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Bibliometric analysis of the cornerstone biomarker in clinical laboratories and emergency medicine: High-sensitivity cardiac troponin

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Abstract

High-sensitivity cardiac troponin (hs-cTn) assays have transformed the diagnosis and management of acute coronary syndromes (ACS) and have become central to modern emergency and laboratory medicine. Despite the rapidly expanding literature, no comprehensive bibliometric study has evaluated global publication patterns or Turkey's contribution to this field. This bibliometric analysis examined hs-cTn-related journal articles and reviews indexed in Scopus between 2010 and 2024. A structured search strategy using TITLE-ABS-KEY fields was applied, excluding non–high-sensitivity assays. After manual cleaning, deduplication, DOI verification, and consolidation of consensus documents, 4178 global records and 107 Turkey-affiliated publications were included. Bibliometric indicators (annual growth, citations, h- and g-index), keyword evolution, co-authorship, international collaboration, co-citation networks, and Bradford's Law journal distributions were analyzed using Bibliometrix (R) and VOSviewer. Global hs-cTn research demonstrated continuous expansion with a 10.5% annual growth rate and a total of 128,560 citations (mean 56.3 per article). The field showed strong international collaboration, led by the United States and Western Europe. Highly cited documents were dominated by major ESC and AHA/ACC guidelines and COVID-19–related studies. Keyword analyses revealed an evolution from ACS-focused diagnostic research to broader prognostic and translational themes. Turkey contributed 2.5% of global output, with publication activity increasing notably after 2018 and peaking in 2021. Turkey's research showed a regionally concentrated collaboration network and a narrower journal distribution. This study provides the first comprehensive bibliometric mapping of hs-cTn research, demonstrating rapid growth, strong guideline-driven influence, and expanding clinical breadth. Turkey contributes meaningfully but remains regionally concentrated. Future studies may benefit from strengthened international collaboration and broader dissemination channels.

Keywords: Acute coronary syndrome, artificial intelligence, bibliometric analysis, clinical laboratory, emergency medicine, high-sensitivity cardiac troponin

Introduction

The integration of high-sensitivity cardiac troponin (hs-cTn) testing into standard clinical laboratory practice for identifying acute coronary syndrome (ACS) has led to a significant paradigm shift in emergency medicine [1,2]. These new-generation assays, capable of detecting very low concentrations of cardiac injury markers at the nanogram level, accelerate the diagnostic process by identifying myocardial damage earlier in patients with chest pain in the emergency department. Consequently, hs-cTn contributes to lowering mortality and morbidity by allowing earlier recognition and management of myocardial infarction (MI), while its high negative predictive value supports the safe early discharge of patients at low risk [3].

Since the introduction of hs-cTn assays in the early 2010s, hs-cTn-focused research has expanded markedly, with numerous large-scale prospective studies on early diagnosis and rapid discharge [3-5]. While the European Society of Cardiology (ESC) included hs-cTn tests in its ACS guidelines as early as 2011, the United States (US) Food and Drug Administration (FDA) only approved the first hs-cTn test in 2017 and subsequently included it in the American Heart Association/American College of Cardiology (AHA/ACC) Guidelines [6].

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However, in Turkey the clinical uptake of hs-cTn assays has been relatively slow, impeded by delayed integration of updated guidelines and limited laboratory infrastructure, with some emergency departments still relying on older troponin tests [7]. Many clinicians initially lacked familiarity with interpreting hs-cTn results or were concerned about assay pitfalls (e.g., false-positive elevations), underscoring the need for greater physician education [8]. Additionally, health policy and resource constraints – including regulatory hurdles and reimbursement limitations – have further limited access to new diagnostic platforms, hindering the rapid national adoption and optimal clinical effectiveness of hs-cTn testing in Türkiye [9].

Bibliometric analysis is a method that quantitatively examine the number, development, and impact of scientific publications. These methods can reveal the growth of research in a field over the years, the most cited articles, prominent authors, active journals, and collaborations among researchers. This allows us to understand how the field is developing, which topics are being focused on, and what future research might be needed [10]. Beyond simply providing numbers and statistics, bibliometric analyses also guide clinical medicine. They help identify research priorities, highlight important studies that influence guidelines, and reveal knowledge gaps. They also provide clinicians and decision-makers with a strategic roadmap for evidence-based practice by translating large-scale research results into meaningful patterns. This allows for consistent monitoring of scientific progress and better aligns research with the needs of patient care [11].

To date, no comprehensive bibliometric analysis specifically addressing hs-cTn has been published. This study aimed to systematically evaluate the global literature on hs-cTn between 2010 and 2024 using bibliometric methods. Another objective was to analyze Turkey-affiliated publications as a subgroup to better understand the country's role and contribution within the international hs-cTn research landscape. In this way, we evaluated Turkey's contribution to scientific production in this field and discussed its relationship with global research trends.

Material and Methods

Data Source and Search Strategy

This bibliometric analysis evaluated the global literature on hs-cTn between 2010 and 2024. dataset covers 2010–2024 because full citation years are required. The year 2010 was chosen as the starting point because it marks the transition to the clinical implementation of commercial hs-cTn assays, including the Roche hs-cTnT [12] and Beckman Coulter Access hs-cTnI tests [13], as well as the publication of key early validation studies [14–17], developments that collectively define the modern hs-cTn era.

All bibliometric data for this study were collected and analyzed using the Scopus database (Elsevier), which is widely recognized for its comprehensive coverage of biomedical literature. The search was performed on November 2, 2025, using the Advanced Search interface and the TITLE-ABS-KEY fields. The query aimed to identify publications explicitly focused on hs-cTn between 2010 and 2024, while excluding studies involving conventional or older-generation assays.

The following Boolean query was applied in the Scopus Advanced Search interface: TITLE-ABS-KEY ("high sensitivity troponin" OR "high-sensitivity troponin" OR "hs troponin" OR "hs-cTn" OR "hsTn" OR "hs cTnT" OR "hs cTnI" OR "high sensitivity cardiac troponin" OR "high-sensitivity cardiac troponin") AND PUBYEAR > 2009 AND PUBYEAR < 2025 AND NOT TITLE-ABS-KEY ("conventional troponin" OR "standard troponin" OR "old generation" OR "cTn assay 4th generation" OR "3rd generation troponin" OR "contemporary troponin") AND (LIMIT-TO (LANGUAGE , "English")) AND (LIMIT-TO (DOCTYPE , "ar") OR LIMIT-TO (DOCTYPE , "re")) AND (LIMIT-TO (SUBJAREA , "MEDI") OR LIMIT-TO (SUBJAREA , "BIOC") OR LIMIT-TO (SUBJAREA , "MULT") OR LIMIT-TO (SUBJAREA , "PHAR") OR LIMIT-TO (SUBJAREA , "NURS") OR LIMIT-TO (SUBJAREA , "HEAL") OR LIMIT-TO (SUBJAREA , "IMMU") OR LIMIT-TO (SUBJAREA , "NEUR")) AND (LIMIT-TO (PUBSTAGE , "final")) AND (LIMIT-TO (SRCTYPE , "j")).

