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ORIGINAL RESEARCH

Sex Differences in Cardiovascular Research: A Scientometric Analysis

Dominic Millenaar, MD; Markus Dillmann, MSc; Tobias Fehlmann, MSc; Alexander Flohr, MSc; Roxana Mehran, MD; Rasha Al-Lamee, MD; Lucas Lauder, MD; Christian Ukena, MD; Michael Böhm, MD; Andreas Keller, PhD; Felix Mahfoud, MD

BACKGROUND: We sought to investigate sex-specific differences in authorship of cardiovascular research over the past decade.

METHODS AND RESULTS: All 387 463 cardiovascular publications between 2010 and 2019 were retrieved from Web of Science. Articles increased from 19 960 to 29 604 articles per year (*P*>0.001). The number of articles written by female first authors increased by 76.3% (6434–11 343 articles) and by 35.0% for male first authors (13 526–18 261) (*P*<0.001). The first author was more likely to be a female author in articles with female last authors. The median impact factor (IF) for articles by female first authors was lower (2.46 [interquartile range, 7 1.11–4.03] versus 2.51 [interquartile range, 1.17–4.10]; *P*<0.001). Female authorship articles reached the highest IF in North America (average IF, 3.7), with the lowest in Africa (average IF, 1.8).

CONCLUSIONS: Publications in cardiovascular research have increased over the past decade, particularly by female authors. Female researchers are cited less often compared with their male peers. The IF remains lower for articles by female researchers.

Key Words: cardiovascular ■ citation analysis ■ gender ■ research ■ sex

See Editorial by Petito and Smith

Despite an increasing number of women in medical schools and medical training, women remain underrepresented in scientific publications, as investigators in cardiovascular clinical trials, and on editorial boards of scientific journals in cardiovascular medicine.[1,2] Concurrently, women are less likely to win high-status research awards[3] and have lower chances for grant funding, which may in part be explained by disparities in academic ranking between women and men.[4] This difference between female and male authors, often referred to as a "gender gap,"[5] can also be noticed when analyzing women as cardiovascular medicine trainees.[6] Among all adult cardiology trainees in the United States in 2017 to 2018, only 21.4% were women.[6] In interventional cardiology, only 10.2% were women, which is the lowest fraction of women across all medical training specialties.[6] A similar distribution can be found in other countries, such as Australia and New Zealand, with only 15% female practicing physicians in cardiology and 5% in interventional cardiology.[7] In contrast, the total number of women and men enrolled in medical schools in the United States in 2019/2020 was 46 878 and 45 855, respectively, without significant sex differences among graduates (9557 versus 10 381).[8] In some countries, such as Germany, the number of female medical students exceeds the number of male students (62% versus 38%).[9]

Recent analyses suggested an increase in research output in the past decades in high-impact journals in general medicine[10] and cardiology[11] by female physician-scientists. However, a comprehensive analysis investigating gender differences in cardiovascular research across various topics and journals is lacking. Authorship of academic literature remains an essential metric determining career advancement opportunities, realizing research grants, or participating in competitive

Correspondence to: Dominic Millenaar, MD, Department of Internal Medicine III, Cardiology, Angiology, Intensive Care Medicine, Saarland University Hospital, Kirrberger Strasse 1, IMED, Building 41, 66421 Homburg, Saar, Germany. E-mail: dominic.millenaar@uks.eu

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CLINICAL PERSPECTIVE

What Is New?

- This scientometric analysis demonstrates an increase of all cardiovascular research articles between 2010 and 2019 worldwide.
- This increase was proportionally higher for female authors.
- However, a small yet consistent gap remains for the difference in research quality and quantity between female and male authors.

What Are the Clinical Implications?

- The relatively higher increase in scientific output by female authors should encourage further expansion and support of mentoring programs for female physician-scientists.

Nonstandard Abbreviations and Acronyms

H-Index	Hirsch Index
IF	impact factor
WoS	Web-of-Science Core Collection

training programs.[12] Against this background, the present study aims to investigate all cardiovascular research articles of the past decade (from 2010 to 2019) with regard to sex differences in authorship, the geographical origin of publication, and publication quality.

METHODS

The data that support the findings of this study are available from the corresponding author on reasonable request.

Data Search

All cardiovascular original research articles were identified between 2010 and 2019 from the Web-of-Science Core Collection (WoS). A comprehensive search term was used as mentioned elsewhere,[13] with no restrictions to language, type of journal, or country of publication. The search was performed in the WoS as a title search, considering all publications categorized as "articles." Most of these were original articles, and review articles and editorials were not included. The entire WoS database was searched without any restrictions or specifications on the thematic orientation of a journal. In total, 387 463 articles were analyzed, each containing 18 items (publication date, institute, country, continent, number of citations, number of total authors, as well as given and surname, sex, country, continent, and Hirsch Index [H-Index] of both first and last author), adding up to a total of 6 974 334 analyzed items. Other databases, such as Medline, were cross-checked to reduce the risk of missing articles. Subsequent screening of all selected articles by 2 independent investigators (D.M. and A.K.) led to a post hoc sampling, as depicted in Figure 1. In case of disagreement, a third investigator was consulted (F.M.). Accordingly, the total number of 257 940 articles was analyzed.

