

Medicine-Engineering Interdisciplinary Research Based on Bibliometric Analysis: A Case Study on Medicine-Engineering Institutional Cooperation of Shanghai Jiao Tong University

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Abstract: This article aims to provide reference for medicine-engineering interdisciplinary research. Targeted at the scientific literature and patent literature published by Shanghai Jiao Tong University, this article attempts to set up co-occurrence matrix of medicine-engineering institutional information which was extracted from address fields of the papers, so as to construct the medicine-engineering intersection datasets. The dataset of scientific literature was analyzed using bibliometrics and visualization methods from multiple dimensions, and the most active factors, such as trends of output, journal and subject distribution, were identified from the indicators of category normalized citation impact (CNCI), times cited, keywords, citation topics and the degree of medicine-engineering interdisciplinary. Research on hotspots and trends was discussed in detail. Analyses of the dataset of patent literature showed research themes and measured the degree for technology convergence of medicine-engineering.

Key words: medicine-engineering interdisciplinary, institutional cooperation, bibliometrics, bibliographic coupling, journals dual-map overlay, co-citation, citation topics, medicine and engineering technology convergence

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0 Introduction

The history of scientific development shows that the crossover and integration of life sciences, engineering and physical science generates new disciplines and has a significant impact on human life. Since the 21st century, the life sciences research has developed rapidly and intersected with groundbreaking inventions in the fields of mechanics, optics, materials, electronics and computer to address the major challenges in the areas of medicine, health and life today^[1]. In 2015, the United States launched the “Precision Medicine Initiative”, which proposed an ambitious vision and specific goals for future disease treatment and personalized health, kicking off a new medicine-engineering era. Just like the medical revolution created by the rise of molecular biology in the last century, medical-related industries represented by cutting-edge engineering technologies, such as medical big data, artificial intelligence, brain science and precision medicine, are promoting the progress of medical technology with unprecedented

power.

At present, the research of intersection of medicine and engineering usually focuses on two aspects. One is the qualitative research based on management perspective, for example, the research on the feasibility demonstration of building medicine-engineering intersection platform in universities, the approval of project topics, and the scope and way of cooperation in the implementation process of medicine-engineering intersection. The research is mostly in the form of questionnaire survey and interview. For example, Wang et al.^[2] analyzed the performance of key projects of clinical medicine disciplines of Fudan University and concluded that the intersection and penetration of clinical disciplines and basic disciplines, as well as medical disciplines and science & engineering disciplines, should be actively promoted. Office of Research Management of Shanghai Jiao Tong University^[3] and Scientific Research Department of School of Dentistry Tongji University^[4] summarized the development direction of medicine-engineering intersection by combining medicine-engineering research in their own universities. Ji and Liu^[5] used SWOT method to analyze the advantages, disadvantages, opportunities and challenges of medicine-engineering interdisciplinary development, and explore the development strategy of

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medicine-engineering intersection with the actual situation of universities. The other is the quantitative analysis based on funds for medicine-engineering interdisciplinary project and award-winning results. For example, Dai^[6] conducted a case study analysis of funded medicine-engineering projects by combining statistical tools with management methods. Xu^[7] explored the medical engineering cross patterns by taking researchers in medicine-engineering funds and award-winning results as nodes and using the analytical methods of network science and computer applications. Few of these studies are quantitative studies of medicine-engineering cooperation based on a bibliometric method and from the perspective of scientific collaboration.

The intersection of medicine and engineering is the only way for the innovation and development of modern medicine, and it is also a historical opportunity for the eternal development of modern engineering. In the 1970s, a number of world-class universities, such as Harvard University and Massachusetts Institute of Technology, established interdisciplinary research institutes, which opened the prelude for scientific research institutions to attach importance to promoting the development of medicine and engineering integration^[8]. In the 1980s, China promoted the combination of medicine and engineering work by merging science and engineering universities with medical colleges and setting up biomedical engineering majors^[9]. With the implementation of the construction of “world-class universities and first-class disciplines” in China, more and more colleges and universities have included the intersection of medicine and engineering in the strategic planning of creating world-class universities^[10]. Shanghai Jiao Tong University (SJTU) merged with the former Shanghai Second Medical University in 2005 (Shanghai Jiao Tong University School of Medicine, hereinafter referred to as SHSMU). The merged Shanghai Jiao Tong University follows the law of medical development under the pattern of comprehensive university, integrates the high-quality resources of the two universities, promotes the mutual intersection and penetration of medical and engineering disciplines, and presents the development trend of medical and engineering integration. In 2005, Shanghai Center for Systems Biomedicine, the first interdisciplinary research center in China, was established, which was built according to the mode of large discipline and concentrated on first-class talents in biology, medicine, physics, electronics, mathematics and computer. In 2007, MED-X Research Institute was established as an important supporting platform for interdisciplinary research in medical engineering, medical theory, medical management and medical literature. In 2019, China’s first White Paper on Artificial Intelligence Medical Care was released. In terms of scientific research achievements, since 2007, “Cross-disciplinary

Research Fund of Medical Engineering” has been set up, and many supporting projects such as National Natural Science Foundation of China have hatched. At the same time, it highlights the clinical application effect of affiliated hospitals, and produces original achievements with core technical value by laying out a number of key projects. In the prevention and control of COVID-19 epidemic, the medical teams of Ruijin Hospital and the Ninth People’s Hospital affiliated to SHSMU cooperated with the scientific research team of Jiao Tong University in Wuhan to give full play to the advantages of Shanghai Jiao Tong University’s powerful medical discipline and first-class science and engineering disciplines, and applied digital technologies such as artificial intelligence (AI), 5G communication and 3D printing to the first-line prevention and treatment needs of patients, hospital sense prevention and control, and logistics support. In a short time, they jointly developed a series of innovative technologies with independent intellectual property rights, such as “Xiaobai” a new generation of artificial intelligence robot, an assistant for wearing and taking off AI protective clothing, a remote stethoscope with 5G technology, a remote consultation platform for difficult cases in COVID-19, and a mask-type anti-infection device based on 3D modeling and printing technology, and isolation device for preventing operation from splashing, which were quickly put into clinical practice and played an active role in the process of fighting the epidemic.

The development of medicine-engineering crossover is not only in line with the national “Healthy China” strategy, but also an important hot spot and trend in the development of engineering field. In the post-epidemic era, it is imperative to explore the crossover model of medicine-engineering development that is compatible with “Healthy China”. How to leverage the advantages of comprehensive disciplines of universities and find the best strategic layout of medicine-engineering crossover is a question to be considered. Therefore, through the quantitative study of the medicine-engineering cooperation of SJTU, this article presents the situation and characteristics of medicine-engineering cross-collaboration, explores the research frontiers and hotspots, and provides reference for medicine-engineering researchers to carry out cross-collaboration research, and also expands the depth and breadth of medicine-engineering interdisciplinary cross-collaboration, which is of great significance to promote the construction of scientific and technological innovation capacity of higher education institutions.

1 Related Theories

1.1 Medicine-Engineering Interdisciplinary

Interdisciplinary intersection refers to the research activity that can break the barriers of existing

disciplines and organically integrate theories, methods or thinking of different disciplines into one^[11]. As a new disciplinary research approach, the intersection of medicine and engineering is still in the stage of continuous development and change, and it is difficult to make a clear and unified definition of its concept and scope. According to the definition of the medicine and engineering interdisciplinary in a report published by Beijing Institute of Technology and Elsevier^[1], the so-called “medicine-engineering interdisciplinary” is short for “the intersection of medicine and engineering (science and literature)”. The scope of “Medicine” covers various disciplines in life sciences and health, such as clinical medicine, biology and biochemistry, genetics, molecular biology, pharmacology and toxicology, neuroscience, psychiatry, immunology, and microbiology. The term “Engineering” refers to a wide range of disciplines such as engineering, science, humanities and social sciences other than “medicine”. The term “Intersection” emphasizes the overlap between “Medicine” and “Engineering”. In terms of the methods of intersection, it can be divided into applied medicine-engineering intersection based on engineering disciplines and innovative medicine-engineering intersection based on medical disciplines. The definition will be followed in this article.

