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A BIBLIOMETRIC EXAMINATION OF THE EXISTING KNOWLEDGE FRAMEWORK AND ADVANCEMENTS IN VASCULAR NETWORK ENGINEERING

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Abstract—Vascular network creation is a precedence in tissue engineering and regenerative medicine, where the pursuit is to recreate complex vascular networks that are integral to functional tissue constructs. Although advancements have been made in the creation of vascular channel substitutes and vascularized tissue constructs, more efforts must be directed toward clinically pertinent solutions. In this work, 714 published articles (1986–2025) available in the Web of Science database were examined using the Bibliometrix R package and VOSviewer. Output from studies in this discipline has increased sharply after the year 2009, with the USA at the forefront. *ACTA Biomaterialia* had the largest number of articles published (43), and *Biomaterials* journal was also the most frequently cited source with more than 3,500 citations. There was a high rate of international collaborations, with 184 cases involving scientists from 37 nations, headed by USA-China collaboration. Major research areas connect vascular network engineering and tissue engineering, vascularization, hydrogels, biofabrication, and biomaterials. Keyword and co-citation analysis identified imminent topics including wound healing, mechanical characterization, biocompatibility, 3D bioprinting, drug delivery, and cardiac patches, indicating impending topics and directions.

Keywords – bibliometric analysis; metadata; vascular network; tissue engineering; quantitative evaluation; co-citation

I. INTRODUCTION

Tissue engineering is focused on the production of functional tissue constructs for regenerative medicine. This hinges on vascular network development that mimics the hierarchical structure of the original vasculature. Although much progress has been made, there is a need for standardization in mechanical characterization, the formulation of hydrogels with superior performance, and the quality control of biofabrication processes.

Here, bibliometric analysis represents a potent instrument for the quantitative evaluation of research trends and mapping of the scientific landscape in a specific area. Through the application of the systematic examination of publication metadata, including authorship, citations, affiliations, and keywords, bibliometric analysis offers crucial information regarding the development of research fields. For example, it enables researchers to identify highly cited papers that have made significant contributions to the field, analyze collaborative collaborations between authors and institutions, and identify geographic locations that are prominent in specific areas of innovation [1].

Moreover, bibliometric analysis is also an important function in identifying research gaps. Through the identification of underemphasized themes and trends in the literature, researchers can identify areas that need to be studied further. Not only does this help in the development of new study questions but also ensures that subsequent studies add value to the construction of scientific knowledge. In addition, bibliometric tools determine potential partners and lead institutions, and as such, interdisciplinary collaboration is the norm in addressing complex challenges like vascular network engineering [2].

Research institutions and universities also employ bibliometric performance measures to compare themselves against other entities and plan for resource allocation [3]. Therefore, a bibliometric study of vascular network engineering provides a systematic approach to achieving developments within the field, facilitating collaborative work, and creating a platform for conducting relevant studies.

This study examines the knowledge paradigm and progression in the area of vascular network engineering based on bibliometric analysis of papers obtained via a custom Boolean search strategy on the Web of Science (WoS) library.

II. METHODOLOGY

A. Data Collection

Data for this analysis was retrieved from the Web of Science (WoS) Core Collection using the Boolean search key: "('mechanical characterization' OR 'hydrogels' OR 'quality control') AND ('vascular system' OR 'vascular tissue' OR 'blood vessel' OR 'vascular channel')." As at the day of the fetching the data, January 20, 2025, 714 publications spanning the years 1986–2025 were retrieved and included in the analysis. The data

was exported from WoS as BibTex ('.bib') file for usage in Bibliometrix and Tab Delimited file for usage in VOSviewer.

B. Bibliometric Analysis

Bibliometric analysis was conducted with the help of two main tools: VOSviewer and the Bibliometrix R package.

VOSviewer is a specialized computational tool that was specifically designed to produce and visualize bibliometric networks [4]. The networks can be of any relation type including but not limited to co-authorship, co-citation, or keyword co-occurrence. In this study, VOSviewer was used to produce visualizations reflecting collaborative networks between authors, institutions, and countries. In addition, keyword co-occurrence networks were also analyzed in order to search for emerging trends and themes in vascular network engineering research.