Data Acquisition and Sex Analysis

Data were extracted from WoS, including all underlying meta-data, and analyzed using the Science Performance Evaluation web application (Saarland University, Saarbrücken, Germany), as described elsewhere.[14,15] In brief, extracted data from WoS were analyzed by Science Performance Evaluation using multiple scientometric analyses on preselected input data, specified by the user beforehand. The Science Performance Evaluation platform was created using the framework "Django" (https://www.djangoproject.com/) as an open-source web development tool. Several other open-source packages were applied to expand and customize Science Performance Evaluation, such as the python library SexMachine (https://pypi.org/project/SexMachine/) for all sex analyses. Herein, authors are categorized into women, men, or unknown according to their given names. As this analysis was based on self-reported information by the researchers, according to the Sex and Gender Equities in Research guidelines,[16] we analyzed information of the researchers' sex, rather than their gender, which would take social and behavioral factors into account, which were not considered.[17] For direct comparison analyses, only female and male authors were considered. As the WoS meta-data contain only initials instead of full first names before 2005, the search period was restricted to the past decade (2010–2019).

Data analysis on journal impact factors (IFs) was obtained from the Journal Citation Reports by Clarivate Analytics from each separate year of all publications.[18] In the case of shared authorship, only the primary author and his or her affiliation were analyzed for technical reasons.

H-Index

The H-Index is an index to characterize the scientific output of a researcher.[19] It is defined as the number of publications *h* by a researcher that have each been cited at least *h* times. Originally, the H-Index was described to measure one author's scientific work; however, it can also be used in a modified way to assess the research quality of institutes, regions, or countries