1.2 Institutional Cooperation and Medicine-Engineering Interdisciplinary

The essence of scientific cooperation is the exchange and integration of knowledge in the same discipline or between different disciplines^[3]. And the essence of intersection is the integration of knowledge from different disciplines. From the perspective of scientific communication, the process of intersection of discipline is achieved through the collaboration of researchers or scientific institutions from different disciplines in solving scientific problems beyond a single discipline^[12]. Therefore, scientific cooperation is gradually the mainstream way of research of interdisciplinary science. Li^[13] pointed out that it is the interdisciplinary collaboration between authors, teams or institutions that makes their scientific results interdisciplinary. Bordons et al.^[14] defined interdisciplinary science as the cooperation between researchers from different fields and that cooperation can contribute significantly to interdisciplinary research. Therefore, although scientific cooperation cannot directly reflect the structural characteristics of interdisciplinary, the unique complexity of interdisciplinary research determines that scientific cooperation must become its dominant mode of scientific activity. The collection of educational and publication information of co-authors is extremely challenging in the face of the vast amount of literature. Since co-authors contain not only personal information, but also information about the relevant research institutions, the disciplinary attributes of the authors can be determined

by the disciplinary attributes of the institution names. Therefore, interdisciplinary research can be represented by a collection of publications from a group of research institutions with different disciplinary attributes. In this article, we take the cooperation literature of medical and engineering institutions of Shanghai Jiao Tong University as the research object, and try to explore the situation of institutional cooperation and intersection of medicine and engineering from the level of address information of the co-author institutions, so as to reveal the activity pattern and law of intersection of medicine and engineering from another perspective.

2 Data and Methods

Scientific literature and patent literature constitute the data sources of this article. Scientific literature is an important carrier of scientific knowledge. On the one hand, the discipline to which scientific literature belongs is a direct source to measure the interdisciplinary, and the institutional address contained in it is the information to obtain the data of medicine-engineering intersection in this article; on the other hand, the knowledge absorption and diffusion through scientific literature can also well present interdisciplinary integration. Patent literature can better reflect the current development trend of science and technology convergence due to its own legal effect and its characteristic of being directly transformed into productivity. Therefore, it is an indispensable part of the data source for the study of characteristics of medicine-engineering intersection technology.

When conducting the data pre-survey, we found that, as all database platforms classify subjects by journals, most of the medicine-engineering interdisciplinary papers are singularly classified in engineering subjects or medical subjects, and the number of medicine-engineering interdisciplinary papers included in both subjects is small. Therefore, searching medicine-engineering papers from the disciplinary perspective will affect the rate of data completeness and accuracy. From Subsection 1.2, it can be seen that creating the medicine-engineering intersection dataset from the perspective of institutional cooperation can better reflect the activity pattern of medicine-engineering intersection, and then analyzing the dataset from multiple dimensions by using the bibliometric method and the visualization technique of knowledge mapping can reveal the development trend of medicine-engineering intersection of Shanghai Jiao Tong University and identify the themes of medicine-engineering intersection.

2.1 Research Data

2.1.1 Creation of SJTU Medicine-Engineering Interdisciplinary Dataset Based on Scientific Literature

In this article, based on the core collection of Web of Science (WoS) database, the original and review

types of literature published by Shanghai Jiao Tong University in the past five years (2016-01-01—2020-06-14) were selected, and a total of 53 229 valid data were obtained, and Derwent Data Analyzer (DDA) software of Clarivate Analytics was used to filter out 39 433 papers in which SJTU researchers were the first author or corresponding author, and the institutional data were cleaned to create a medicine-engineering intersection dataset of SJTU.

(1) Extraction of secondary institutions in the address field. Among the 39 433 documents published by SJTU as the first or corresponding author, there are 58 020 complete author addresses, and since only the internal institutions of SJTU medicine-engineering intersection are analyzed, a total of 22 263 addresses of SJTU are filtered. In the data processing of institutional addresses, the feature words that contain Dept, Hosp, Med, Sch, Ctr, Coll, Inst, Lab, Assoc, Fac, Div, Stat, Lib, Res, etc. involving secondary institutions were extracted from the complete addresses of authors in the target literature using DDA software, based on the complete citation information in the dataset. Based on the extracted feature words, a thesaurus was built to further extract the information of secondary institutions. Finally, 38 972 secondary institutions were extracted, covering 39 433 literature records, accounting for 98.83%.

(2) Classification of secondary institutions into medical or engineering discipline based on feature words of secondary institutions. First, the WoS disciplinary names were collated with the extracted discipline feature words in the names of the secondary institutions of SJTU, and the extracted discipline feature words were classified into medical and engineering disciplines according to the WoS discipline classification system. Due to the complexity and variety of related discipline feature words contained in the institutional address names, the discipline information is not unified and specific enough to achieve fully detailed institutional discipline matching. Therefore, during the data processing of institutional addresses, the details below are to be followed: ① What is shown in the institutions are generally abbreviations of professional terms, such as Med, Bio, Surg, and Hosp. Most of them are relatively clear, and we can directly determine their medical discipline attributes based on them. However, there are some terms like Inst Nat Sci, Natl Engr Res Ctr Die, etc. that are relatively difficult to determine, and we need to manually search for them in combination with the full name of the author institution to finally clarify their specific disciplinary affiliation. ② For institutions such as Sch Biomed Engr, Med X Res Insitute, Bio Inst X, and Inst Med Robot, which contain words characteristic of both medical and engineering disciplines, they are considered as interdisciplinary institutions of medicine and engineering,

and are classified into two disciplines of medicine and engineering respectively. Finally, these feature words were aggregated and organized, and a total of 313 words were obtained for both medical and engineering disciplines. For records that could not be matched using the disciplinary feature words, the unmatched records were identified one by one by combining the manual verification method, while supplementing and improving the initial disciplinary feature words in the lexicon. After several rounds of screening, finally 38 965 documents with disciplinary information of secondary institutions were correctly identified, covering 38 972 document records, accounting for 99.98% of the total.

(3) Re-extraction of institutions in the address field and subdivision. Based on the information of medicine and engineering institutions grouped in 38 965 documents obtained, a co-occurrence matrix of medicine-engineering intersection of institutions within Shanghai Jiao Tong University was constructed, and 3 002 valid data of medicine-engineering intersection of SJTU were obtained. A new dataset was created for the 3 002 documents, and new fields were created for the medical and engineering groups that had been cleaned to contain only the addresses of SJTU institutions, and each SJTU institution was subdivided again from the new medical and engineering fields. The principles are followed in the process of subdividing the medical and engineering institutions: ① The number of institution groups equals to the number of institutions appear in the address, and there is no strict distinction between primary, secondary, tertiary, etc. institutions. ② In the medical field of SJTU, only the medical-related and medicine-engineering-related institution groups are kept; in the engineering field of SJTU, only the engineering-related and medicine-engineering-related institution groups are kept.

2.1.2 Creation of SJTU Medicine-Engineering Intersection Dataset Based on Patent Literature

In this article, we use Patyee Database to retrieve the patents applied by SHSMU in Chinese mainland from January 1, 2016 to June 14, 2020, with the disclosure date before May 30, 2021, and by constructing the search expression of SHSMU, which includes 56 research institutes and 13 affiliated hospitals, we got a total of 2 354 patent applications of SHSMU. Similarly, by using DDA co-occurrence matrix analysis, we obtained a total of 105 patent applications by SHSMU in cooperation with SJTU. The processing flow is detailed as follows.

① Since the institutional address of the applicant of the patent documents can only be displayed to the first-level institution, the patent documents applied by SHSMU were retrieved first. ② The patent documents of the two institutions whose applicants were from SHSMU and SJTU were extracted separately, and the cross-data set of medicine and engineering of SHSMU

and SJTU was constructed, and the trend analysis and subject identification were carried out. ③ With reference to the 35 technology classifications of World Intellectual Property Organization (WIPO), the technology converging analysis was carried out.

2.2 Research Methods

2.2.1 Research Method Based on Scientific Literature

The InCites platform is a research evaluation tool built by Thomson Reuters Group based on the collection and analysis of data from seven indexed databases in the WoS core collection. In this article, by using the InCites platform, the development trends of this field are discussed from the aspects of the change trend of published papers, the proportion of top 10% papers, the level of influence, and citation topics of medicine-engineering intersection area, through the indicators such as category normalized citation impact (CNCI), times cited, and key words.

Software such as Citespace, DDA and VOSviewer is used to analyze periodical bibliographic coupling, journals dual-map overlay and source co-citation of papers in medicine-engineering intersection area. The principle of periodical bibliographic coupling is to establish the relationship between journals through the coincidence degree of the same references cited by different journals. The basic assumption is that the greater the amount of literature coupled between two journals, the more similar the two journals^[15]. Journals dual-map overlay is realized on the basis of single-map overlay of all-discipline journals, and contains two basemaps^[16]. The figure on the left is a periodical cluster map established according to the citation relationship of periodicals (called citing journal map), which represents the knowledge base. On the right is a periodical cluster map^[17] established according to the cited journal map, which represents the output, application or diffusion of knowledge. The number of arcs in the map can show the frequency of knowledge flow among disciplines. The more the arcs, the higher the frequency of knowledge flow. The right side can reflect the knowledge sources of disciplines, the position of curve endpoints and the density degree of distribution represent the absorption of different knowledge by disciplines, and the number of curves reflects the knowledge sources of disciplines. Overlay maps of disciplines can directly show the degree of cross-discipline and the cluster of disciplines with high similarity^[18]. WoS discipline classification is clustered into 19 major discipline areas, and each discipline area corresponds to a label. Each node in the graph represents a WoS discipline classification, the size of the node represents the relative number of literatures, and the distance between the nodes represents the closeness of disciplines.