Bibliometrix, an open-source R package, provides comprehensive quantitative and qualitative bibliometric analysis capabilities [5]. The package was used in preprocessing the data by cleaning metadata, identifying duplicate records, and mining significant bibliometric metrics such as publication trends, citation frequencies, and thematic development. The package's advanced capabilities allowed for in-depth analysis of author productivity, institutional production, and keyword. This study applied both the package's in-built "Keyword Plus" functionality and "Authors Keyword" to explore the most relevant keywords. In addition to that, text editing was applied by loading a list of synonyms to streamline the list of words.

Combining Bibliometrix and VOSviewer enabled an in-depth examination of the structure of knowledge within the field. In particular, Bibliometrix thematic maps identified important research areas and their connections, and VOSviewer network visualizations showed collaboration patterns and important contributions. Combined, these analyses shed light on the evolution of vascular network engineering and provided potential research directions.

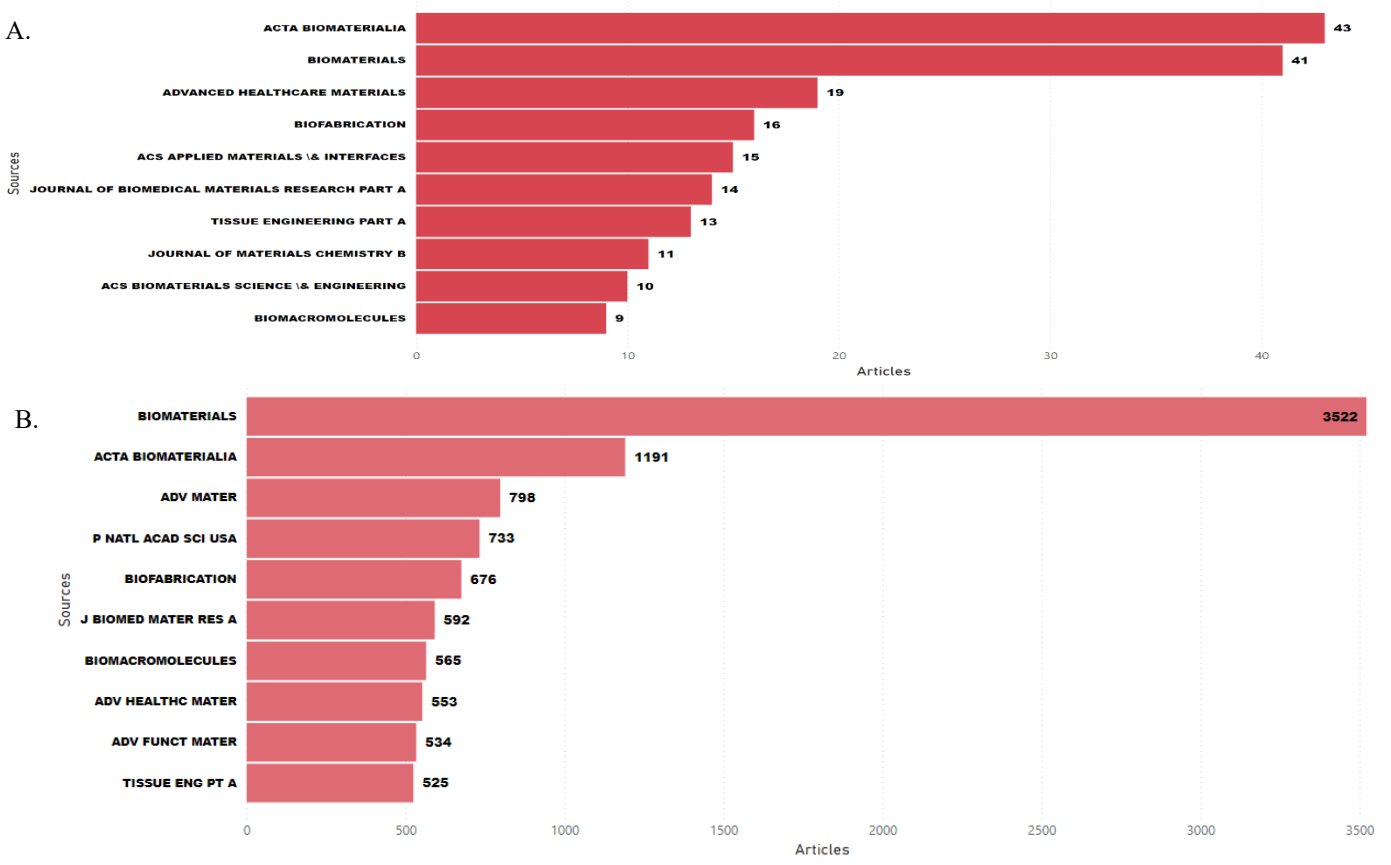
III. RESULTS & DISCUSSION

A. Sources

Trend analysis of literature identifies a steady increase in the rate of research articles on vascular network engineering, with significant growth being identified over the last decade. Among the major developments include advancements in hydrogel-based bioinks and progress in microvascular fabrication techniques. Publications of key contributions have been primarily in *ACTA Biomaterialia* and *Biomaterials*, which collectively account for 43 and 41 publications, respectively, making them the top two relevant journals.

According to citations, *Biomaterials* has the highest number of citations at 3,522, with *ACTA Biomaterialia* ranking second at 1,191 citations. Figure 1 represents the top ten most cited materials. With regard to impact, *Biomaterials* and *ACTA Biomaterialia* remain in the first rank as the most impactful journals with H-indices of 33 and 26, respectively, in Figure 1. H-index is a measure that rates both productivity (number of published papers) and impact (number of citations), i.e., a research unit has an H-index of x if it publishes x papers having at least x citations.

The findings indicate the quality and important research conducted by *ACTA Biomaterialia*, *Biomaterials*, and other high-ranking journals within the field. The journals serve as critical publications for scientists desiring to conduct research and significantly contribute within the field of vascular network engineering.