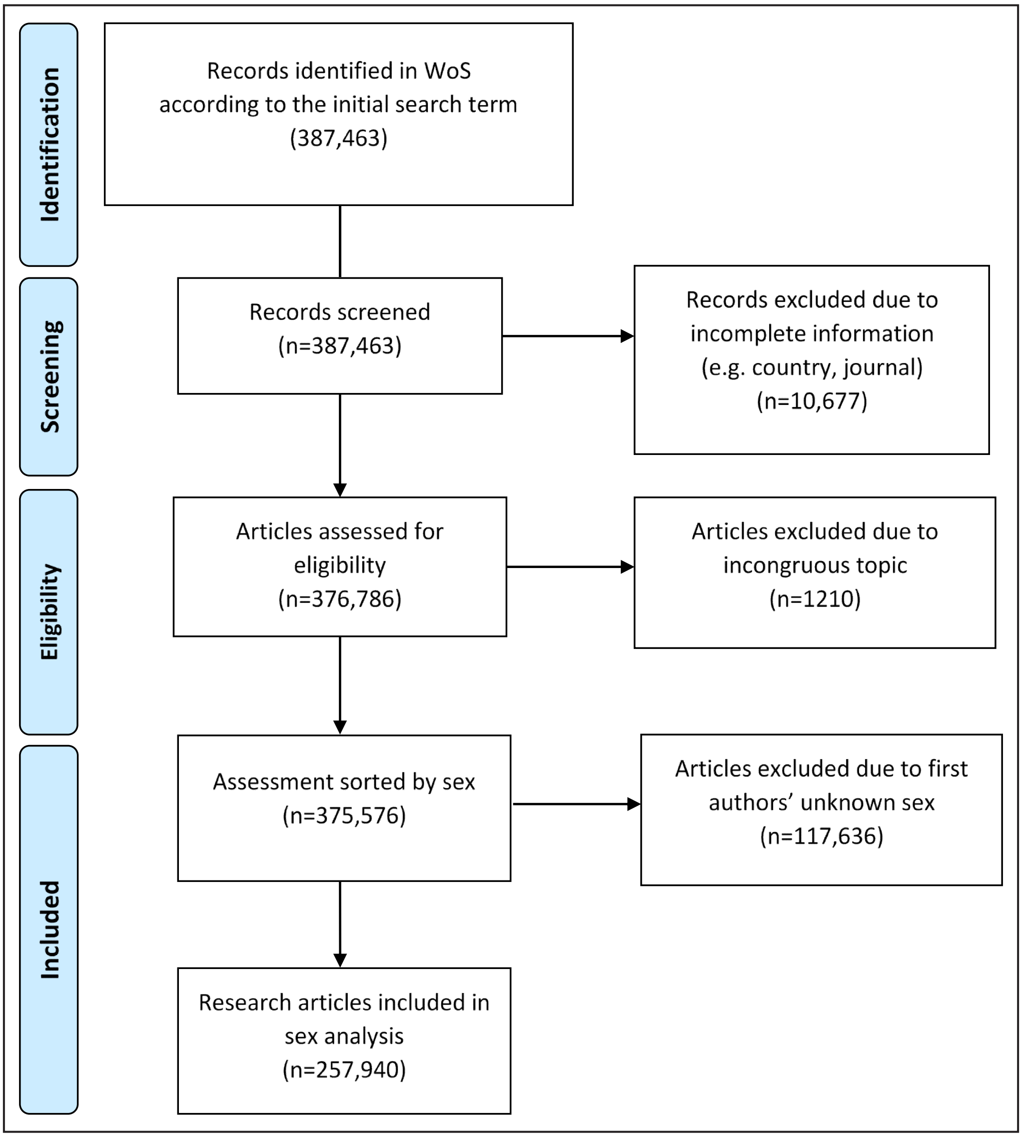

Figure 1. Preferred Reporting Items for Systematic Reviews and Meta-Analyses flow diagram, showing selection of research articles.
WoS indicates Web-of-Science Core Collection.

as a modified H-Index. For the modified H-Index, all publications and their citations of the particular institute or region are considered for the calculation of the index.[15]

Statistical Analysis

The Student *t* test was used to compare 2 groups with normally distributed parameters. For multiple comparisons, 2-way ANOVA was used. For binary variables, between-group comparisons were analyzed using Pearson χ^2 tests. Linear regression models were used for the analysis of trends over time between 2010 and 2019, with the year centered at 2010 for better interpretability. All statistical tests were performed using IBM SPSS Statistics, version 26.0 (IBM, Armonk, NY), and GraphPad Prism, version 7 (GraphPad Software, San Diego, CA). All *P* values were 2 sided, with a significance level of 0.05.

RESULTS

Sex Differences in Cardiovascular Publications

All original articles between 2010 and 2019 matching the search term were included in the analysis, adding up to 387 463 articles worldwide. After excluding articles because of incomplete information or incongruous topic, 257 940 articles were included in our analysis (Figure 1). Of these articles, 91 387 (35.4%) were published by female first authors and 166 553

(64.6%) were published by male first authors. The difference between female and male authors was even higher in last authorship positions (22.9% versus 77.1%).

There was an overall increase of research articles in the past decade, with 19 960 published articles in 2010 and 29 604 published articles in 2019 (relative increase of 48.3%). When analyzing this increase for female and male first authors separately, the relative increase of articles was 76.3% for female first authors (6434 articles in 2010 and 11 343 articles in 2019) and 35.0% for male first authors (13 526 articles in 2010 and 18 261 articles in 2019). When assessing the increase in female last authorship positions, it is notable that the number of articles almost doubled from 4237 to 8059 (90.2%) over the past decade. In contrast, the number of articles published by male last authors increased only from 17 037 to 22 968 (34.8%) (Figure 2A). A logistic regression model was performed to evaluate a trend over time on the increase of number of publications by female authors from 2010 to 2019. The logistic regression model was statistically significant (χ^2=382.071; P<0.001). Likewise, the mean H-Index of female authors and the mean IF of publications by female authors increased significantly in the same period (χ^2=492 645 [P<0.001] and χ^2=398.215 [P<0.001], respectively).

Female first authors published twice as often together with female last authors compared with their male counterparts. The last author of articles by female first author was also female in 28.2% (25 793 articles), whereas only 14.1% of publications with male first authors had female last authors (23 560 articles) (Figure 3A). The relative "chance" for a female first author to publish an article in case the last author was also female was 1.99 (95% CI, 1.96–2.02; P<0.001) compared with a male last author.

Differences in Publication Quality

To assess the publication quality, we analyzed the average IF per article according to Journal Citation Reports, the authors' H-Index, and the average number of citations per publication.

The median IF of all articles was 2.50 (interquartile range [IQR], 1.15–4.09). The median IF per article was 2.46 (IQR, 1.11–4.03) for female first authors and 2.51 (IQR, 1.17–4.10) for male first authors (P<0.001). Similarly, the median IF for female last authors was 2.36 (IQR, 0.94–3.98) compared with 2.59 (IQR, 1.22–4.17) for male last authors (P<0.001) (Figure 3B). Between 2010 and 2019, there was no increase in IF for either female or male authors (Figure 2B). Among top-tier journals, defined as the upper tertile (IF >3.5), women comprised 20.9% of senior authors, whereas in the mid-tier (middle tertile) or lower tier (lower tertile, IF <1.6), women comprised 22.7% and 25.1%, respectively.