Rao-Stirling index which integrates the variety, balance and disparity of subject diversity can measure the degree of interdisciplinary literature^[19]. The measure-

ment formula is as follows:

$$D = \sum_{i \neq j} (1 - S_{ij}) P_i P_j, \quad (1)$$

where, $1 - S_{ij}$ represents the distance between subject i and subject j ; S_{ij} is the similarity between subjects i and j ; P_i is the proportion of the i th subject. From the definition of medicine-engineering interdisciplinary concept, in this article the medical and engineering disciplines include several disciplines, such as clinical medicine, biomedicine, neuroscience and so on in medical disciplines; physics, chemistry, engineering and other disciplines in engineering disciplines, which reflects the diversity of medicine-engineering interdisciplinary. Therefore, the Rao-Stirling index can be used as a comprehensive index to measure the degree of medicine-engineering interdisciplinary. Normally, the secondary institutions can reflect their related disciplines to a certain extent, so this article attempts to explore the degree of medicine-engineering interdisciplinary through the Rao-Stirling index of cooperation between medical and engineering institutions of SJTU.

2.2.2 Research Method Based on Patent Literature

With the development of medicine-engineering interdisciplinary, it has gradually shown a new trend of medicine-engineering cross-technology, and evolved a new concept of “medicine-engineering technology converging”. Technology converging is based on the integration and reorganization of existing technologies in different fields^[20]. Therefore, the intersection of technologies in medicine-engineering field is medicine-engineering technology converging. This article takes patent literature as the entry point to explore medicine-engineering technology convergence. First, patent literature is by far the best unit to measure technology converging^[21]. Second, it can better reflect the current development trend of convergence of science and technology. Luan and Qin^[22] designed a series of converging indices based on the Derwent classification (DC) system of 20 technology ministry categories, including technology converging index, average technology converging index, and average converged index. In this article, the technology convergence index is suitable for the measurement of medicine-engineering intersection converging with the following formula:

$$TCI_{AB} = N_{AB}/N_A, \quad (2)$$

where, TCI is the converging index; TCI_{AB} is the converging index of technology A converging technology B ; N_A indicates the number of patents contained in technology field A ; N_{AB} is the number of patents belonging to both technology field A and technology field B . This index is used to measure the degree of technology converging with another specific technology. The larger the

value, the higher the degree of convergence of the two technologies. For example, if a medical technology field contains 50 patents, and the medical technology field and the engineering technology field jointly contain 20 patents, then the degree of convergence of the medical technology field with the engineering technology field is $TCI = 0.4$.

Patyee Database is a patent search and analysis software developed by Aokai based on the patent data center. In this article, the patent search function of Patyee is used to search the domestic patent applications of SHSMU, and the comprehensive patent analysis func-

tion of Patyee platform is used to analyze the search results in detail.

3 Research Results

According to the information of medical and engineering institutions obtained after data processing, 3002 papers of medicine-engineering intersection in SJTU were obtained through DDA co-occurrence matrix analysis. There are 5 participating medical secondary institutions, such as the right institutions in Fig. 1; 20 engineering secondary institutions, such as

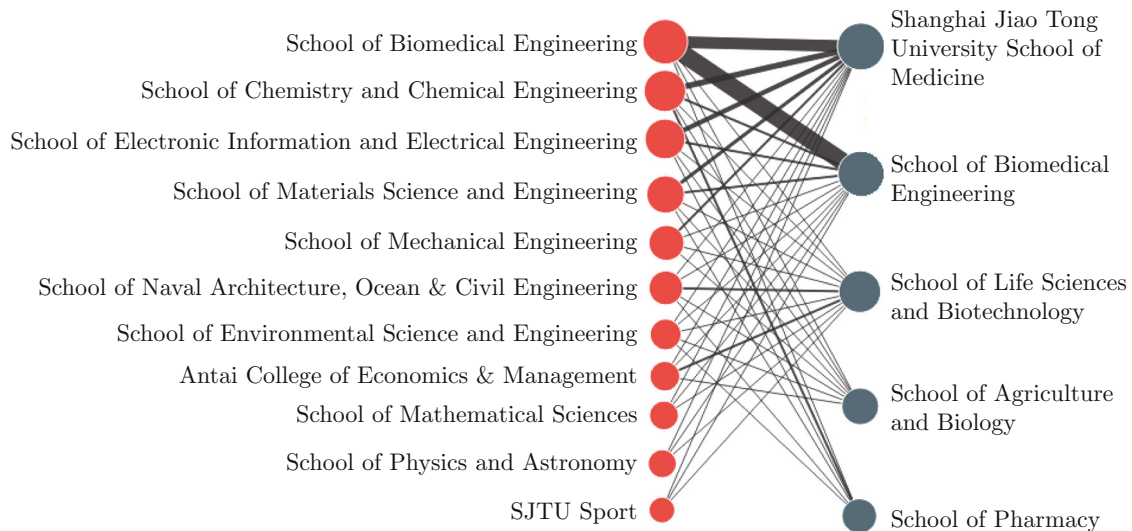


Fig. 1 SJTU Intersection histogram of secondary institutions of medicine and engineering

the left institutions in Fig. 1; 61 medicine-engineering intersection institutions^①.

3.1 Trends and Impact Levels of SJTU Medicine-engineering Interdisciplinary Publications

As the main force of SJTU medical institutions, SHSMU has always attached importance to clinical practice, which occupies a very unique advantage in SJTU medicine-engineering intersection and is able to develop a number of clinical medical science and technology innovation results mainly in innovation. In recent years, the cooperation between SHSMU and the Engineering Institution of SJTU has been very close,

as can be seen in Fig. 1, where the SHSMU and the Engineering Institution of SJTU collaborated to publish 1198 papers^②, which ranked the first among the medical institutions of SJTU. The crossover between SHSMU and School of Biomedical Engineering is the most significant (the thicker the line in the bar graph, the more significant the crossover), with 608 papers published, followed by School of Chemistry and Chemical Engineering (297 papers), School of Electronic Information and Electrical Engineering (224 papers), School of Materials Science and Engineering (169), and School of Mechanical Engineering (74), with a significant intersection of engineering disciplines such as biology, chemistry, computer science, electrical and electronic engineering, materials science, physics, and engineering.

The annual publication volume and citation frequency can reflect the research development trend and influence level, which is one of the important reference indicators for evaluating the discipline development. As shown in Fig. 2, the number of collaborative

^①Medicine-engineering intersection institutions are scientific research institutions engaged in crossover research of medical engineering and medical science. By infiltrating and integrating medical science with different disciplines such as engineering and science, the main goal is to develop medicine-engineering intersection and promote crossover and translational medical research institutions, such as Institute of Biomedical Manufacturing and Quality of Life Engineering, Institute of Medical Robotics, and Institute of Nano-Biomedical Engineering.

^②Since a paper will be done by more than two institutions in most cases, there will be overlapped in the publication statistics of intersection institution.

publications of medicine-engineering intersection institutions of SJTU has been increasing year by year (the data collection time of this article ends in June 2020, so the number of publications in this year is incomplete and is not included in the statistics), and the citation frequency also shows an increasing trend, which indicates that SJTU attaches importance to the intersection and integration of medicine-engineering disciplines, and in the process of promoting medicine-engineering intersection, the influence of literature of medicine-engineering interdisciplinary also increases year by year. Here, N_p is the number of publications and N_c is times cited.

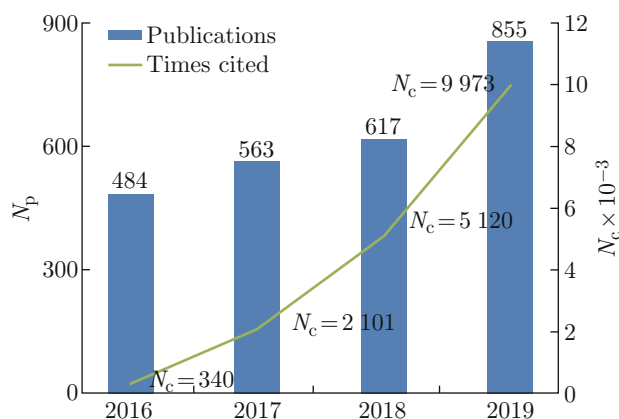


Fig. 2 Trends of SJTU medicine-engineering interdisciplinary publications and citations from 2016 to 2019

CNCI reflects the relative index of the influence of scientific research achievements after eliminating the influence of disciplines^[23]. The CNCI value is equal to 1, indicating that the cited performance (cited frequency, cited percentage, etc.) of this group of papers is equivalent to the global average level; if it is greater than 1, the cited performance of this group of papers is higher than the global average level; if it is less than 1, the cited performance of this group of papers is lower than the global average level. Figure 3 shows the CNCI of the medicine-engineering intersection papers of SJTU from 2016 to 2020. On the whole, the CNCI value (1.29) of medicine-engineering intersection is higher than the average value (1.25) of all disciplines, and also significantly higher than the global benchmark value (1) and the benchmark value (1.2) of C9 universities in Chinese mainland, which indicates that the citation influence (paper quality) of the overall papers of medicine-engineering intersection in SJTU is above the global average level and also above the average level of C9 universities in Chinese mainland.