The search retrieved 4254 documents, limited to peer-reviewed journal articles and reviews written in English and published in final stage. Subject areas were restricted to medical and related disciplines, including Medicine, Biochemistry, Multidisciplinary, Pharmacology, Nursing, Health Professions, Immunology, and Neuroscience. To ensure reproducibility, all search parameters and export settings were predefined and documented.

To assess Turkey's national contribution, an additional Country/Territory filter in Scopus was applied by selecting Turkey/Türkiye. In Scopus, this filter is based on author affiliation metadata and includes all records with at least one author address from the selected country [18], corresponding to the full counting approach commonly used in bibliometric analyses. Using this filter, a total of 109 publications affiliated with Turkish institutions were identified.

Data Extraction

The bibliographic data retrieved from the Scopus database were initially exported in CSV format, including all available metadata fields (authors, affiliations, abstracts, keywords, source titles, citation counts, and DOIs). The dataset was manually cleaned in Microsoft Excel.

Duplicates were identified and removed based on the combination of DOI, title, and author fields. Additionally, co-published consensus papers (e.g., Fourth Universal Definition of Myocardial Infarction, 2018) that appeared in multiple journals with identical content were merged into a single representative record.

Records lacking a valid DOI were excluded to ensure accurate source tracing and citation tracking. While this may lead to

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the exclusion of a small number of older or regionally indexed publications, the proportion of such records in Scopus is minimal. Therefore, the potential impact on overall bibliometric trends is considered negligible.

Microsoft Excel (v2021) was used solely for data preprocessing and summary tabulations. After these steps, a total of 4178 unique publications were retained for the global bibliometric analysis, and 107 records were included in the Turkey-affiliated hs-cTn research subanalysis.

Bibliometric Data Processing and Analysis

After data curation, comprehensive bibliometric and network analyses were conducted to characterize both the global and Turkey-affiliated hs-cTn research landscapes. All analyses were carried out using Biblioshiny (Bibliometrix R package, version 5.0.0) and VOSviewer (version 1.6.20), and the resulting outputs were exported as tables and figures for visualization and reporting.

Descriptive indicators included annual scientific production, growth rate, total and average citation counts, and author-level metrics such as the h-index, g-index, and co-authorship index. The h-index (h) represents the number of papers (h) that have received at least h citations each, serving as a combined indicator of both productivity and citation impact. The g-index (g) is defined as the highest number (g) such that the top g publications collectively received at least g^2 citations, giving greater weight to highly cited papers and complementing the h-index in evaluating research influence. The co-authorship index quantifies the average level of collaboration among authors within the dataset. It is calculated as the total number of author appearances divided by the total number of publications, reflecting the mean number of co-authors per document. A higher value indicates a greater degree of collaborative research activity within the field.

The most cited global and Turkey-affiliated publications were identified, and their citation indicators were analyzed.The Total Citations (TC) represent the cumulative number of citations received by each publication, while TC per Year denotes the average number of citations per year since publication (TC divided by the number of years since publication). The Normalized Total Citations (NTC) were calculated as the ratio of each article's TC to the mean TC of all articles published in the same year, allowing comparison of citation impact across different publication years by accounting for temporal citation differences.

Journal-level evaluation was performed using Bradford's Law to identify core sources.

Keyword-based analyses comprised frequency distribution, word cloud visualization and keyword co-occurrence mapping. Keywords was restricted to authors' keywords. General terms (e.g., study, analysis, patient) were removed, and synonymous terms (e.g., hs-cTn, high-sensitivity cardiac troponin) were merged to minimize redundancy.

Network analyses included country collaboration, journal co-citation, and bibliographic coupling co-authorship (authors, countries, institutions),.

Both global and Turkey-affiliated hs-cTn research landscapes collaboration maps were generated to visualize international and regional research networks.

Ethical Approval

This study is a bibliometric analysis based exclusively on data retrieved from publicly accessible databases. No human participants, patient data, or biological materials were involved. Therefore, ethical approval and informed consent were not required.

Results

A total of 4,254 publications on hs-cTn were retrieved from the Scopus database for the period 2010–2024, authored by more than 670 researchers across 75 journals. The annual growth rate was 10.5%, with an average of 14.5 co-authors per document, indicating an expanding and collaborative field. The overall citation count reached 128,560, corresponding to an average of 56.3 citations per article, an h-index of 112, and a g-index of 149.

Publication Trends

The annual distribution of hs-cTn publications showed a consistent upward trajectory from 2010 to 2024, as illustrated in Figure 1A.

For Turkey-affiliated studies, a similar trend was observed (Figure 1B), with relatively few publications in the early 2010s and a notable increase after 2018, peaking around 2021.

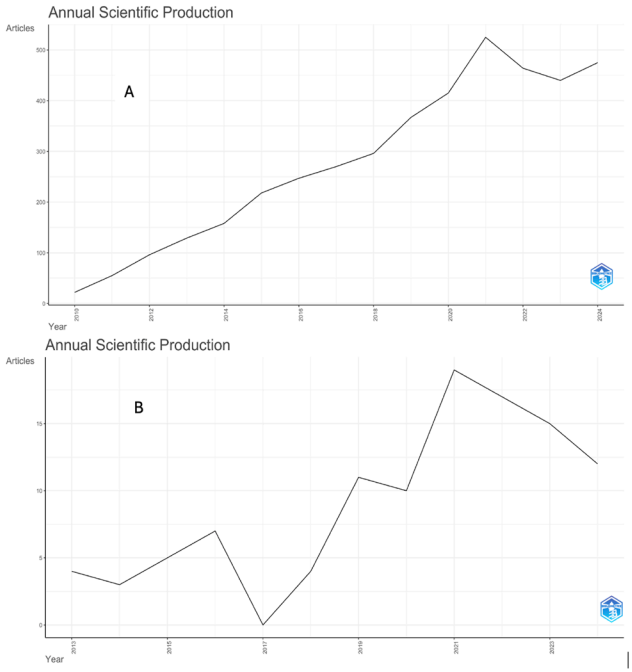

Figure 1. Annual scientific output on high-sensitivity cardiac troponin (2010–2024). A.Global. B. Turkey-affiliated Publications

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Most Cited Global Publications

The ten most globally cited papers are listed in Table 1. The most frequently cited publication was "Fourth Universal Definition of Myocardial Infarction" by Thygesen et al. (2018, Global Heart) with 8,334 citations, followed by "2015 ESC Guidelines for the Management of Acute Coronary Syndromes in patients presenting without persistent ST-segment elevation" by Roffi et al. (2016, European Heart Journal) and "2020 ESC Guidelines for the Management of Acute Coronary Syndromes" by Collet et al. (2021, European Heart Journal).

