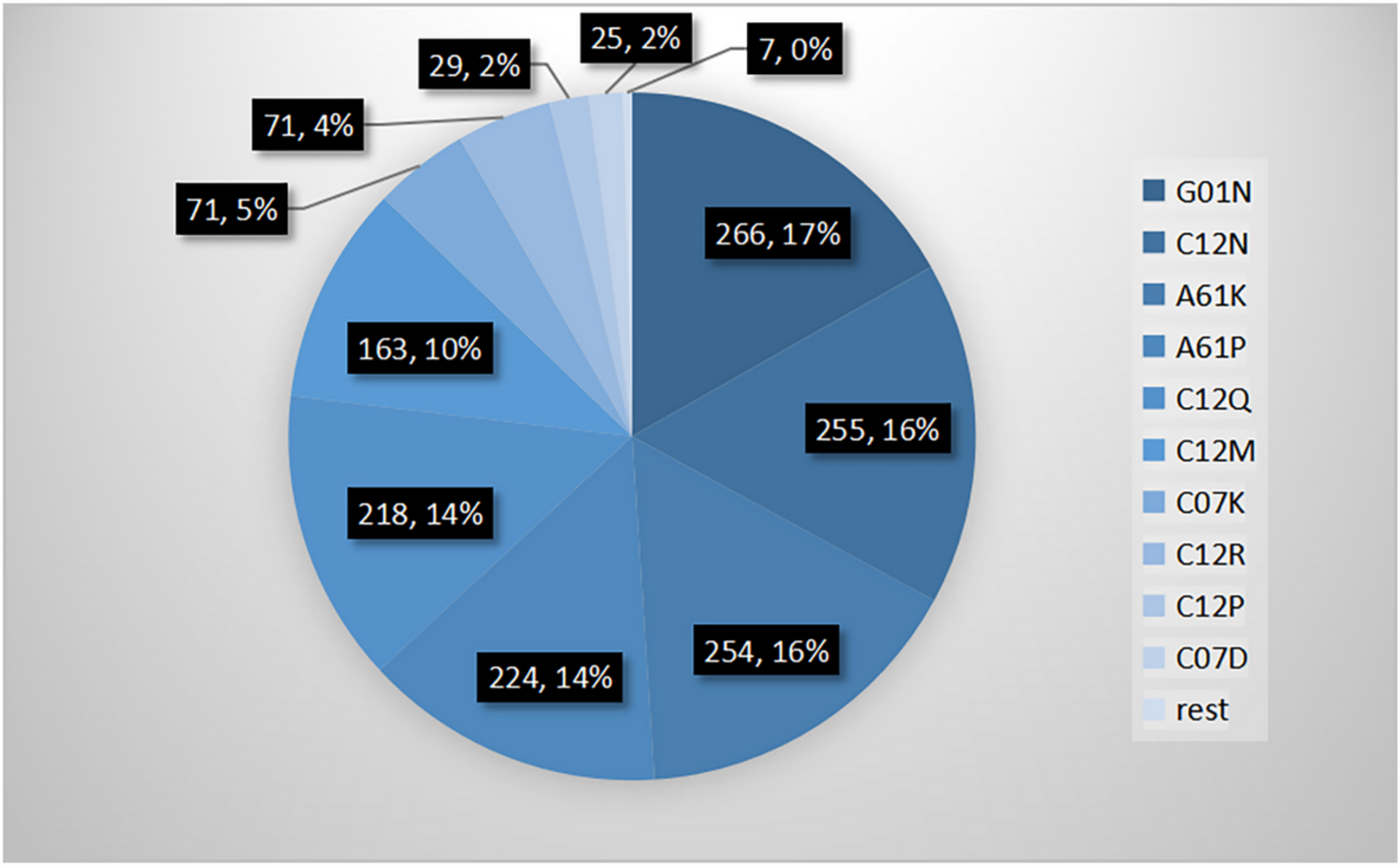


Figure 2

Professional distribution of biomedical patents in China from 2011 to 2021.