The overall median H-Index of all first authors (regardless of sex) was 1 (IQR, 1–1), and the median H-Index of all last authors was 1 (IQR, 1–2). Female first authors had a median H-Index of 1 (IQR, 1–1), and male first authors had a median H-Index of 1 (IQR, 1–1) (P<0.001). The differences were statistically significantly lower for female authors mainly because of the large sample size. However, the median and the according IQR were numerically almost equal, thus implying no clinical relevance. Likewise, the H-Index of female last authors was significantly lower compared with male last authors (median, 1 [IQR, 1–2] and median, 1 [IQR, 1–2], respectively; Figure 3C).

There was a significant difference between the number of citations of articles by first female and first male authors (median, 6 [IQR, 1–15] versus median, 6 [IQR, 1–17]; P<0.001). Likewise, female last authors were cited less frequently per article on average compared with male last authors (median, 5 [IQR, 1–15] versus median, 6 [IQR, 2–17]; P<0.001) (Figure 3D).

Number of Coauthors per Publication

The median number of coauthors per publication was 7 (IQR, 4–9). There was a significant difference in the number of coauthors between articles by female first authors and articles by male first authors (median, 6 [IQR, 4–9] versus median, 7 [IQR, 4–10]; P<0.001). Accordingly, the number of coauthors in articles with female last authors was lower than with male last authors (median, 6 [IQR, 4–9] versus median, 7 [IQR, 4–10]; P<0.001). Female authors were least represented in articles with >15 coauthors (3623 articles by female first authors and 8941 articles by male first authors; female/male ratio, 0.41). Similar distributions were seen for last authors (Figure 2C).

Sex-Specific Publications Around the Globe

Female cardiovascular publications were distributed unevenly around the globe, as depicted in the heat map (Figure 4). Most articles were published in Europe (41 115 articles [45.2%]), followed by North America (28 468 articles [31.3%]) and Asia (12 640 articles [13.9%]). The other continents accounted for only 8688 publications (9.6%). The ratio between female and male first authors of all countries as a surrogate for scientific advancement in each geography revealed Latin America as the continent with the most even distribution of both sexes in first authorship positions (ratio, 0.92). The lowest ratio was observed in Asia (0.40), reporting the largest gap between female and male authors, followed by Africa (0.59), Europe