Table 1. The top ten most globally cited publications on high-sensitivity cardiac troponin (2010–2024) ranked by total and normalized citations

Paper	DOI	TC	TC per Year	NTC
THYGESEN, 2018, GLO HEART	10.1016/j.gheart.2018.08.004	8334	1041.75	134.48
ROFFI, 2016, EUR HEART J	10.1093/eurheartj/ehv320	5215	521.50	87.96
COLLET, 2021, EUR HEART J	10.1093/eurheartj/ehaa575	3973	794.60	162.93
SHI, 2020, JAMA CARDIOL	10.1001/jamacardio.2020.0950	3300	550.00	65.67
BYRNE, 2023, EUR HEART J	10.1093/eurheartj/ehad191	2767	922.33	209.77
PÜNTMANN, 2020, JAMA CARDIOL	10.1001/jamacardio.2020.3557	1718	286.33	34.19
ZHENG, 2020, J INFECT	10.1016/j.jinf.2020.04.021	1703	283.83	33.89
MADJID, 2020, JAMA CARDIOL	10.1001/jamacardio.2020.1286	1429	238.17	28.44
INCIARDI, 2020, JAMA CARDIOL	10.1001/jamacardio.2020.1096	1392	232.00	27.70
GUZIK, 2020, CARDIOVASC RES	10.1093/cvr/cvaa106	1101	183.50	21.91

TC: Total citation, NTC: Normalized Total Citation. Citation data were retrieved from Scopus on November 2, 2025

When normalized for publication year, the most influential papers were "2023 ESC Guidelines for the Management of Acute Coronary Syndromes" by Byrne et al., "2020 ESC Guidelines" by Collet et al., and "Association of Cardiac Injury With Mortality in Hospitalized Patients With COVID-19" by Shi et al. (2020, JAMA Cardiology).

Most Cited Turkey-Affiliated Publications

The ten most cited Turkey-affiliated studies are presented in Table 2. The leading publication was "2015 ESC Guidelines for the Management of Acute Coronary Syndromes in patients presenting without persistent ST-segment elevation" by Roffi et al. (2016, European Heart Journal), followed by "Delta Checks in the Clinical Laboratory" by Randell and Yenice (2019, Critical Reviews in Clinical Laboratory Sciences), and "Does Aspirin Use Prevent Acute Coronary Syndrome in Patients With Pneumonia?" by Öz et al. (2013, Coronary Artery Disease).

When adjusted for publication year, the top two rankings remained unchanged, while Barman et al. (2021), "Echocardiographic Features of Patients With COVID-19 Infection: A Cross-Sectional Study," emerged as the third most impactful Turkish contribution, representing one of the most recent high-impact studies in this field.

Table 2. Top ten most cited Turkey-affiliated publications on high-sensitivity cardiac troponin (2010–2024), ranked by total and normalized citation counts

Paper	DOI	TC	TC per Year	NTC
ROFFI, 2016, EUR HEART J	10.1093/eurheartj/ehv320	5215	52.50	6.93
RANDELL, 2019, CRIT REV CLIN LAB SCI	10.1080/10408363.2018.1540536	56	8.00	4.56
ÖZ, 2013, CORON ARTERY DIS	10.1097/MCA.0b013e32835d7610	46	3.54	2.97
BARMAN, 2021, INT J CARD IMAGING	10.1007/s10554-020-02051-9	41	8.20	4.14
DIAZ–GARZON, 2021, CLIN CHEM	10.1093/clinchem/hvaa261	35	7.00	3.54
CERIOTTI, 2020, CLIN CHEM LAB MED	10.1515/cclm-2019-1182	35	5.83	3.40
UÇAR, 2014, BLOOD PRESS	10.3109/08037051.2013.840429	26	2.17	1.73
GUCLU, 2016, CLIN BIOCHEM	10.1016/j.clinbiochem.2015.12.012	26	2.60	0.03
AKSU, 2015, CARDIOVAS J AFRI	10.5830/CVJA-2015-027	23	2.09	1.53
BARMAN, 2020, CORON ARTERY DIS	10.1097/MCA.0000000000000781	23	3.83	2.23

TC: Total citation, NTC: Normalized Total Citation. Citation data were retrieved from Scopus on November 2, 2025

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Keyword World Cloud Analysis

The word cloud visualization (Figure 2A) highlights the most frequent author keywords related to high-sensitivity cardiac troponin between 2010 and 2024. The most prominent terms were acute myocardial infarction, cardiac troponin, acute coronary syndrome, and biochemical marker, indicating that diagnostic applications in acute coronary events constituted the central research focus. Keywords such as prognosis, risk stratification, and heart failure suggest a growing interest in the prognostic and clinical utility of hs-cTn beyond acute diagnosis. The presence of terms like COVID-19 and mortality further reflects the expansion of research into emerging clinical contexts. In addition, among the author keywords, 'troponin T' appeared slightly more frequently than 'troponin I', although both occurred consistently across the dataset.