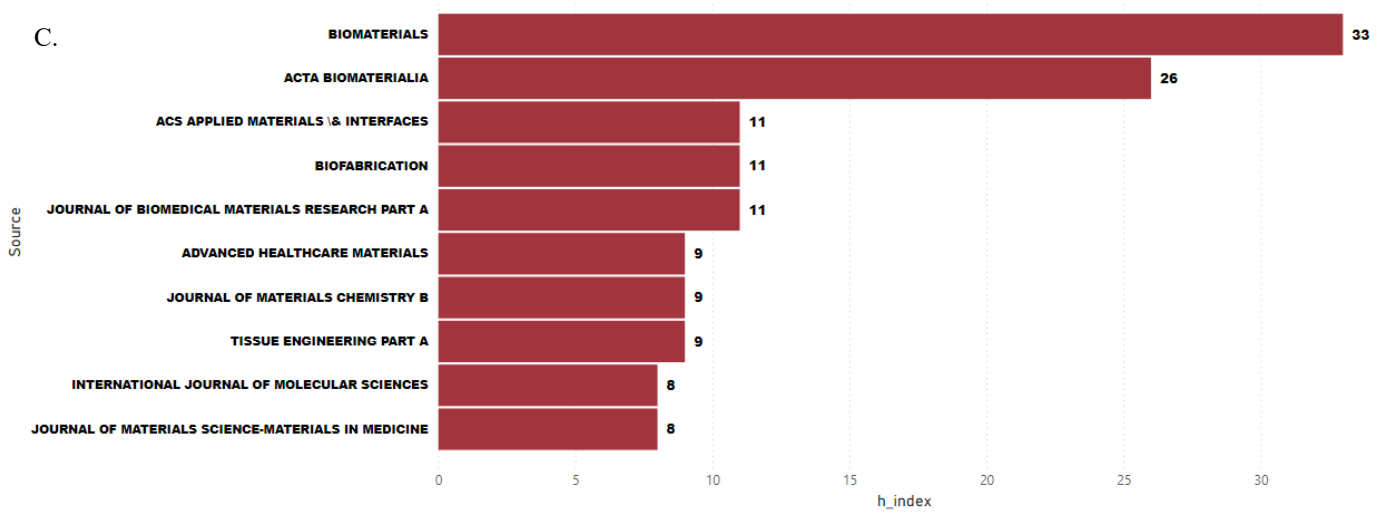


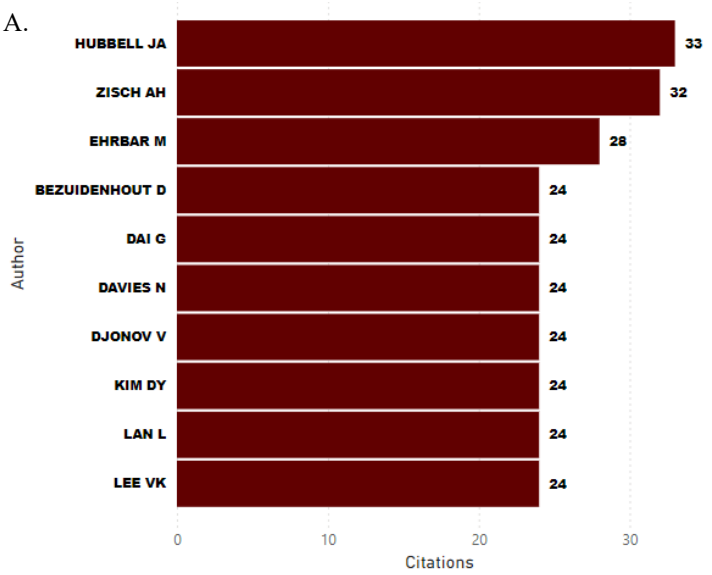
Figure 1: Bar chart of: A. Top 10 most relevant journal sources, B. Top 10 most cited journal sources, C. Top 10 impact by H-index journal sources.

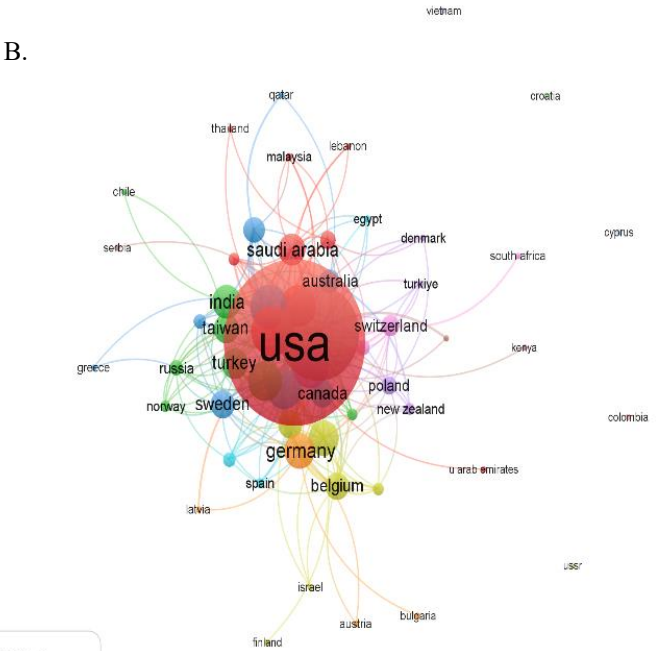
B. *Contributors & Affiliations*

The research enabled the identification of leading authors and institutions involved in vascular network engineering. The research revealed the leading authors and their institutions by analyzing the number of publications, citation rates, and productivity patterns over time. Wang X was the most productive author with the greatest productivity, having published 24 works, followed closely by Wang Y with 23 publications. However, even though Wang X and Wang Y have the greatest number of publications, Hubbell J.A. and Zisch A.H. are the most cited authors with 33 and 32 citations, respectively. Interestingly, Wang X and Wang Y are not included in the top ten most-cited authors (Figure 2). With institutions making notable strides in vascular network engineering research, Shanghai Jiao Tong University, the University of Michigan, and Johns Hopkins University lead with publication numbers of 57, 49, and 36, respectively (Figure 2). Collaborative networks highlighted the dominance of the USA and China, leading international cooperation in research on vascular network engineering. Both countries are also responsible for most research output via co-authorship analysis, whether multiple or single-country partnerships (Figure 2).