3.2 Distribution and Knowledge Diffusion of Medicine-Engineering Interdisciplinary Journals

The source journals of medicine-engineering interdisciplinary literature in SJTU can reflect the knowledge

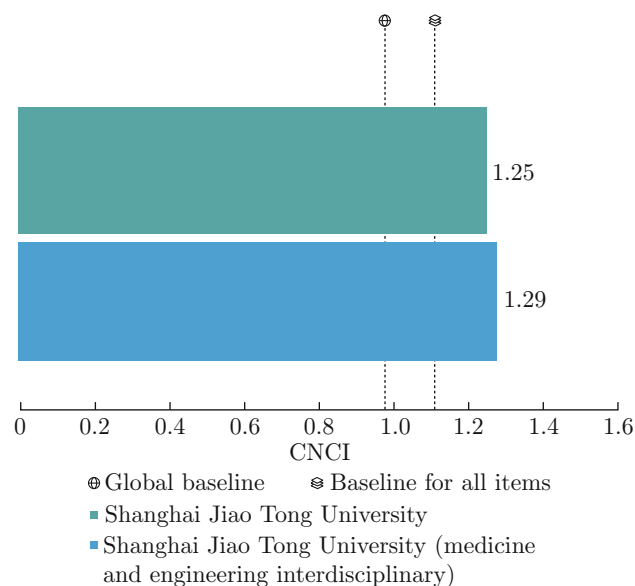


Fig. 3 CNCI of medicine-engineering intersection papers from 2016 to 2020

carriers of medicine-engineering intersection research. The statistical analysis of the distribution of the source journals of medicine-engineering intersection research results is shown in Fig. 4, where N_j represents journal sorts. On the whole, the research results of medicine-engineering intersection come from 940 publications, and from the power distribution of the number of journal issues, as shown in the left of Fig. 4. Although the source journals are extensive, a large number of results are still concentrated in a few journals, and these few journals form the source journals of medicine-engineering intersection. The top 10 source journals in terms of number of publications are listed on the right of Fig. 4. The density of journals for the coupling analysis is shown in Fig. 5. The font size of the elements in the figure is used to distinguish the difference in the number of publications of each journal, and the larger the font size, the more the papers published. The position of journals in the two-dimensional space reflects the similarity between journals, and the closer the distance, the more similar the journals. The density map can clearly divide the journals into two major clusters: one is the journals representing interdisciplinary and frontier area of medicine such as *Scientific Reports*; the other journal cluster is the journals representing aspects of applied materials and engineering fields such as *ACS Applied Materials & Interfaces*.

Knowledge diffusion is also called “knowledge flow”^[24]. Chen and Hicks^[25] believed that knowledge diffusion refers to the change and application of knowledge recorded in scientific publications. From the perspective of citation analysis, knowledge diffusion refers to the inheritance of knowledge in scientific literature through citation, also known as “knowledge diffusion

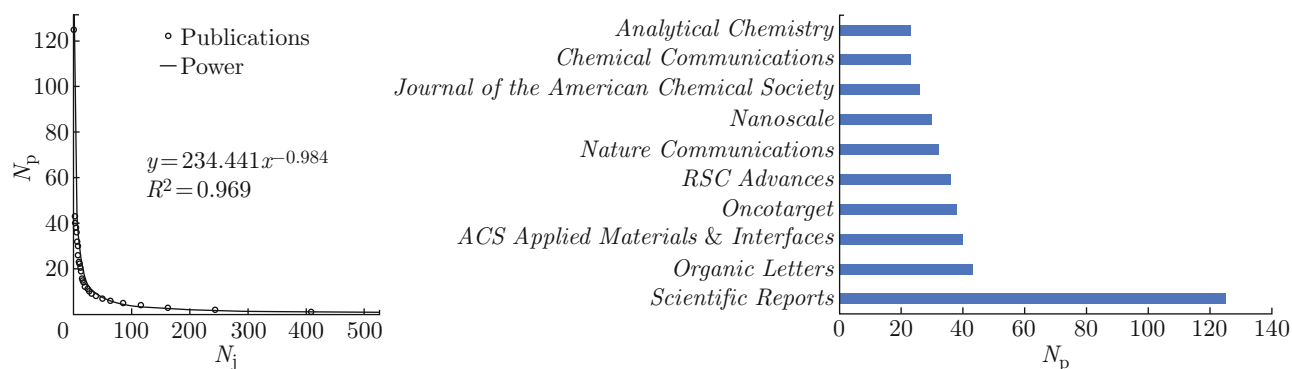


Fig. 4 Distribution of the journals of SJTU medicine-engineering interdisciplinary papers from 2016 to 2020

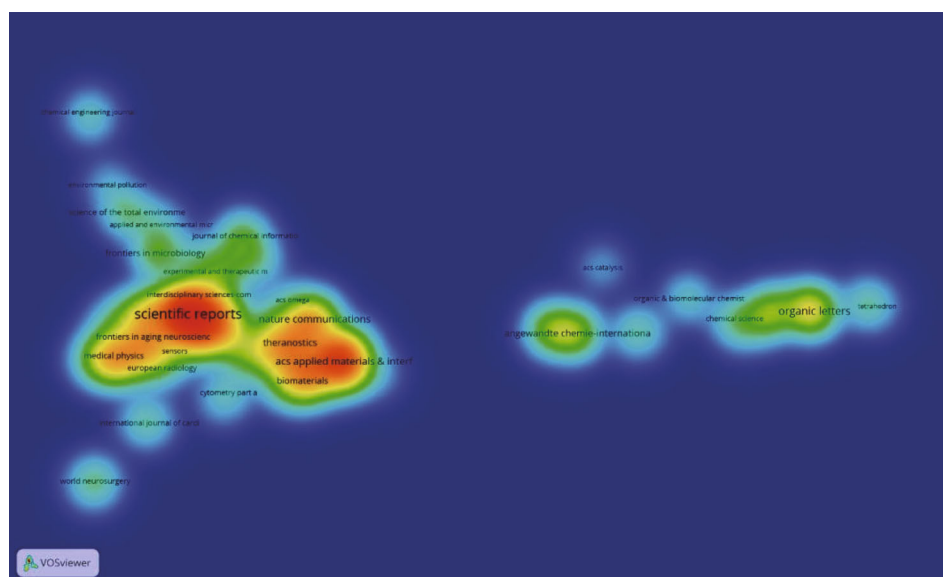


Fig. 5 Coupling analysis on journals of SJTU medicine-engineering interdisciplinary papers from 2016 to 2020

based on citation". In this article, CiteSpace is used to draw the double overlay map of journals to analyze the medicine-engineering interdisciplinary publications of SJTU at the journal level, so as to help discover the knowledge flow of medicine-engineering intersection in SJTU. Figure 6 shows the double overlay map analysis of the journals publishing papers of medicine-engineering intersection of SJTU and the journals cited by the medicine-engineering intersection of SJTU. From the left part, we can see that the active medicine-engineering fields are physics, materials and chemistry. The representative journals in this field are mainly *Organic Letters* (48 papers). In addition to citing their own disciplines, they mainly cited the molecular, biological, and immunological journals such as *Journal of the American Chemical Society* (3 773 papers), *Angewandte Chemie International Edition* (2 823 papers), and *Biomaterials* (1 678 papers). In the disciplines like molecular, biology and immunology, the representative journals in this field are *Oncotarget* (38 papers) and *Theranostics* (28 papers). Besides their

own disciplines, they mainly cited *Nature* (2 701 papers), *PNAS* (2 345 papers), and *Science* (2 071 papers) in the disciplines like physics, materials and chemistry from the right part. In contrast, the density of medical, healthcare and clinical journals is relatively low, but *Medical Physics* (17 papers) and *International Journal of Computer Assisted Radiology and Surgery* (11 papers) in this field have also published many medicine-engineering interdisciplinary papers of SJTU. The basis of this part of knowledge comes from its own disciplines, and the other from mathematics, mechanics, systems, computers and other disciplines. It can be seen that the knowledge base and knowledge diffusion of medicine and engineering interdisciplinary research of SJTU mainly come from the disciplines such as molecular, biology, immunology, medicine and clinical medicine in medical disciplines, and physics, materials, chemistry, computer, mathematics and mechanics in engineering disciplines.