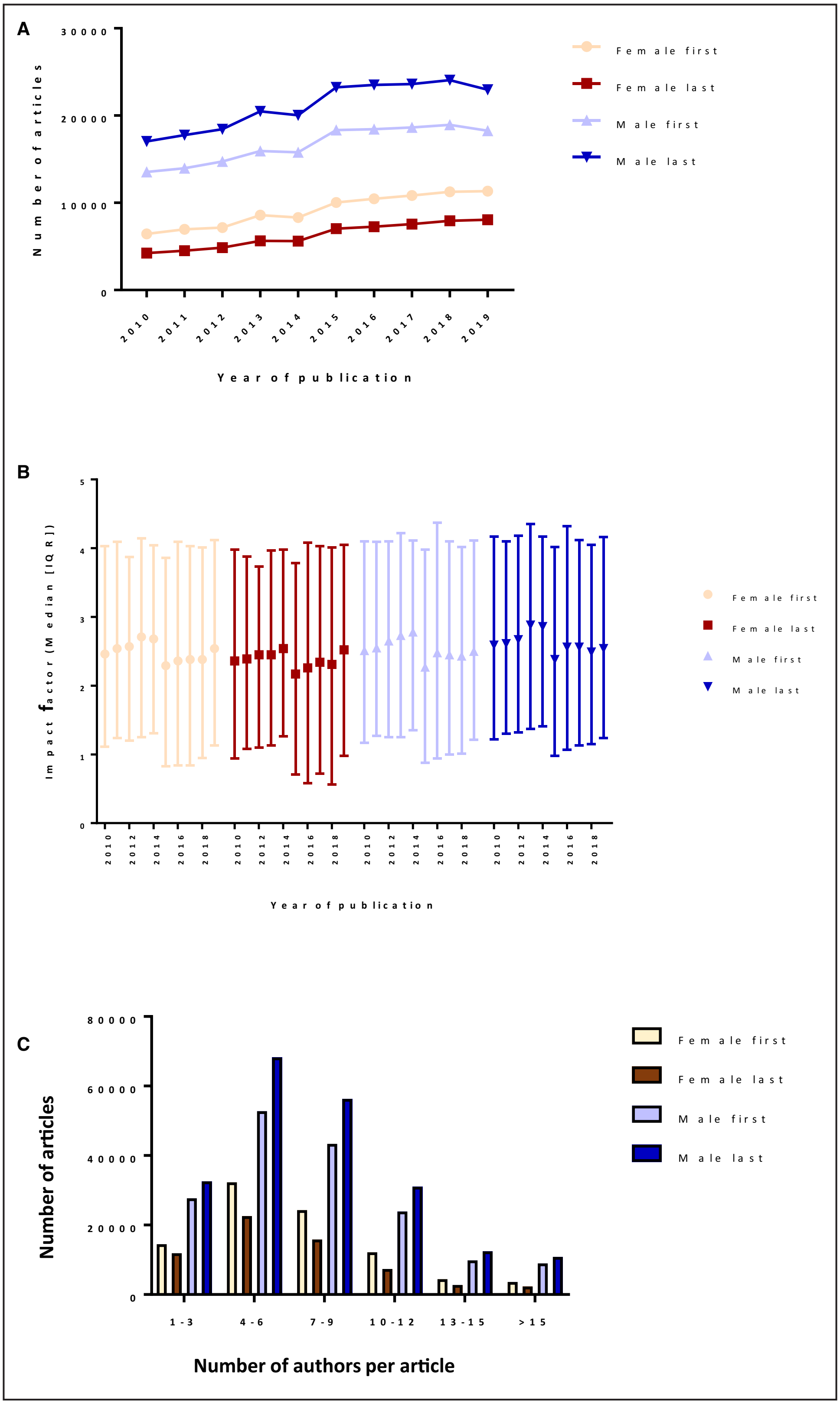

Figure 2. Analysis of change in number of articles between 2010 and 2019 of first and last and female and male authors (A).
Change of median impact factor with interquartile range (IQR) per article for all authors between 2010 and 2019 (**B**). Distribution of number of articles according to the number of coauthors per article. The median number of coauthors was 6 (IQR, 4–9) for female first authors and 7 (IQR, 4–10) for male first authors (**C**).

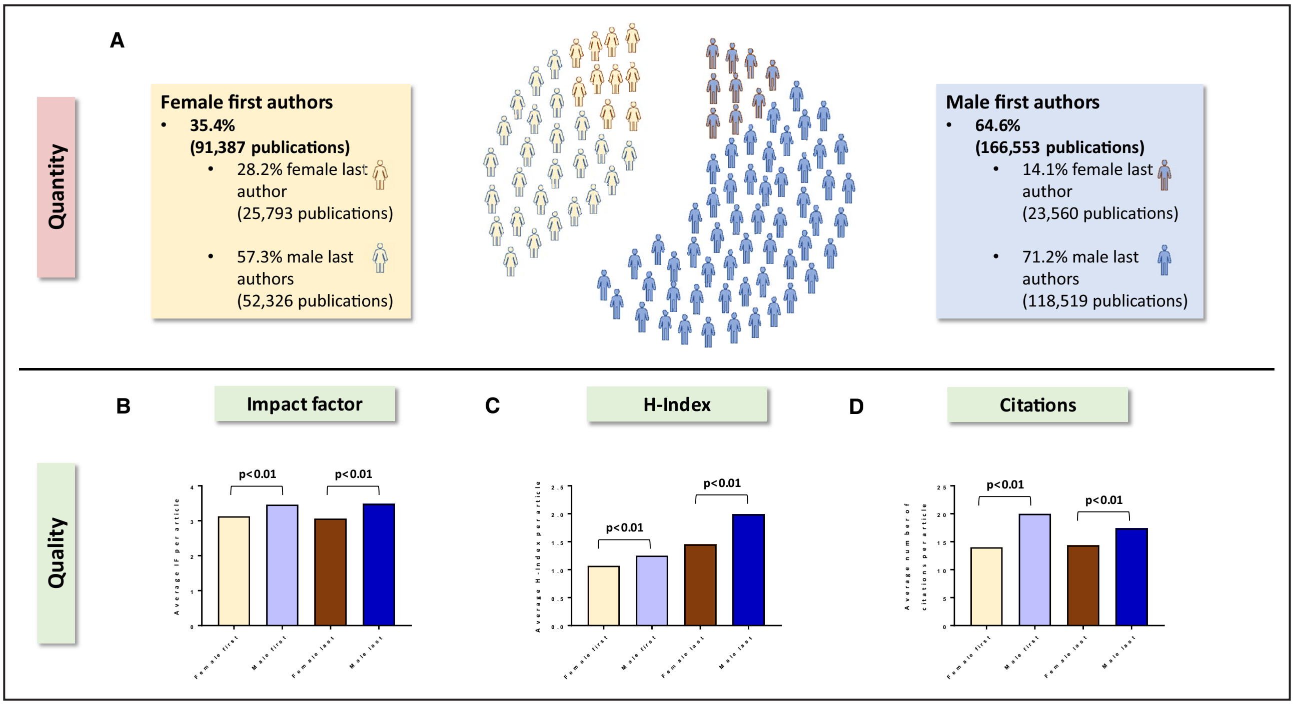

Figure 3. Graphic visualization of overall cardiovascular research quality and quantity for female and male authors between 2010 and 2019.