C. *Research Themes*

Extensive keyword co-occurrence analysis of the literature extracted frequently used words, namely "hydrogel," "biomaterials," "biofabrication techniques," and "wound healing" as the most frequently occurring words (Figure 3). Biomaterials and hydrogels appeared to be the most relevant words based on appearance in published work on vascular network engineering appearing in a total of 281 articles. This underscores the understanding and emphasis researchers agree on the need to get the right simulant material being the basis of recapitulating vascular tissue from which blood vessels and consequently vascular network can be created. Additionally, topics like "mechanical properties," "blood-vessel formation," and "material development" emerged as subject areas with growing academic concern (Figure 3). Upcoming research themes are biomimetic scaffold architectures and establishing quality control systems to benchmark and analyze fabricated constructs. However, there are still significant gaps, especially regarding the development of standard protocols for mechanical testing and printability tests, particularly in the context of 3D bioprinting methods.





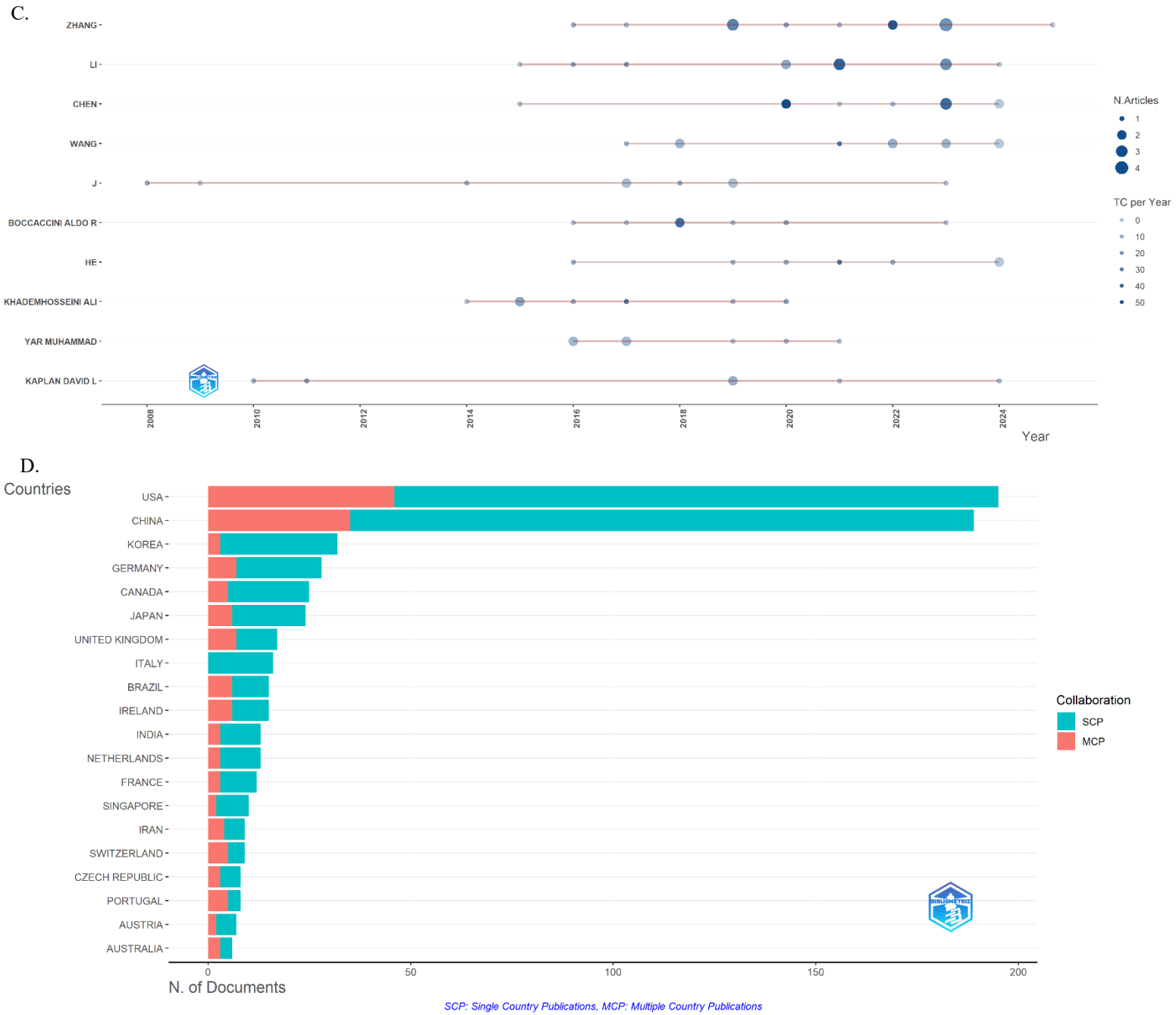
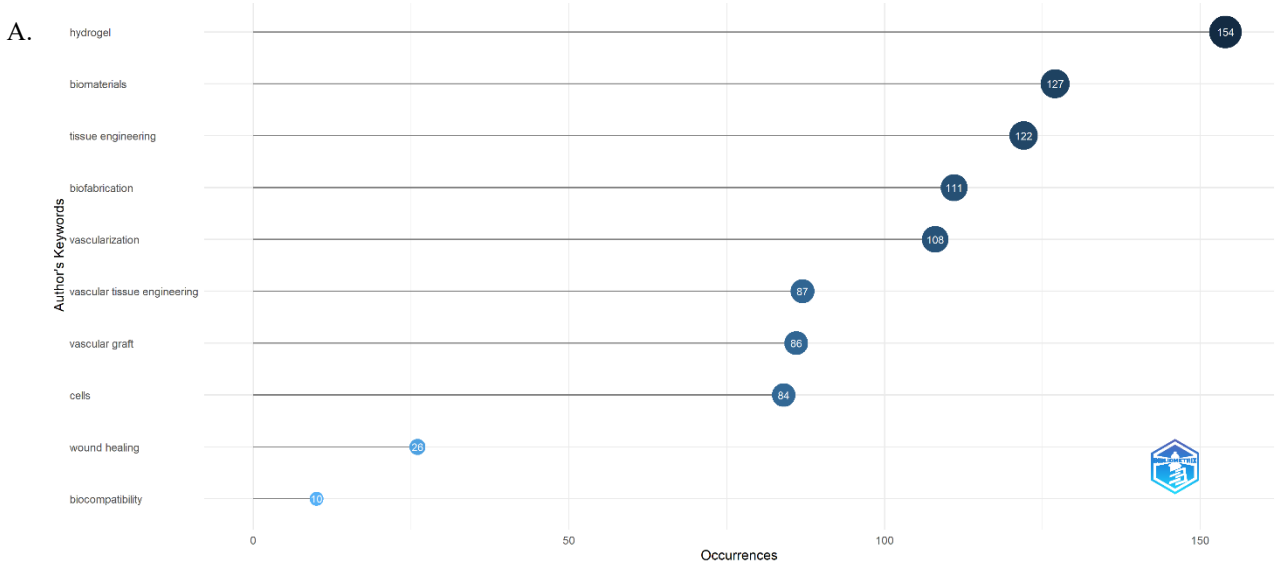


Figure 2: Graphical representations of: A. Most cited authors, B. Collaboration network across countries, C. Authors' production over time, D. Corresponding author's countries indicative of partnerships