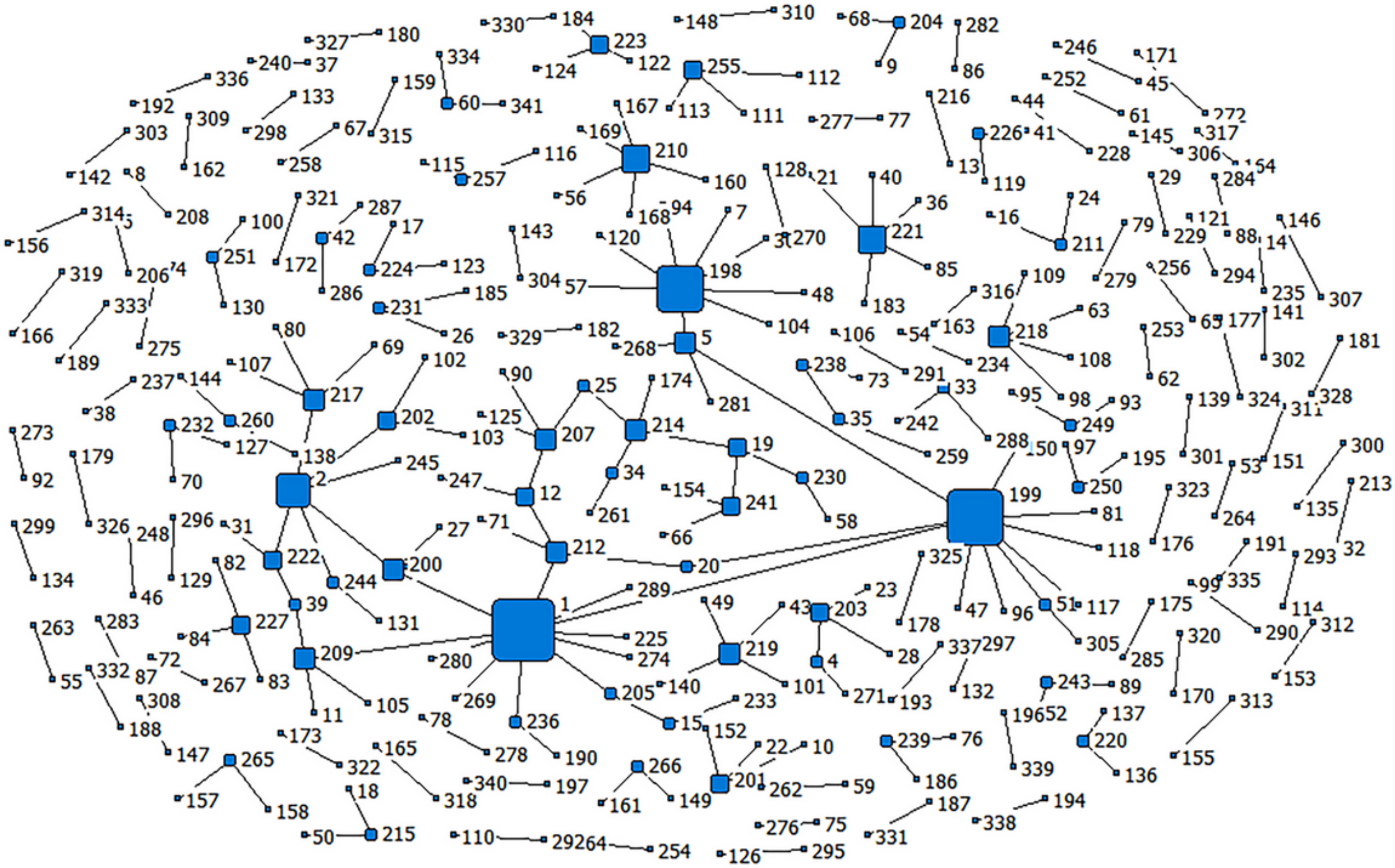

Figure 3

Visual diagram of the innovative collaboration network between hospitals and the biomedical industry.