In order to better show the disciplinary distribution of medicine-engineering research results at SJTU,

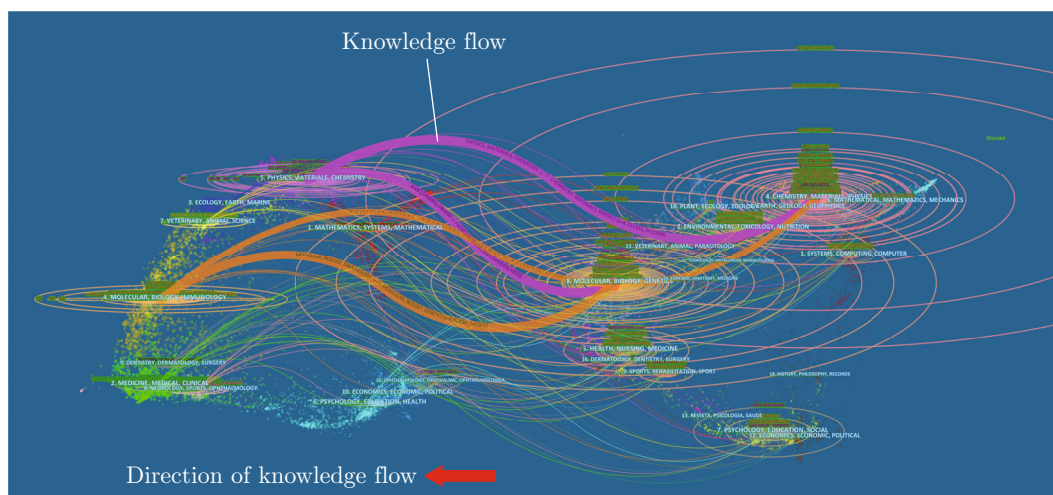


Fig. 6 Double overlay map of journals of SJTU medicine-engineering intersection publications from 2016 to 2020

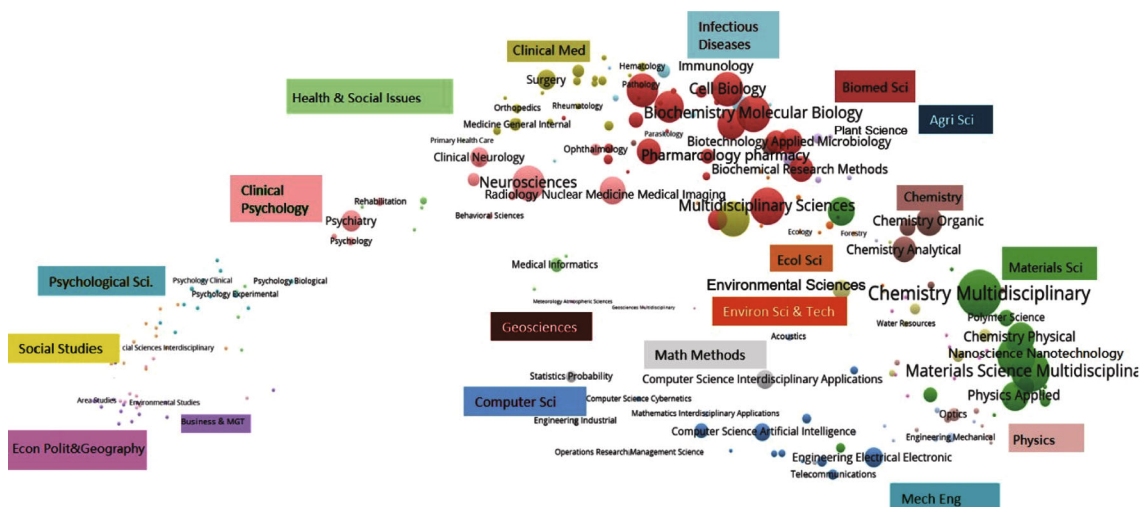


Fig. 7 Overlay maps of SJTU medicine-engineering disciplines from 2016 to 2020

this section uses VOSviewer software to draw the overlap. As shown in Fig. 7, the disciplinary distribution of medicine-engineering research results at SJTU is wide, but mainly concentrated in biomedical science, materials science, chemistry, computer science, clinical medicine, clinical psychology, and mechanical engineering. The largest distribution of literature is in the biomedical science field, with multidisciplinary science being the largest node. In addition, biochemistry molecular biology, cell biology, and medicine research experimental and genetics heredity are also relatively large nodes, which indicates that the amount of literature related to them is relatively large and can be regarded as the current research hotspots of the SJTU medicine-engineering intersection. The engineering discipline most closely associated with medical disciplines such as clinical medicine, infectious diseases, and biomedicine is chemistry, followed by materials sci-

ence, physics, etc. Among the clinical medicine disciplines, engineering biomedicine is the largest node, and surgery, cardiovascular system, internal medicine, oral surgery, gastroenterology and hepatology, orthopedics, pediatrics, and respiratory system are also relatively large nodes. Among them, engineering biomedicine is most closely associated with mathematical computational biology.

Using VOSviewer and DDA software to calculate the Rao-Stirling index of cooperation literature between SHSMU and SJTU, as shown in Table 1, we can understand the diversified integration degree of SJTU medicine-engineering interdisciplinary. There are three levels about the degree of interdisciplinary literature. The Rao-Stirling index of most literature is between 0.2 and 0.5, which belongs to the moderate interdisciplinary literature. Those greater than 0.5 belong to highly interdisciplinary level. Those less than 0.2

belong to low-level^[19]. From Table 1, it can be seen that the overall literature of medicine-engineering interdisciplinary in SJTU belongs to highly interdisciplinary literature, indicating that the overall degree of medicine-engineering interdisciplinary in SJTU is high. The degree of cooperation literature between SHSMU and School of Biomedical Engineering is the highest, followed by the cooperation literature between SHSMU

and Schools of Mechanical Engineering, Mathematical Science, Physics and Astronomy, and Electronic Information and Electrical Engineering. Although more literature cooperated between SHSMU and School of Chemistry and Chemical Engineering cooperation, the Rao-Stirling index of them is 0.47, which belongs to moderate interdisciplinary level, i.e., moderate overall degree of interdisciplinary.

Table 1 Rao-Stirling index of SJTU medicine-engineering interdisciplinary literature

Medicine-engineering intersection institution	Rao-Stirling index
Medicine-Engineering Intersection (overall)	0.74
SHSMU - School of Biomedical Engineering Intersection	0.82
SHSMU - School of Chemistry and Chemical Engineering Intersection	0.47
SHSMU - School of Electronic Information and Electrical Engineering Intersection	0.69
SHSMU - School of Mechanical Engineering Intersection	0.78
SHSMU - School of Naval Architecture, Ocean & Civil Engineering Intersection	0.63
SHSMU - Antai College Economics & Management Intersection	0.65
SHSMU - School of Mathematical Science, Physics and Astronomy Intersection	0.72

3.3 Analysis of Research Hotspots and Trends in SJTU Medicine-Engineering Interdisciplinary Field

Keywords extracted from papers could represent a specific research direction, research topic, or subject of a field. Higher frequency of keywords means stronger correlation in this field, which can further suggest that these keywords are related to a specific research topic^[26]. In this article, DDA software is selected to extract and clean the subject words. On the one hand, DDA software has powerful data cleaning capability; on the other hand, the software can disassemble and get an optimized phrase no matter how long the text is through the natural language processing (NLP) tech-

nology, and at the same time, the term frequency-inverse document frequency (TF-IDF) technique is used to evaluate the importance of a particular topic word to a document set and assign weights. These functions enable the subject word sets of SJTU medicine-engineering literature to show a certain degree of importance. The titles, keywords and abstracts of 3 002 papers were subject to NLP, and the obtained word sets were further organized to remove distracting factors. Then the word sets obtained by NLP technique were analyzed and assigned weights by TF-IDF word frequency inverse document technique to build the top 50 subject word sets, and the visualization results were derived, as shown in Fig. 8. The weight of each word



Fig. 8 Keywords of SJTU medicine-engineering interdisciplinary field from 2016 to 2020

is proportional to the frequency of occurrence, and it can be seen that “deep learning”, “Parkinson’s disease (PD)”, “oxidative stress”, “drug delivery”, “photodynamic therapy (photothermal therapy)”, “gut microbiota”, “non-small cell lung cancer (NSCLC)”, “3D printing”, “convolutional neural network”, “circulating tumor cells”, “long lung coding RNA”, “bone regeneration”, “gold nanoparticles”, and “inflammatory cytokine” are still high-frequency keywords in the field of SJTU medicine-engineering intersection field.