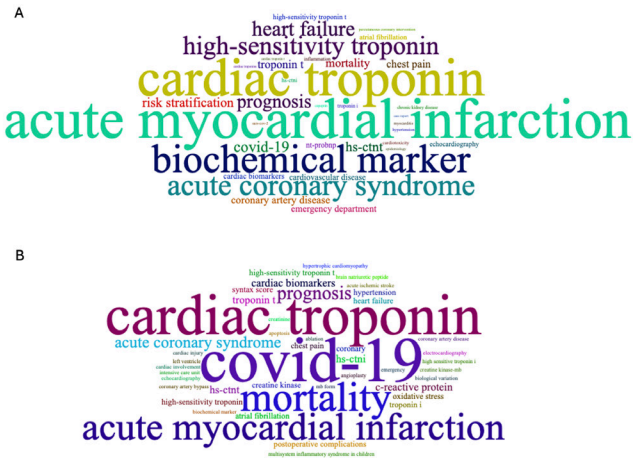

Figure 2. Word cloud visualization of the most frequent author keywords related to high-sensitivity cardiac troponin (2010–2024). A.Global. B. Turkey-affiliated Publications

The word cloud of Turkey-affiliated publications (Figure 2B) demonstrated that COVID-19, cardiac troponin, acute myocardial infarction, and mortality were the most frequent author keywords between 2010 and 2024. This pattern indicates that research activity in Turkey has been strongly influenced by the pandemic, with a particular emphasis on the prognostic and diagnostic roles of high-sensitivity troponin. Terms such as acute coronary syndrome, prognosis, and heart failure highlighted the clinical orientation of the field, whereas C-reactive protein, oxidative stress, and biochemical marker reflected the integration of laboratory and pathophysiological perspectives. Overall, the keyword structure suggests a translational focus connecting biochemical assessment with patient outcomes in cardiovascular disease.

Keyword Co-occurrence Analysis

As illustrated in Figure 3, the keyword co-occurrence network revealed four major thematic clusters. The blue cluster encompassed acute coronary syndrome, myocardial infarction, chest pain, emergency department, and high-sensitivity cardiac troponin. The green cluster included troponin, mortality, myocardial injury, myocarditis, cardiotoxicity, COVID-19, and SARS-CoV-2. The red cluster, containing prognosis, heart failure, atrial fibrillation, hypertension, diabetes, chronic kidney disease, risk assessment, NT-proBNP, and high-sensitivity cardiac troponin T/I. Finally, the yellow cluster, comprising coronary artery disease, troponin T, troponin I, and percutaneous coronary intervention. Overall, troponin occupied a central position connecting all clusters.

In Turkey-affiliated publications (n=107), the keyword co-occurrence analysis revealed fewer but thematically consistent clusters compared with the global dataset, predominantly centered on acute coronary syndrome, COVID-19, mortality, and troponin-related prognostic research. Supplementary analyses, including the Turkey-specific keyword co-occurrence network, are provided in Supplementary Figure S1 (see Supplementary Materials for details).

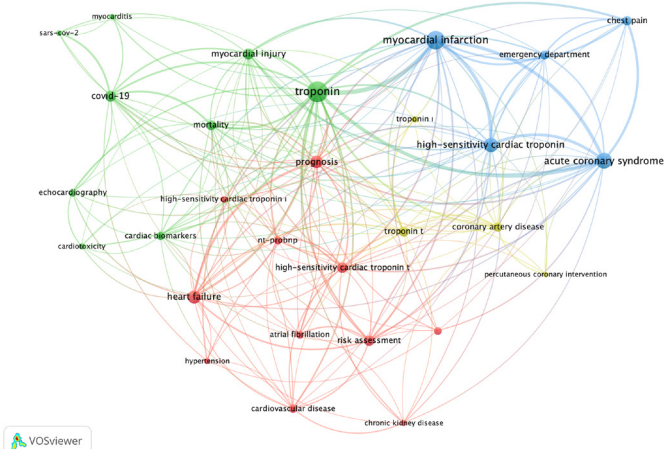

Figure 3. Keyword co-occurrence network of global publications on high-sensitivity cardiac troponin (minimum number of keyword occurrences = 50). Blue = acute coronary syndrome and diagnostic applications; Green = myocardial injury, COVID-19, myocarditis, and inflammatory mechanisms; Red = heart failure, prognosis, and comorbidities; Yellow = coronary artery disease and interventional cardiology topics

Journal and Source Analysis

As illustrated in Figure 4, the distribution of publications across journals followed Bradford's Law, indicating that a small number of journals accounted for the majority of the output in this field. The core zone consisted primarily of Clinical Chemistry, International Journal of Cardiology, Journal of the American Heart Association, Clinical Biochemistry, and Clinical Chemistry and Laboratory Medicine. These journals together represented the main publication channels for research on this topic.

The overall pattern revealed that Clinical Chemistry was the most productive source, followed by International Journal of Cardiology and Journal of the American Heart Association. A steep decline in article counts beyond the core zone suggested that the literature was highly concentrated within a few high-impact journals, reflecting the interdisciplinary nature of the field

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at the intersection of clinical chemistry and cardiology.

As shown in Figure 5, the distribution of Turkey-affiliated publications across journals revealed a narrower core compared to the global dataset. According to Bradford's Law, a limited number of journals accounted for the majority of publications, indicating a more concentrated dissemination pattern. The core zone included European Review for Medical and Pharmacological Sciences, Cardiology in the Young, Coronary Artery Disease, and International Journal of Medical Biochemistry, each contributing between four and six documents.

Other journals such as Acta Cardiologica, Acta Cardiologica Sinica, Arquivos Brasileiros de Cardiologia, Biomarkers in Medicine, and Cardiology Journal contributed smaller but notable portions of the total output. This distribution suggests that Turkish authors predominantly published in clinically oriented cardiology journals, with fewer contributions to broad laboratory and emergency medicine sources. Overall, the Turkish dataset demonstrated a more focused publication profile.