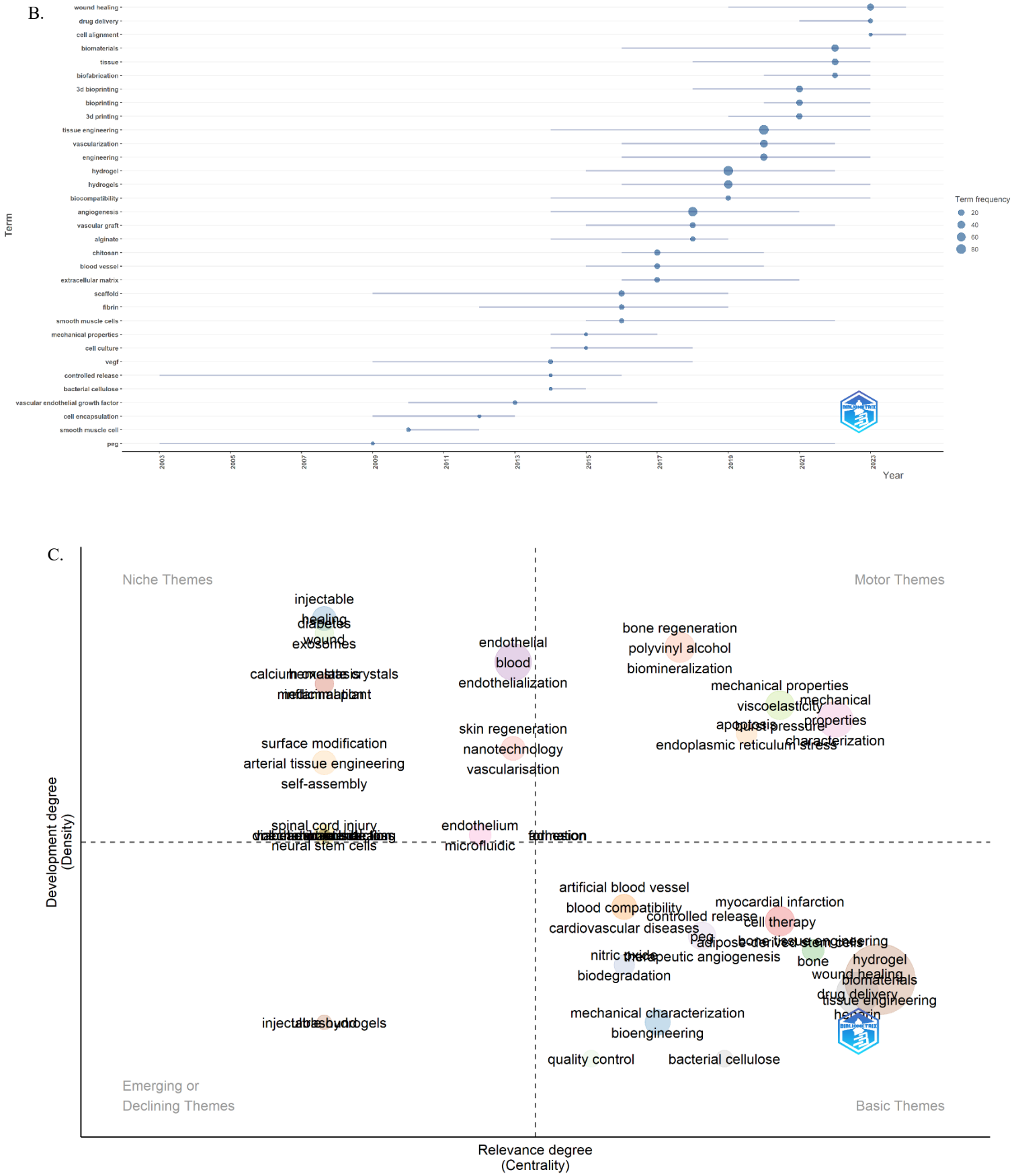


Figure 3: Keyword co-occurrence analysis showing: A. Most relevant keywords, B. Trending topics, C. Thematic diagram

IV. CONCLUSION

This bibliometric analysis presents a comprehensive overview of research trends and knowledge patterns in vascular network engineering. Much progress notwithstanding, standardization and interdisciplinarity are needed to transcend current limitations. Future work needs to be focused on the integration of sophisticated manufacturing techniques, the creation of advanced hydrogel formulations, and the use of rigorous quality control systems.

ACKNOWLEDGEMENT

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