Number of female and male first authors' publications illustrated by female and male figures, proportionally to their number of publications (**A**). Outline color indicates the last author's sex, with gold for female and blue for male. Research quality of first authors measured by average impact factor (IF) per research article (**B**), average Hirsch Index (H-Index) per article (**C**), and average number of citations per article (**D**), separate for female first (gold) and male first (light blue), as well as female last (brown) and male last (blue) author.

(0.57), and North America (0.55) (Table S1). The lowest average IF for female articles was found in African articles, with an average IF of 1.8, and Latin America, with an average IF of 1.9, whereas the highest IF was found in North America (3.7), followed by Europe (3.2) (Figure 4).

DISCUSSION

This scientometric study analyzed sex aspects in cardiovascular research across all journals over the past decade. To the best of our knowledge, this is the first detailed analysis to provide comprehensive information on cardiovascular publications by female and male authors across all journals. Our analysis revealed an overall increase in number of cardiovascular research articles, driven by a relative increase in female first and last authorship positions. The increase of male authorships remained consistent throughout, yet with higher relative growth of female authorship positions. A detailed analysis of the associated IF revealed that articles by female authors achieved a lower average IF compared with their male peers. Likewise, female authors' publications were less frequently cited, whereas there was no clinically relevant difference in the H-Index between men and women. The number of authors per publication was lower in articles published by female first authors. In geocoded analyses, we found various geographical differences between female and male authors. However, the accuracy of the sex assignment also shows regional differences, so that these analyses can only be interpreted in a limited way.

Our data revealed that female authors were first authors in 1 of 3 articles published in the past decade. The "gender gap" in medical research is well described.[5] In 1970, the percentage of US publications with female first authors was 5.9% and as low as 3.7% for female last authors; these numbers increased to 29.3% and 19.3% in 2004, respectively.[5] Herein, we showed that the number of female first author publications and female last author publications increased to 38.3% and 35.1% in 2019, respectively (accounting for an increase by 76.3% and 90.2% from 2010 to 2019, respectively). However, considering the comparably low number of women as trainees (21.4% in all adult cardiology, and 10.2% in interventional cardiology) in the United States, this percentage of publications appears relatively high.[6] Thus, despite the overall increase of research articles in cardiovascular medicine regardless of the authors' sex, the relative