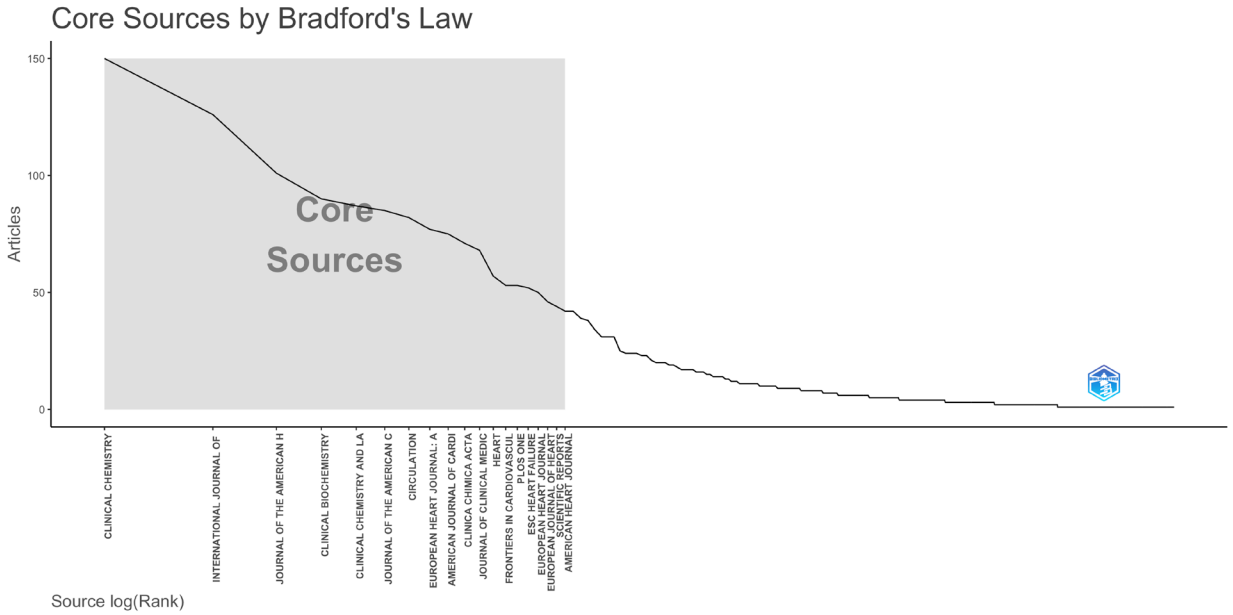

Figure 4. Core journals in high-sensitivity cardiac troponin research according to Bradford's Law. The plot illustrates the cumulative distribution of articles across journals, identifying the core zone (shaded area) that includes the most productive sources contributing to hs-cTn publications

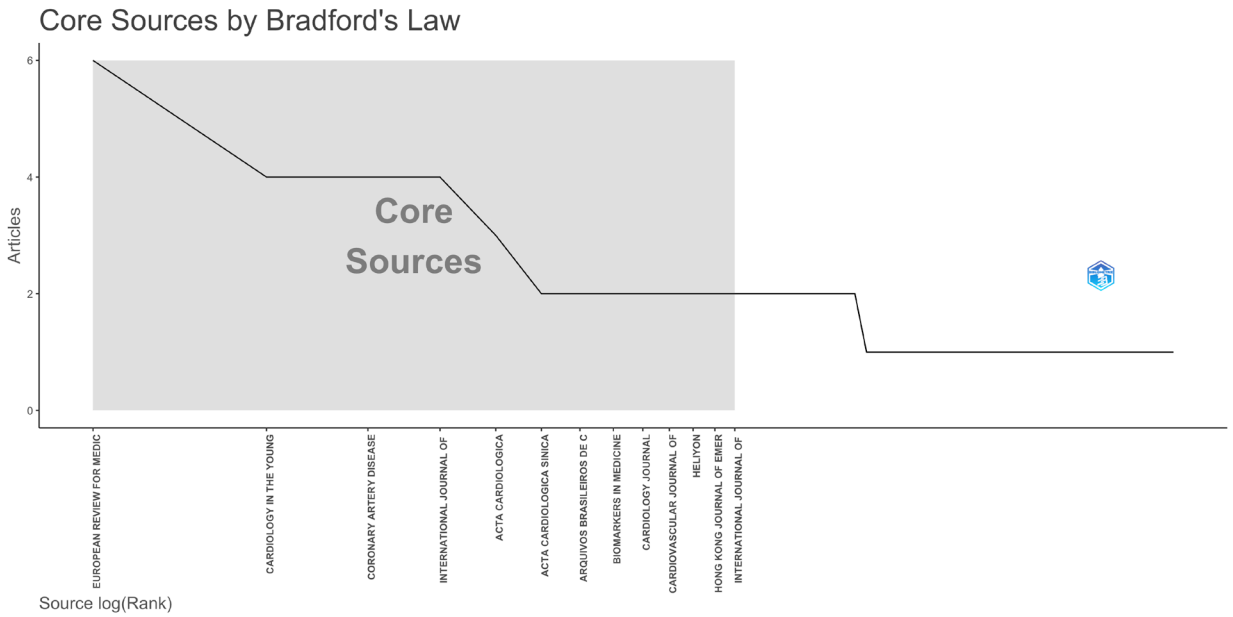

Figure 5. Core journals of Turkey-affiliated articles in high-sensitivity cardiac troponin research according to Bradford's Law. The plot illustrates the cumulative distribution of articles across journals, identifying the core zone (shaded area) that includes the most productive sources contributing to hs-cTn publications

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International Collaboration

As illustrated in Figure 6A, the United States (U.S.) appeared as the most prominent hub, shown in the darkest blue, with connections extending across nearly all continents. This finding indicates that the U.S. holds a central position in global scientific production and international research collaboration. Western European countries, including the United Kingdom, Germany, France, the Netherlands, and Italy, also exhibited dense interconnections. This pattern reflects both the strength of intra-European research networks and their close collaborative ties with the U.S. In East Asia, countries such as China, Japan, South Korea, and Australia showed strong mutual connections as well as significant collaborations with Western research centers. Notably, China demonstrated extensive links with both Europe and the United States, highlighting its growing influence in the global research network.

As shown in Figure 6B, Turkey appeared as a regional hub with strong collaborative ties primarily directed toward Western Europe, particularly Germany, the United Kingdom, France, and Italy. A smaller number of links extended toward the United States, while collaborations with Asian or Oceanian countries remained limited. This pattern suggests that Turkey maintains an active but regionally concentrated position within the global research network.