Research is a dynamic ecosystem. As authors advance their fields by publishing new papers that cite existing ones, research topics diversify, new topics debut and older topics fall into decline^[27]. In 2020, Clarivate launched citation topics, which aggregates nearly 70 million papers into discrete clusters of relevant literature based on the strength of citation relationships, and these clusters form the core of citation topics. The approach is to build a classification system containing 10 macro citation topics, 326 meso citation topics, and 2444 micro citation topics, from broad macro topics to narrow micro topics to explore details layer by layer, so as to better understand the most important and significant research themes and directions in the field. The analysis shows that from 2016 to 2020, the literature of SJTU medicine-engineering field is involved in 9 macro citation topics, including clinical and life sciences, chemistry, electrical engineering, electronics and computer science, engineering and material science, and physics, as well as 202 meso citation topics and 651 micro citation topics. Since the medicine-engineering theme should have a high degree of medicine-engineering discipline distribution, and the

important topics of medicine-engineering intersection should have a certain cumulative frequency, this article extracts the top 2 micro citation topics from the first 5 macro citation topics in order of citation frequency from highest to lowest, so as to constitute the top 10 themes of SJTU medicine-engineering field, as shown in Fig. 9. Among them, 2.67 Nanoparticles micro citation topic under the chemical macro citation topics involves the 151 documents retrieved from the previous search, with 2928 citations and CNCI of 1.67, including 2.67.370 Magnetic Nanoparticles, 2.67.47 Surface-Enhanced Raman Scattering, 2.67.231 Silver Nanoparticles and other micro citation topics, which are currently the most important research hotspots in the SJTU medicine-engineering field; 1.196 Micro & Long Noncoding RNA micro citation topic under the macro citation topics of Clinical & Life Sciences involves 72 papers with 1342 citations, and the micro citation topics of 1.120 Inflammatory Bowel Diseases & Infections involves 37 papers with 1244 citations, which are the more important research topics in the SJTU medicine-engineering field. In addition, 7.12 Metallurgical Engineering and 7.251 Electrical-Harvesting & Discharging micro citation topics under Engineering & Materials Science macro citation topics, 4.17 Computer Vision & Graphics and 4.61 Artificial Intelligence & Machine Learning under the Electrical Engineering, Electronics & Computer Science macro citation topics, and 5.250 Imaging & Tomography and 5.38 Optical Electronics & Engineering under the macro citation topics of Physics also reflect the more significant current research directions in the SJTU medicine-engineering field.

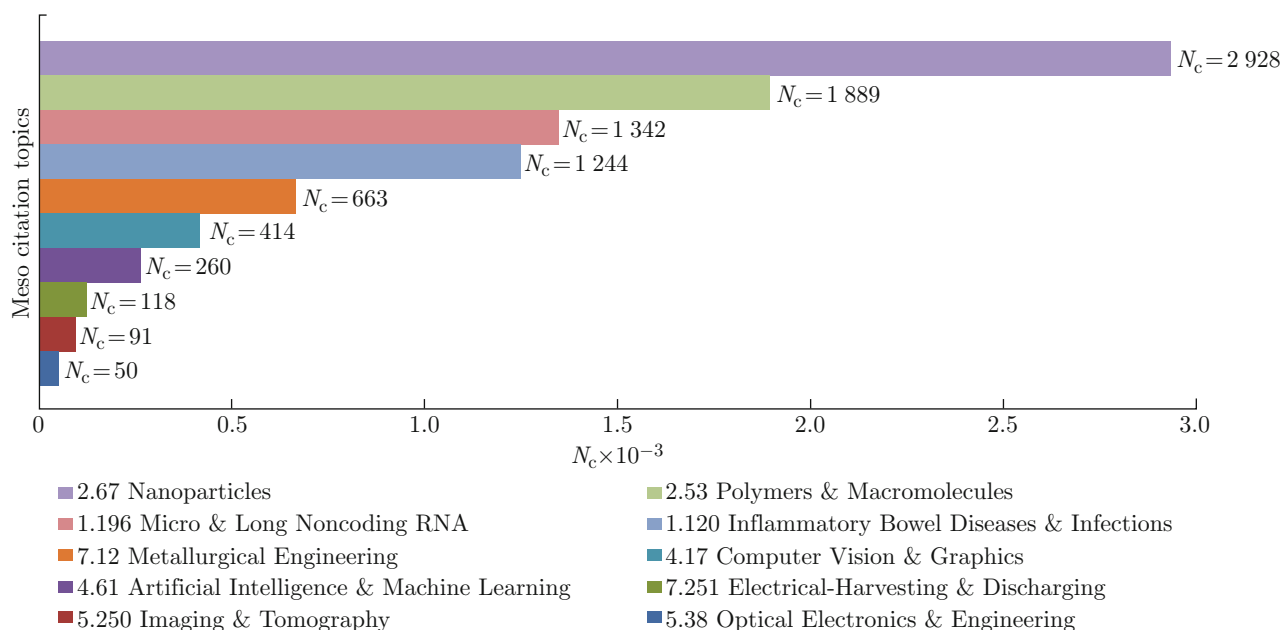


Fig. 9 Citation topics in SJTU medicine-engineering interdisciplinary field from 2016 to 2020

3.4 Analysis of SJTU Medicine-Engineering Technology Convergence

Patent literature is an important literature to measure the level of industry-university research in universities. During 2016—2020, the number of patent co-applications between SHSMU and SJTU is 105, as shown in Fig. 10. The more the cooperation, the thicker the two-node connecting line. Most of them are the patents applied by the Ninth People’s Hospital in cooperation with Shanghai Jiao Tong University. The top 10 patents in technical fields according to the IPC classification number group are A61M16/04 (tracheal tubes), A61F 5/01 (orthopaedic devices, e.g., long-term immobilising or pressure directing devices for treating bro-

ken or deformed bones such as splints, casts or braces), A61B90/40 (apparatus fixed or close to patients specially adapted for providing an aseptic surgical environment), B33Y50/00 (data acquisition or data processing for additive manufacturing), A61H1/02 (stretching or bending apparatus for exercising), B33Y 80/00 (products made by additive manufacturing), G06T7/00 (image analysis), A61M1/00 (suction or pumping devices for medical purposes; devices for carrying-off, for treatment of, or for carrying-over, body-liquids; drainage systems), G06T 17/00 (3D modelling for computer graphics), A61B90/00 (instruments for performing medical examinations of the interior of cavities or tubes of the body by visual or photographic inspection, e.g., endoscopes).

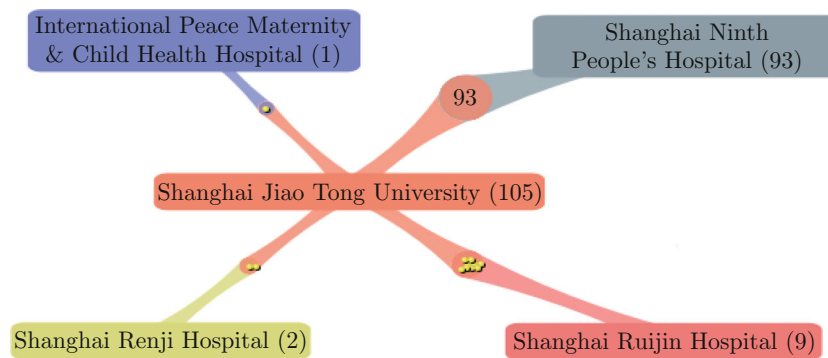


Fig. 10 Cooperation between SHSMU and SJTU for patent applications

In the same way as Subsection 3.3, the titles and abstracts of 105 patents are sorted out, and the top 50 topic set is established. As shown in Table 2, “air guide port”, “alarm system”, “operation ports”, “film pressure sensor”, “knee joint fusion”, “membrane body”, “3D printing”, “bone crushing device”, “surgical robot”, “machine learning”, and so on are the high-frequency keywords in the field of SJTU medicine-engineering technology converging.