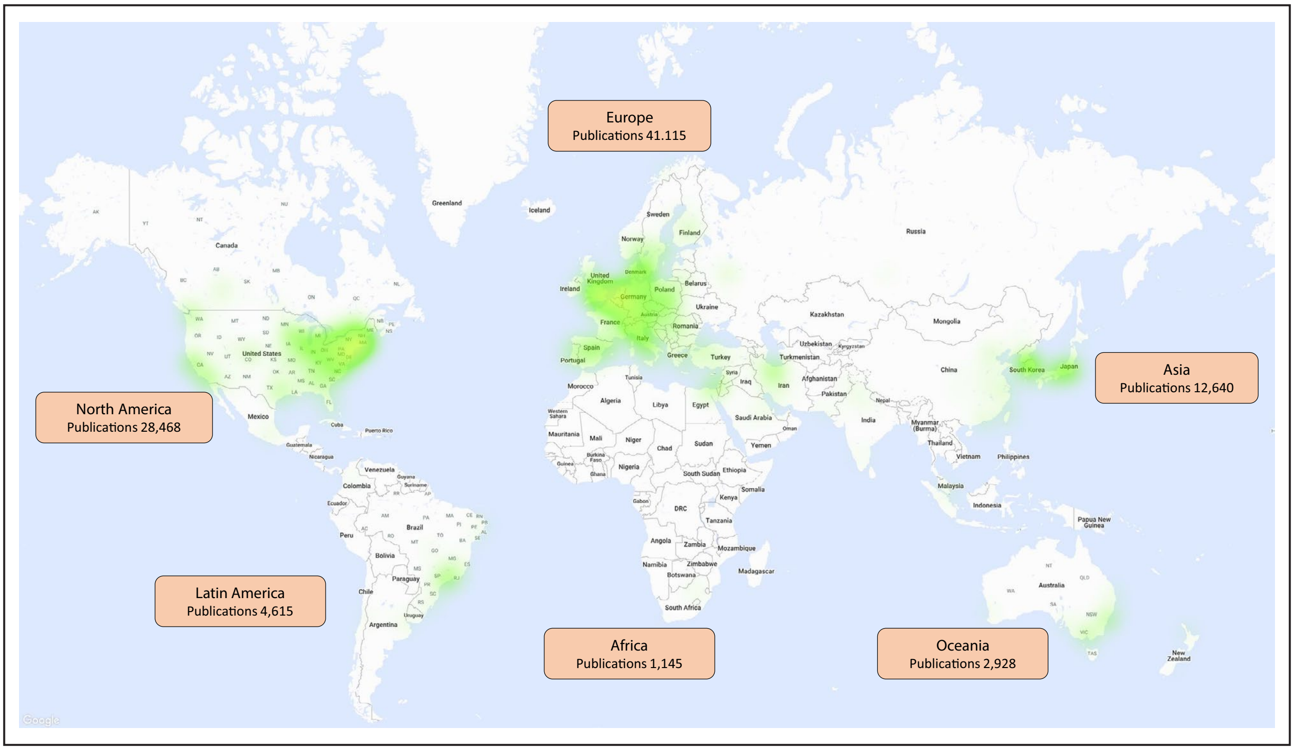

Figure 4. Representative institute heat map of the world, visualizing female publications in cardiovascular research.
The extent of scientific output is color coded. The red boxes refer to each continent's number of female first authors' publications. map-data © Google, inegi, orion me.

increase of research work by female authors was more than doubled compared with men. This is in line with a recent analysis showing an increase of female representation in published cardiology research in the past 4 decades in 3 high-impact cardiology journals (*Journal of the American College of Cardiology*, *Circulation*, and *European Heart Journal*), which is expanded by the present analysis for all journals publishing cardiological research articles.[20]

Interestingly, the number of female last authors was twice as high for female first authors than their male counterparts. These data suggest a mentor-mentee relationship between female researchers, which has been described in other medical subspecialties, such as otolaryngology.[21] Female authors had fewer coauthors than men, possibly attributed to challenges women face in achieving relevant author positions in a larger group of authors. The underrepresentation of female authors has also recently been described for international heart failure guidelines as well as authorship in large clinical trials.[22]

Remarkably, our analysis also revealed regional differences in publication behavior. Latin America turned out to have almost equal numbers of research articles for women and men. The most male-dominated region was Asia, especially Japan. This gap was even more obvious when focusing on last authorship positions. When interpreting these results, however, one has to remember that sex assignment among Asian authors in particular yielded the most unknown results. Hence, the results may therefore differ slightly from the true figures (for the characteristics of authors who could not be assigned, see also Table S2). A recent observational study revealed an increase of female authors in Japanese journals until 2009, which has plateaued after 2010.[23] However, in Japan, the rate of female physicians is the lowest among the rates for the Organization for Economic Cooperation and Development countries.[24]

Research quality by female authors was slightly lower compared with male authors, as measured by the average IF of all published articles. In articles with the highest IF, female authors, especially last female authors, were underrepresented. Furthermore, publications by female first authors were cited less often than those by male first authors (14 versus 18 times). However, notably, the frequency of citation also depends on the absolute number of publications by women and men. Hence, articles by male authors are more likely to be cited by researchers because there are higher absolute numbers in the published literature. Furthermore, as the number of citations for a specific research article increases over time, the most recent increase in scientific output by female authors may become measurable sometime in the future. A recently published study showed a higher number of citations for female scientists,[11] although that analysis focused on 6 prominent cardiology journals only. The H-Index is a valid and frequently used tool to evaluate scientific research quality.[15] Herein, female first authors had a slightly lower H-Index (female/male ratio, 0.91). This difference was marginally more pronounced for last authorship positions, with a ratio of 0.82. Possible sex bias in the peer-review process has been reported for female authors,[3] although the acceptance rate of submitted abstracts to scientific meetings was similar in women and men.[25]

Indeed, as a result, several approaches have been proposed to address these issues. On the one hand, equal pay between women and men is essential, especially because women continued to receive significantly less pay, even when adjusted for measures of personal, job, and practice characteristics.[26] Furthermore, next to encouraging talented women at early stages of their career,[27] several mentorship programs for female physician-scientists in cardiology have been established, to pave the way to a successful career.[28]