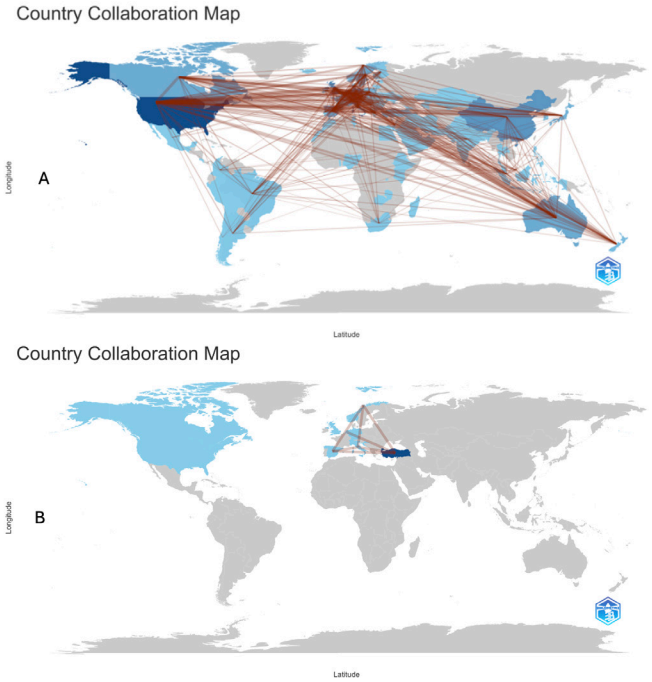

Figure 6. Country collaboration network in high-sensitivity cardiac troponin research (2010–2024). A.Global. B. Turkey-affiliated Publications

Co-citation and Bibliographic Coupling

The journal co-citation network (Figure 7A) revealed three major clusters. The red cluster, dominated by Journal of the American College of Cardiology, Circulation, and European Heart Journal, represented the clinical cardiology core of the field. The green cluster comprised specialized cardiovascular and internal medicine journals such as American Heart Journal and European Journal of Heart Failure, reflecting focused sub-disciplines. The blue cluster, including Clinical Chemistry and Clinica Chimica Acta, indicated the analytical and laboratory medicine dimension. These interlinked clusters highlight the translational nature of the field, bridging laboratory diagnostics with clinical cardiology research.

The journal co-citation network of the Turkey-affiliated dataset (Figure 7B) exhibited a simplified but similar structure to the global network, consisting of three main clusters. The red cluster, including Circulation, The Lancet, JAMA, and New England Journal of Medicine, represented the clinical cardiology and general medicine core. The blue cluster, dominated by Clinical Chemistry and European Heart Journal, reflected the analytical and laboratory dimension closely linked to clinical cardiology. The green cluster comprised American cardiology journals such as American Heart Journal, American Journal of Cardiology, and Heart, indicating the influence of U.S.-based cardiovascular literature. Overall, this pattern highlights that Turkish publications are primarily anchored in Western, high-impact cardiology and laboratory journals, maintaining strong translational links between analytical and clinical research domains.

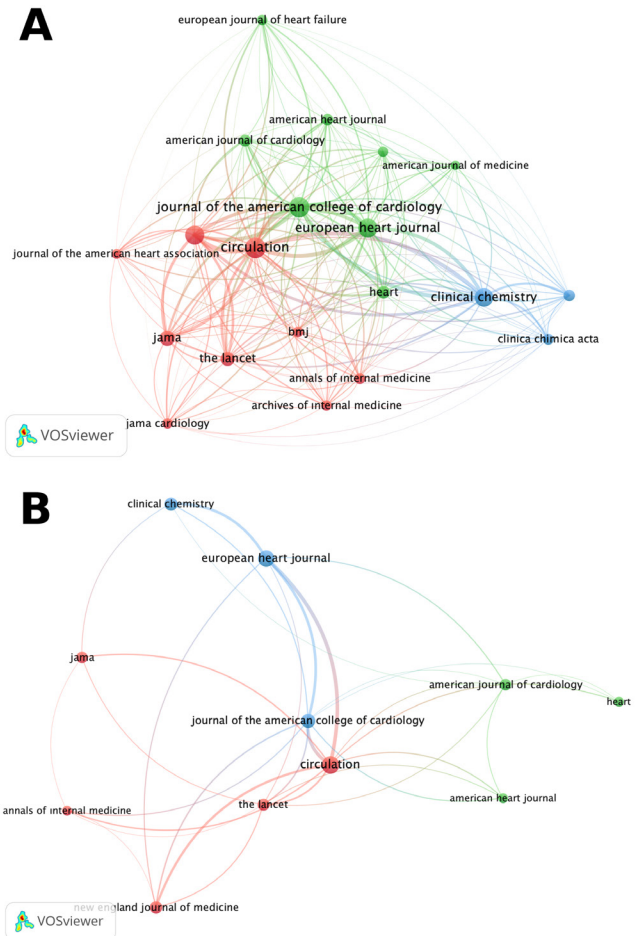

Figure 7. Journal co-citation map. A. Global based on fractional counting (only sources with ≥100 co-citations included). B. Turkey-affiliated publications based on full counting (sources cited at least 5 times)

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Authorship and Institutional Productivity

The co-authorship network analysis identified several geographically and thematically distinct collaboration clusters (Figure 8A). The blue cluster is dominated by U.S.-based clinical researchers (Ballantyne CM, Selvin E, De Lemos JA, Defilippi CR, Christenson RH, Januzzi JL) focusing on clinical validation and population-based performance studies.

The red cluster includes European and IFCC-affiliated investigators (Apple FS, Jaffe AS, Sandoval YB, Omland T, Lindahl B, Blankenberg SS, Mills NL, Cullen LA, Kavsak PA) primarily engaged in assay standardization and diagnostic threshold determination.

The green cluster represents the Basel research group (Mueller C, Boeddinghaus J, Wildi KS, Reichlin TR, Twerenbold R, Rubini Giménez M), recognized for pioneering early rule-out and emergency department algorithms.

Finally, the yellow nodes (Katus HA, Giannitsis E) signify assay development pioneers and contributors to the analytical foundation of hs-cTn testing.

Overall, the network demonstrates a highly interconnected global research ecosystem, where key figures such as Jaffe AS, Mueller C, and Januzzi JL act as central connectors bridging multiple scientific clusters.

The co-authorship network of Turkey-affiliated publications (Figure 8B) revealed several locally connected clusters, indicating active but regionally concentrated collaborations among national researchers. Although multiple groups showed strong internal links, the overall network density was lower than that observed in the global map, suggesting that international collaborations remain relatively limited.

Table 3 summarizes the most productive authors and institutions contributing to hs-cTn research in Turkey between 2010 and 2024. The leading contributor was Atici A. (n=9), followed by Barman H.A. (n=8) and Gungor B. (n=6). The most active institutions were the Department of Cardiology, University of Health Sciences, Istanbul (n=19); the Department of Cardiology, Istanbul Medeniyet University (n=7); and the Department of Emergency Medicine, University of Health Sciences (n=7).