With regard to the technology fields in which SHSMU

and SJTU cooperated to apply for patents, the WIPO Patent Classification and Technology Field IPC Comparison Table was used to convert the patent IPC classification to the 35 technology categories of WIPO^[28]. From Fig. 11, it can be seen that the cooperative patent research and development mainly focuses on medical technology (80%), but also demonstrates the phenomenon of integration with a number of other technology fields, such as computer technology (8.57%), other special machines (11.4%), furniture and games (5.71%),

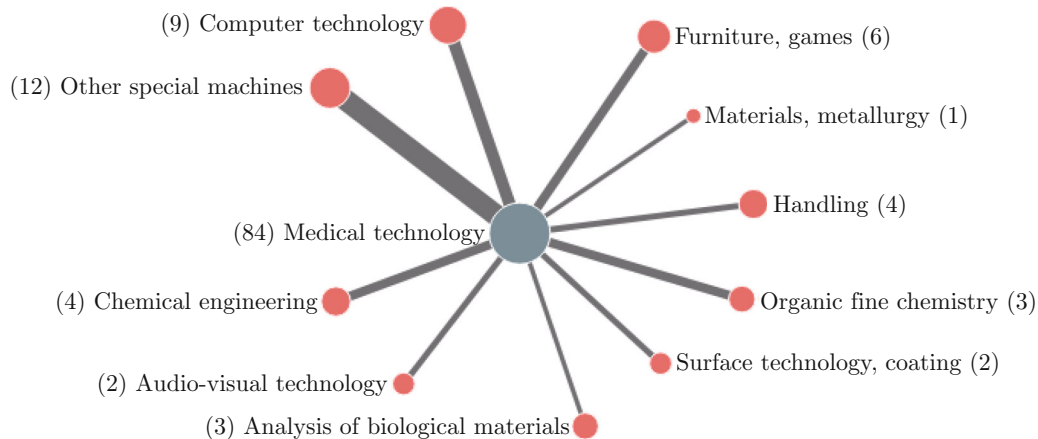


Fig. 11 Distribution of technology fields of cooperation patents between SHSMU and SJTU

Table 2 Top 50 subject headings for patent applications cooperation between SHSMU and SJTU

Record	Subject words	Weight	Record	Subject words	Weight
4	Air guide port	2.81	2	Correcting hallux valgus	2.41
4	Alarm system	2.81	2	Culture chamber	3.42
4	Operation ports	2.81	2	Deflation unit	2.41
3	Film pressure sensor	2.65	2	Elbow joint training device	2.41
3	Knee joint effusion	2.65	2	Electric auxiliary knee articular cavity air bag device	2.41
3	Membrane body	3.75	2	Electrode part shell	3.42
2	3D printing cervical vertebra stretching pillow	2.41	2	Finger cuff	2.41
2	3D printed insole body	2.41	2	First connecting pipe	3.42
2	3D printing ankle-foot orthopedic device	2.41	2	Force transducer	2.41
2	Adjustable double-ankle knee joint orthotic device	2.41	2	Forearm support unit	2.41
2	Air bag	2.41	2	Indicating lamp	3.42
2	Auxiliary knee articular airbag device	2.41	2	Inflatable support unit	2.41
2	Balloon air pump	2.41	2	Surgical robot	2.41
2	Biological support	2.41	2	Intelligent medical infusion automatic liquid	2.41
2	Bluetooth module	2.41	2	Invasive operation isolation bag pad	2.41
2	Body fixing belt	2.41	2	Load reducing-type orthopaedic knee brace	2.41
2	Bone crushing device	2.41	2	Machine learning	2.41
2	Buckle components	2.41	2	Mandible defects restoration structure	2.41
2	Calculating device	2.41	2	Medical excrement collecting bag	2.41
2	Cell culture	2.41	2	Perfusion type bioreactor	2.41
2	Cervical vertebra orthopedic pillow	2.41	2	Processing chip	2.41
2	Circulation pump	3.42	2	Puncture guiding unit	2.41
2	Clinical operation isolation device	2.41	2	Switch rod	3.42
2	Conduit tube body	2.41	2	Valve plate	3.42
2	Condyle contact plate	2.41	2	Vascular puncture positioner system	2.41

handing (3.81%), chemical engineering (3.81%), etc. The TCI formula described in Subsection 2.2.2 was used to measure the degree of technology converging between the SHSMU and SJTU. The highest TCI is 0.14 for medical technology and other special machines. The main technologies are 3D printed prosthesis and various components for biomedical applications. Medical technology and computer technology ranked second in terms of converging index which is 0.11, mainly for medical image processing methods, computer program construction for orthotics, computer equipment, and storage media. The next ones in order of converging are furniture, games (0.07), handing (0.05), chemical engineering (0.05), organic fine chemistry (0.04), analysis of biological materials (0.04), audio-visual technology (0.02), surface technology, coating (0.02), and materials, metallurgy (0.01).

4 Conclusion

In this article, from the perspective of cooperation between medicine-engineering institutions, the medicine-engineering papers are taken as the research object, and the situation of medicine-engineering

cooperation and topic recognition are analyzed. And the cooperation between SHSMU and SJTU is taken as an example. The medicine-engineering data set is constructed as the data source of this article by extracting the institutional information of the address field of the papers. It is found that the SJTU medicine-engineering interdisciplinary trend is increasingly obvious, and the research results are increasing year by year with good overall quality and higher citation impact than the global average.

The institutional cooperation of medicine-engineering interdisciplinary is diversified, and the mode of intersection is mostly “one-to-many” or “many-to-many”, thanks to the great collaboration between SHSMU and School of Biomedical Engineering, School of Chemical Engineering, School of Electronic Information and Electrical Engineering, School of Materials Science and Engineering, and School of Mechanical Engineering. Through the analysis of research hotspots, the SJTU medicine-engineering interdisciplinary cooperation is concentrated in three areas: ① Nano-biomedical engineering, where nano biotechnology-related research accounts for the highest percentage, and SHSMU and School of Biomedical

Engineering, School of Chemistry and Chemical Engineering, School of Materials Science and Engineering, School of Electronic Information and Electrical Engineering, and School of Physics and Astronomy collaborate on nanoparticle-based infrared photothermal therapy for tumors, nanomaterials for drug delivery in cancer therapy, nanoparticle synthesis, application and biosafety, and quantum dots for biomedical applications. As an important direction in the development of nanotechnology, nanomedicine has rapidly become a frontier and hot issue in the development of SJTU medicine-engineering intersection. In addition, those research themes with high attention, such as regenerative medicine and sports medicine, focus on 3D printed tissues and organs, biodegradable magnesium alloy implant materials, biosensor detection technology, bone regeneration, stem cells, orthopedic and sports medicine, and prosthetics researched by SHSMU in cooperation with School of Materials Science and Engineering, School of Mechanical Engineering, and School of Physics and Astronomy. ② In terms of brain science, brain and neurological disorders are currently the key research directions in the intersection of SJTU medicine-engineering. Brain science is in a critical period of development, and SHSMU is collaborating with the School of Biomedical Engineering and the Antai School of Economics and Management to study the causes and pathogenesis of neurological diseases, such as Alzheimer's disease, Parkinson's disease, depression, stroke, as well as early diagnostic indicators and therapeutic countermeasures developed for the diseases, such as brain imaging technology and EEG technology. The research on establishing deep learning capabilities driven by data, brain-like computing driven by cognitive bionics, emotion recognition, classification and other artificial intelligence is at an emerging stage. Specifically, SHSMU and School of Biomedical Engineering, School of Electronic Information and Electrical Engineering, School of Mechanical Engineering, and School of Mathematical Sciences are collaborating to develop research on the application of implants with 3D technology to surgical robots or surgical navigation systems, wearable medical devices, building block mathematical models to establish intelligent assisted diagnosis technologies, and treatment protocols or detection systems based on medical big data mining research and development. ③ In term of precision medicine, the main focus is on the diagnosis and treatment of tumors, involving topics such as gene editing and sequencing, cellular immunotherapy, and inhibitor drugs. Specifically, SHSMU and School of Life Sciences, School of Biomedical Engineering, School of Physics and Astronomy, and the School of Naval Architecture, Ocean & Civil Engineering are collaborating on the application of long non-coding RNAs and exosomal cells in early tumor therapy,

intestinal microecology and homeostatic immunity, non-small cell cancer epidermal growth factor receptor, CRISPR/Cas9 genome editing technology, and other research. The current research hotspots focus on targeted therapy and cellular immunity in early tumor diagnosis and treatment.