Limitations

As the data were extracted from WoS, the analysis depends on the integrity of the published articles and the chosen search term to be as specific as possible. Although the results from WoS were cross-checked with other medical databases, the risk of missing articles cannot be entirely excluded. Affiliations to nations were analyzed according to the first author. Therefore, multicenter studies are reduced to this country. The sex assignment was based on the author's given name and took international characteristics into account (eg, the first name "Andrea" was typically regarded as female, whereas it was considered male in Italian authors). However, as some unisex first names can regularly be found in female and male (eg, Denise, Kim, Casey, Robin, and Jamie), sex assignment was impossible, marking this author's sex as unknown. Likewise, the author's sex remained unclear when only initials were published. This leads to a certain number of unassignable authors, marked as "unknown." A total of 117 000 articles have been excluded from analysis for unobtainable author sex. In Asian countries in particular, sex classification was sometimes difficult, so that regional evaluations should be interpreted with caution (characteristics of publications of authors with unknown sex are depicted in Table S2). However, our results are generally in line with previous other trials using manual sex classification.[5] The analysis of first and last authorship positions is based on the traditional authorship assignment, in which the first author contributes most to the study under the supervision of the last senior author, which is common practice. In rare cases of alphabetical author order, this analysis could be misleading. For the global research analysis, there may be a possible bias in nations and continents with a fewer publication count. Furthermore, the number of women as trainees in cardiology is not available for all countries worldwide, which should be taken into consideration when analyzing the association between female trainees and researchers. As all authors of cardiovascular research articles were included for analysis, some noncardiologist authors were included as well (eg, students and PhDs). Another factor influencing the results of scientometric analyses is time. In a citation-based analysis, more recent articles have a lower chance of recitation when compared with older publications, irrespective of their impact. This should be taken into consideration when interpreting both the number of citations and the authors' H-Index.

CONCLUSIONS

Cardiovascular medicine research has increased worldwide. Significant differences in research output between female and male authors are seen throughout the past decade. However, there has been a proportionally higher relative increase of research in the past decade led by female first and last authors, compared with their male counterparts. According to geography, this analysis identified Latin America as having the highest ratio of female/male publications. The difference in research quality between female and male authors, as assessed by articles' IF, authors' H-Index, and citations, revealed a small yet consistent gap, especially in high-impact journals.

ARTICLE INFORMATION

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Affiliations

Department of Internal Medicine III, Cardiology, Angiology, Intensive Care Medicine, Saarland University Hospital, Homburg, Saar, Germany (D.M., L.L., C.U., M.B., F.M.); Chair for Clinical Bioinformatics, Saarland University, Saarbrücken, Germany (M.D., T.F., A.F., A.K.); The Zena and Michael A. Wiener Cardiovascular Institute, Icahn School of Medicine at Mount Sinai, New York, NY (R.M.); National Heart and Lung Institute, Imperial College London, London, UK (R.A.); Department for Neurobiology, Stanford University, Stanford, CA (A.K.); and Institute for Medical Engineering and Science, Massachusetts Institute of Technology, Cambridge, MA (F.M.).

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Supplementary Material

Table S1-S2

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SUPPLEMENTAL MATERIAL

Table S1. Publications and IF by first and last author of all continents between 2010 and 2019. IF, impact factor; ratio f/m, ratio between female and male.

	Publications first authorship			IF first authorship			Publications last authorship			IF last authorship		
	female	male	ratio f/m	female	male	ratio f/m	female	male	ratio f/m	female	male	ratio f/m
Africa	1145	1897	0.60	1.8	1.5	1.20	997	2365	0.42	1.8	1.6	1.10
Asia	12640	31554	0.40	2.3	2.4	0.96	9482	36818	0.26	2.3	2.5	0.93
Europe	41115	71608	0.57	3.2	3.4	0.93	24757	92542	0.27	3.0	3.4	0.89
Latin America	4615	5011	0.92	1.9	1.9	0.96	3844	6204	0.62	1.8	2.0	0.92
North America	28468	51355	0.55	3.7	4.4	0.84	21258	66401	0.32	3.6	4.3	0.84
Oceania	2928	3884	0.75	3.0	3.6	0.85	2045	5640	0.36	3.1	3.4	0.91

Table S2. Characteristics of all publications by authors with unknown sex compared to all authors.

	All first authors (N=375,576)	**First authors with unknown sex** (N=117,636)
Last authors' sex, n (%)		
female	62,747 (16.7%)	13,394 (11.4%)
male	211,384 (56.3%)	40,539 (34.5%)
unknown	101,444 (27,0%)	63,702 (54.2%)
Average IF, median [IQR]	2.4 [1.1 – 4.0]	2.2 [1.0 – 3.7]
Average H-Index, median [IQR]	1 [1 - 1]	1 [1 - 1]
Geographic region, n (%)		
Africa	5,452 (1.5%)	2,227 (1.9%)
Asia	102,733 (27.4%)	57,913 (49.2%)
Europa	142,437 (37.9%)	28,863 (24.5%)
Latin America	12,571 (3.3%)	2,793 (2.4%)
North America	103,291 (27.5%)	23,639 (20.1%)
Oceania	9,070 (2.4%)	2,199 (1.9%)
unknown	22 (0.0%)	2 (0.0%)

N, number; IQR, interquartile range