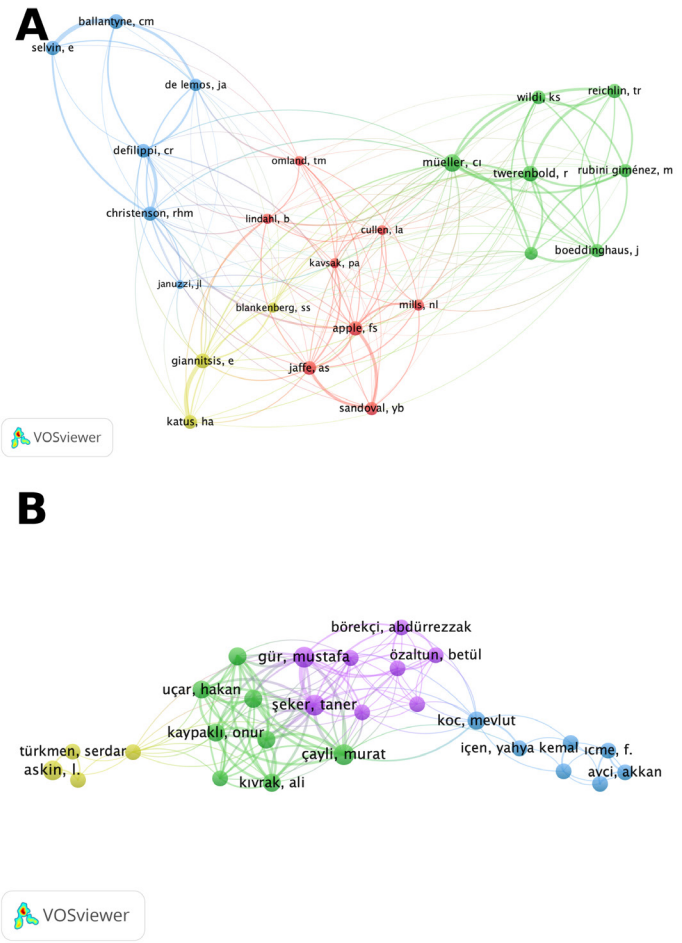

Figure 8. Co-authorship network of leading researchers in high-sensitivity cardiac troponin studies. A. Global (fractional counting, ignore documents with a large number of authors=25, minimum number of documents of author=50). B. Turkey-affiliated publications (full counting; minimum number of documents per author = 2).

Table 3. Top 10 Most-cited documents in the irisin–cardiovascular corpus (Threshold ≥10 Citations; Largest Connected Set=234 Items)

Rank	Author	N	Rank	Institution (Affiliation)	N
1	Atici A.	9	1	Department of Cardiology, University of Health Sciences, Istanbul, Turkey	19
2	Barman H.A.	8	2	Department of Cardiology, Istanbul Medeniyet University, Istanbul, Turkey	7
3	Gungor B.	6	3	Department of Emergency Medicine, University of Health Sciences, Istanbul, Turkey	7
4	Alici G.	5	4	Department of Cardiology, Adana Numune Training and Research Hospital, Adana, Turkey	6
5	Sahin I.	5	5	Department of Cardiology, Istanbul University-Cerrahpasa Faculty of Medicine, Istanbul, Turkey	6
6	Gur M.	5	6	Department of Internal Medicine, University of Health Sciences, Istanbul, Turkey	5
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Discussion

The bibliometric analysis clearly demonstrates that research on hs-cTn exhibited steady growth between 2010 and 2024. The increasing number of publications worldwide each year suggests that the field has not yet reached saturation. Indeed, a related bibliometric study also noted that "the number and trend of publications on this topic indicate that the research has not yet reached the maturity phase" [19]. The annual growth rate of 10.5% identified in our analysis supports the conclusion that hs-cTn is a dynamic and expanding research domain. The acceleration of publication volume after 2017 (coinciding with FDA approval of the first hs-cTn test in the U.S. [6]) likely reflects the global adoption of hs-cTn in clinical practice. Turkey-affiliated publications also increased notably after 2018, peaking around 2021. This trend aligns with the broader integration of hs-cTn into clinical workflows and the heightened research activity prompted by the COVID-19 pandemic [20].

Citation analysis indicates that the global hs-cTn literature has received 128,560 citations, with an average of ~56 citations per article. The h-index of 112 suggests that at least 112 papers have each received 112 or more citations, underscoring the central role of numerous studies in shaping the field. Among the most highly cited publications are consensus documents and international guidelines, including the 2018 Universal Definition of Myocardial Infarction [21] and ESC guidelines for ACS management from 2015 and 2020 [22, 23]. These results reinforce the fact that hs-cTn has become a cornerstone biomarker in clinical guidelines. Indeed, troponin testing has fundamentally redefined the criteria for myocardial infarction, as emphasized in the literature [21]. The elevated normalized citation impact of recent sources such as Byrne et al.'s 2023 ESC guideline [24] also reflects the rapid uptake of contemporary developments. In addition, the highly cited 2020 study by Shi et al. [25], which examined the association between hs-cTn and mortality in COVID-19 patients, highlights the biomarker's relevance during emergent global health crises. This finding demonstrates that hs-cTn research is not limited to classical cardiac syndromes but adapts swiftly to evolving clinical priorities.

Keyword trend analysis offers insights into the primary thematic foci of hs-cTn research and their evolution over time. The predominance of keywords such as "acute myocardial infarction," "cardiac troponin," and "acute coronary syndrome" confirms that early studies concentrated on the diagnostic use of hs-cTn in acute settings. This aligns with its critical role in the early identification of myocardial infarction in emergency departments. However, increasing occurrences of terms like "prognosis," "risk stratification," and "heart failure" indicate an expanded focus on non-acute and longitudinal applications. The literature has established that troponin testing holds prognostic value in chronic conditions such as heart failure and stable ischemic heart disease [26]. This trend reflects a growing emphasis on hs-cTn as a tool not only for diagnosis but also for long-term risk prediction and chronic disease management. The emergence of keywords like "COVID-19" and "mortality" after 2020 further illustrates the pandemic's significant influence on hs-cTn research. Likewise, in Turkey-affiliated publications, COVID-19, cardiac troponin, acute myocardial infarction, and mortality were the most frequent keywords, indicating the local research community's alignment with global priorities during the pandemic. Overall, the keyword patterns suggest that hs-cTn studies increasingly serve as a translational bridge between biochemical assays and clinical outcomes. This denotes an intention to integrate laboratory-derived metrics with patient-centered care strategies.