SJTU medicine-engineering technology convergence covers a wide range of disciplines, including bone science, physics, electronic information and electrical engineering, mathematics, mechanical engineering and other disciplines. Medicine-engineering technology convergence such as medical technology integrating with other special mechanical technology, computer technology, manual technology and other engineering technology has a high degree of convergence. The cooperation institutions are diversified, mainly including the Ninth People's Hospital, Ruijin Hospital, etc., cooperating with SJTU School of Biomedical Engineering, School of Electronic Information and Electrical Engineering, School of Materials Science and Engineering, School of Mechanical Engineering, etc. The research areas mainly focus on the following four aspects. ① Medical instruments and devices include electronic medical equipment, diagnostic and surgical equipment, prosthesis equipment, etc., for example, the clinical operation isolation device developed by the Ninth People's Hospital and SJTU for frontline medical staff in the fight against the "epidemic", the robot of blood vessel assisted puncture system and the auxiliary corrective appliance, 3D printed prostheses. ② Medical materials concentrate on nano-biotechnology, such as nano-technology-based graphene modified materials and hydrogel materials developed by the Ninth People's Hospital and SJTU. ③ Biomarker applies to the use of human LSP1 protein and SNRPA protein in the monitoring of lung cancer recurrence or metastasis developed by Ruijin Hospital and SJTU. ④ Artificial intelligence medical platform system includes computer-aided diagnosis system, medical big data mining system. For example, Ruijin Hospital, Renji Hospital, and the Ninth People's Hospital respectively developed a machine learning-based treatment plan recommendation system, jaw defect reconstruction system, mobile phone assessment system for patient pain, and data mining-based noise hearing loss prediction and susceptible population screening method, device, terminal and medium, etc. Compared with the research of medicine-engineering interdisciplinary, technology convergence highlights the medicine-engineering technology integration and innovation, which involves the medicine-engineering interdisciplinary knowledge. From the analysis of research hotspots, we can see that the research hotspots of SJTU medicine-engineering technology convergence involve nano biotechnology, artificial intelligence technology, precision medicine technology, and so on. These technologies themselves are

already medicine-engineering interdisciplinary. Therefore, to a certain extent, medicine-engineering interdisciplinary is the basis for the medicine-engineering technology convergence. As an extension form of interdisciplinary research, technology convergence promotes the development of medicine-engineering interdisciplinary.

In the past five years, SJTU medicine-engineering interdisciplinary field has entered a stage of rapid development. First, medicine-engineering interdisciplinary is widely distributed. The more active medical disciplines are biomedicine, clinical medicine, neurology, etc. The more active engineering disciplines are materials science, mechanical engineering, physics, computer science, chemistry, etc. Through the analysis of Rao-Stirling index and research hotspots, we can see that as an medicine-engineering interdisciplinary subject, the SJTU biomedical engineering discipline has become a key subject of medicine-engineering interdisciplinary. The research direction of nano, molecular and regenerative medicine, biomedical instrument, imaging, computing and system biomedicine has formed in this field, which has become the source of SJTU medicine-engineering interdisciplinary. Second, the combination of medicine and mechanical engineering is a highly interdisciplinary. Intelligent medical devices, digital medicine, human biomechanics, biomedical manufacturing, biomaterials and other fields have become important research directions of medicine-engineering interdisciplinary. The combination of medicine and computer science, materials science and physics is a potential medicine-engineering interdisciplinary. The research of biomedical materials, biomedical statistics and biophysics, organ repair or transplantation has become an important field for the rapid development of medicine-engineering interdisciplinary. On the whole, medicine-engineering intersection has gradually become the main trend of medical innovation and development, and it is also the only way for the sustainable development of engineering.

Interdisciplinary science is a multidimensional and complex concept. It is difficult to describe its essential characteristics fully from any single dimension. It is necessary to use comprehensive analysis to explore the differences and integration points of various dimensional methods. Therefore, the research on interdisciplinary science is a continuous and in-depth series of research processes. In this article, we only conducted an empirical study from the perspective of medicine-engineering institutional cooperation and took the research of SJTU medicine-engineering interdisciplinary as an example. Although the research objects are typical, the conclusions revealed are limited and the generalizability of its findings needs further exploration. Therefore, the next study should expand the research field and research perspective, focusing on measuring and analyzing the medicine-engineering interdisci-

plinary from the citation relationship or text content and other dimensions in order to get the best medicine-engineering interdisciplinary pattern.

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References

- [1] Beijing Insitute of Technology, Elsevier. Global prospect for top science of interdiscipline of medicine and engineering [R]. Beijing: Beijing Institute of Technology, 2019: 1-7 (in Chinese).
- [2] WANG Y Q, SUN G F, BAO Z H. General knowledge and performance analysis of key clinical projects from the ministry of health [J]. *Chinese Journal of Medical Science Research Management*, 2009(1): 50-53 (in Chinese).
- [3] ZHOU J, LÜ F L, WU X P. Explore scientific research management for the medical-engineering cross projects in university [J]. *The Guide of Science & Education*, 2011(34): 194-195 (in Chinese).
- [4] SHEN J Z, LU X P, YANG A L. Selection and management of medical-engineering integration projects [J]. *Chinese Journal of Medical Science Research Management*, 2001, **14**(1): 25-27 (in Chinese).
- [5] JI X W, LIU H. Discussion on the application of medicine and engineering in clinical teaching [J]. *New Education Era*, 2017(29): 167 (in Chinese).
- [6] DAI Z H. An interdisciplinary empirical study on improving the innovation ability of university science and technology: Take interdisciplinary medicine and engineering science as an example [J]. *Science & Technology Progress and Policy*, 2011, **28**(21): 147-150 (in Chinese).
- [7] XU A H. Approach and application of cross research model analysis for biomedical engineering based on network science [D]. Shanghai: Shanghai Jiao Tong University, 2012 (in Chinese).
- [8] GU M M, LI P Y. The problems and suggestion for interdisciplinary combination between medicine and engineering in research universities of China [J]. *Researches in Medical Education*, 2010, **9**(5): 577-580 (in Chinese).
- [9] WANG L, MA Z, XU X Y, et al. Research report on the status of interdisciplinary combination between medicine and engineering in China and its countermeasures (2019) [J]. *Journal of Clinical Medicine in Practice*, 2019, **23**(5): 1-6 (in Chinese).
- [10] TAN H, SUN L Z. Research and countermeasure analysis on cross-development of medicine and engineering

- (science) in college [J]. *Science and Technology Management Research*, 2012, **32**(14): 161-163 (in Chinese).
- [11] WU Z Q. Promoting disciplinary construction by the way of disciplinary intersection [J]. *Higher Education Development and Evaluation*, 2005, **21**(2): 17-21 (in Chinese).
- [12] ZHANG L, HUANG Y. Interdisciplinarity: Measurement, evaluation and application [M]. Beijing: Science Press, 2019: 97-132 (in Chinese).
- [13] LI J. The concept and measurement of interdisciplinarity [J]. *Documentation, Information & Knowledge*, 2014(3): 87-93 (in Chinese).
- [14] BORDONS M, ZULUETA M A, ROMERO F, et al. Measuring interdisciplinary collaboration within a university: The effects of the multidisciplinary research programme [J]. *Scientometrics*, 1999, **46**(3): 383-398.
- [15] LI J, GUO X H, LI K W. Research on safety culture journals and knowledge transfer [C]//*The 3rd BSM in China Conference*. Beijing: Behavioral Safety Management Commission, 2015: 8-12 (in Chinese).
- [16] CHEN C M, LEYDESDORFF L. Patterns of connections and movements in dual-map overlays: A new method of publication portfolio analysis [J]. *Journal of the Association for Information Science and Technology*, 2014, **65**(2): 334-351.
- [17] KLAVANS R, BOYACK K W. Toward a consensus map of science [J]. *Journal of the American Society for Information Science and Technology*, 2009, **60**(3): 455-476.
- [18] CHEN C M. Mapping scientific frontiers: The quest for knowledge visualization [M]. London: Springer London, 2003.
- [19] HAN Z Q, LIU X P, XU H. Interdisciplinary literature discovery based on Rao-Stirling indices: Case studies in nanoscience and nanotechnology [J]. *Library and Information Service*, 2018, **62**(1): 125-131 (in Chinese).
- [20] LIU N, RONG X Y, MAO J Q. The effect of technological convergence on technological value in emerging cross-fields—taking nano biopharmaceuticals as an example [J]. *Technology and Innovation Management*, 2019, **40**(6): 728-736 (in Chinese).
- [21] CAVIGGIOLI F. Technology fusion: Identification and analysis of the drivers of technology convergence using patent data [J]. *Technovation*, 2016, 55/56: 22-32.
- [22] LUAN C J, QIN X. Methods and indicators of measuring converging index between technology sections [J]. *R&D Management*, 2016, **28**(3): 67-78(in Chinese).
- [23] HAO Y N, ZHOU J L, YU Q. Analysis of special medicine based on InCites and Web of Science [J]. *Chinese Journal of Medical Library and Information Science*, 2020, **29**(4): 47-52 (in Chinese).
- [24] SINGH J. Collaborative networks as determinants of knowledge diffusion patterns [J]. *Management Science*, 2005, **51**(5): 756-770.
- [25] CHEN C M, HICKS D. Tracing knowledge diffusion [J]. *Scientometrics*, 2004, **59**(2): 199-211.
- [26] HU C P, HU J M, DENG S L, et al. A co-word analysis of library and information science in China [J]. *Scientometrics*, 2013, **97**(2): 369-382.
- [27] IAN P. Introducing Citation Topics in InCites [EB/OL]. (2020-12-03). <https://clarivate.com/webof-sciencegroup/article/introducing-citation-topics/>.
- [28] IPC concordance table [EB/OL]. [2021-01-20]. <https://www.wipo.int/ipstats/en/index.html#resources>.