Among the author keywords, 'hs-troponin T' appeared slightly more frequently than 'hs-troponin I'. There are several reasons why the term hs-cTn T is more frequently used in the literature. From a historical and industrial perspective, the first hs-cTn test was hs-troponin T, developed by Roche, which entered clinical use before hs-troponin I and has been widely adopted worldwide [27]. Analytically, the fact that troponin T assays come from a single manufacturer and are calibrated against a single reference standard has led researchers to favor hs-troponin T for consistent results. However, hs-troponin I is measured using different methods from various manufacturers, which can lead to discrepancies in results [28]. From a clinical perspective, early studies and guidelines predominantly used hs-troponin T because it was available, contributing to the increased use of hs-troponin T as a keyword in scientific publications [29]. Additionally, Roche's early launch and widespread promotion of the hs-Troponin T test may have led to more frequent emphasis on this biomarker in research [27].

An analysis of source journals reveals the interdisciplinary nature of the hs-cTn literature and country-level differences in publication venues. Globally, the distribution of hs-cTn publications follows Bradford's Law, with a small number of journals accounting for the majority of the literature. The core sources include Clinical Chemistry, International Journal of Cardiology, Journal of the American Heart Association, Clinical Biochemistry, and Clinical Chemistry and Laboratory Medicine. These journals have hosted most of the field's influential research. Notably, Clinical Chemistry stands out as the most prolific outlet, followed by cardiology-focused journals such as Int. J. Cardiology and JAHA. The sharp decline in article counts beyond the core group confirms a concentration of research dissemination within a limited set of high-impact journals. This reflects the interdisciplinary character of hs-cTn research, situated at the intersection of clinical chemistry and cardiology. The simultaneous prominence of both laboratory medicine and cardiology journals as core outlets reinforces hs-cTn's dual identity.

In contrast, Turkey-affiliated publications exhibit a narrower distribution, with a limited core group of journals. Most studies originating from Turkey were published in European Review for Medical and Pharmacological Sciences, Cardiology in the Young, Coronary Artery Disease, and International Journal of Medical

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Biochemistry. Each of these journals contributed between four and six publications to the corpus. This pattern reflects a relatively focused publication profile, with Turkish researchers publishing primarily in clinical cardiology journals and less frequently in broad laboratory medicine or emergency care sources. It suggests a predominant emphasis on applied clinical topics in Turkey's hs-cTn literature. The underrepresentation of Turkish studies in high-impact international journals (e.g., Clinical Chemistry) may be attributed to competitive barriers or limited access to global networks. Overall, Turkey-affiliated publications contribute meaningfully to the literature but exhibit a more localized and selective dissemination profile.

Analysis of international collaboration networks underscores the role of inter-country interactions in shaping hs-cTn research. As expected, the United States emerged as the most central node, with extensive collaborative ties across all continents. Western European countries (e.g., United Kingdom, Germany, France, Netherlands, Italy) formed dense regional clusters while maintaining strong links with the U.S. In East Asia, China, Japan, South Korea, and Australia demonstrated substantial interconnectivity and active collaboration with Western research hubs. Notably, China has built expansive partnerships with both Europe and the U.S., reflecting its growing influence in cardiovascular research [19]. This confirms that the global hs-cTn research network is anchored in traditional scientific powerhouses (North America, Western Europe), while emerging contributors such as China are expanding their footprint. Indeed, bibliometric studies have identified China, the U.S., and the U.K. as among the most prolific nations in troponin-related research [19].

In this context, Turkey maintains a regionally focused profile. Positioned as a secondary hub, Turkey's strongest collaborative ties are directed toward Western Europe—especially Germany, the U.K., France, and Italy. While a number of co-authorships with the U.S. were observed, collaborative links with Asian and Oceanian countries remain limited. This suggests that Turkey plays an active yet geographically concentrated role in the global hs-cTn research ecosystem. The limited breadth of international partnerships may restrict the global reach of Turkey-affiliated studies. Indeed, a 2011 study from the U.S. demonstrated that internationally co-authored articles received 1.36 times more citations than those authored solely by domestic teams [30]. In this context, the predominantly national collaboration pattern of Turkey-affiliated publications may reduce their international visibility and citation impact. Nevertheless, Turkey's strong integration with Western Europe demonstrates that it contributes meaningfully to regional scientific networks. Expanding participation in EU framework programs and multinational consortia could support deeper global integration.

Turkey's contribution to total scientific output is modest but meaningful. Between 2010 and 2024, 107 Turkey-affiliated publications were identified, representing approximately 2.5% of global hs-cTn research. While this places Turkey outside the top-tier contributors by volume, the recent upward trend in publication activity suggests increasing visibility. In particular, Turkish publications surged during the 2020s. Analysis also reveals that a limited number of institutions and research groups account for a majority of Turkey's contributions. Leading centers include cardiology and emergency medicine departments at the University of Health Sciences in Istanbul and Istanbul Medeniyet University. This indicates that a handful of academic institutions are spearheading national hs-cTn research. Broader engagement from other centers could enhance both the volume and diversity of Turkey's contributions.

Conclusion

In conclusion, this bibliometric analysis confirms that hs-cTn research has undergone continuous and rapid expansion over the past 15 years and now occupies a central role in the scientific literature. Highly cited guideline documents and robust international collaboration networks validate hs-cTn's critical function in clinical laboratory and emergency medicine. Keyword and source journal analyses suggest a thematic evolution from acute diagnostic use to prognostic and translational applications, underscoring the interdisciplinary and clinical breadth of the field. In the Turkish context, a growing research interest is evident, and the country contributes actively to the literature through regional collaborations. Nonetheless, limited international integration remains a challenge. The findings suggest that both global and national hs-cTn research will continue to grow in volume, impact, and clinical relevance in the coming years.

This study's strengths include its large, well-curated dataset and comprehensive multi-platform bibliometric methodology, while its main limitations are the reliance on a single database (Scopus) and the restriction to English-language publications, which may have led to the exclusion of relevant non-indexed or non-English studies. In addition, the study is subject to other common limitations of bibliometric analyses, such as potential author name ambiguity due to inconsistent citation formats, distortion from self-citations or citation inflation, and bias introduced by changes in journal indexing or classification over time. Although efforts were made to clean and merge keywords, variability in terminology may have influenced the structure of keyword co-occurrence and trend analyses. These factors should be considered when interpreting the findings.

Conflict of Interests
The authors declare that there is no conflict of interest in the study.

Financial Disclosure
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Ethical Approval
This study is a bibliometric analysis based exclusively on data retrieved from publicly accessible databases. No human participants, patient data, or biological materials were involved. Therefore, ethical approval and informed consent were not required.

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