

**Diversity and Disparities in Orthopaedic Surgery (Guest Editors Alice Chu MD,
Selina Poon MD, MPH)**

Despite Growing Number of Women Surgeons, Authorship Gender Disparity in Orthopaedic Literature Persists Over 30 Years

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Received: 16 February 2019 / Accepted: 17 May 2019 / Published online: 17 June 2019
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Abstract

Background The most recent demographic data reveal that only 6.5% of practicing orthopaedic surgeons are women, and as far as we know, only two women have held chair positions in academic orthopaedic programs in the United States. Furthermore, orthopaedic surgery is the least gender-diverse speciality recognized by the Accreditation Council for Graduate Medical Education. The factors that contribute to the lack of gender diversity in orthopaedics remain ill-defined. A lag in publication productivity may be a barrier to career advancement for women orthopaedic surgeons, but this has not been well studied.

Questions/purposes (1) What is the proportion of orthopaedic studies published in six major orthopaedic journals

by women first or senior authors from 1987 to 2017? (2) Did men and women orthopaedic surgeons publish in equal proportions during the study period (measured in 5-year intervals)? (3) Are there differences in the characteristics (such as study type or subject focus) of orthopaedic publications authored by women and those authored by men? (4) Has the increased proportion of practicing women orthopaedic surgeons been matched by an equal increase in authorship by women orthopaedic surgeons during the study timeframe?

Methods A cross-sectional analysis was designed to characterize trends in authorship of orthopaedic studies by women over time. All publications from the first issue of

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each of six major orthopaedic journals were evaluated at seven time points (1987, 1992, 1997, 2002, 2007, 2012, and 2017). Characteristics of each first and senior author (including gender, academic degree, and specialty), and study category of each publication were collected. Articles for which this information was not available were excluded (35 of 1073, or 3.3% of published studies, no difference in proportion of excluded studies between journals). The proportions of women and men authors were compared at the seven time points and for six study categories (basic science, case report/technique article, clinical medicine, economics/practice management, editorial content [including true editorials, letters to the editor, commentaries, and book reviews] and review/meta-analysis) using a Fisher's exact test or chi-squared analysis. We compared the rates of change of women authorship, practicing women orthopaedic surgeons, and women orthopaedic residents during the study period using an ANOVA and Tukey's honestly significant difference (HSD) post-hoc test with Cohen's D measure of effect size.

Results From 1987 to 2017, only 1.7% (15 of 880) of senior authors and 4.4% (46 of 1038) of first authors of orthopaedic publications were women orthopaedic surgeons. Based on population proportions (that is, percent of practicing women orthopaedic surgeons compared with men), the proportion of women senior authors was less than would be expected at each time point after 1987 compared with men. There were no differences between the types of studies authored by women or men. Finally, during the study period, the rate of growth of women senior authorship was less than the rates of growth of both practicing women orthopaedic surgeons ($d = 5.3$, 95% CI, 4.8-5.6; $p = 0.023$) and women first authorship ($d = -4.3$, 95% CI -4.6 to -3.6, $p = 0.030$; estimated mean 3.3, $p = 0.013$).

Conclusions Women orthopaedic surgeons published a small proportion of academic orthopaedic research from 1987 to 2017, and women senior authors consistently published less than would be expected based on their population proportion compared with men orthopaedic surgeons. Furthermore, the growth of practicing women orthopaedic surgeons has not been matched by growth in senior authorship by women over the same timeframe.

Clinical Relevance This discrepancy warrants further exploration because a low rate of publication may negatively impact the career advancement of women orthopaedic surgeons and contribute to the overall lack of gender diversity in orthopaedics. We suggest that journals and publishers review their editorial processes to ensure blinding of author names during peer review and editorial decision-making, and to disclose those review processes to authors. We also suggest that institutions encourage women trainees and junior faculty to participate in mentorship programs and specialty societies that promote academic productivity.

Introduction

Orthopaedic surgery is the least gender-diverse specialty recognized by the Accreditation Council for Graduate Medical Education (ACGME) [3]. The most recent data published by the American Academy of Orthopaedic Surgeons demonstrate that only 6.5% of attending orthopaedic surgeons practicing in the United States as of 2016 were women [6], compared with 34% for all practicing physicians [13]. Although orthopaedics has seen an increase in women practitioners during the past 30 years and even greater matriculation of women trainees during the past decade, there are few women in leadership positions. Research in business, science, and medicine has demonstrated that increased diversity among leadership and teams improves productivity, increases innovation, and leads to better patient satisfaction and clinical outcomes [23, 32, 33, 34, 36, 39]. Furthermore, studies in orthopaedics have demonstrated that a perceived lack of women role models is a barrier for women medical students considering entering orthopaedics [19, 26], confounding the issue of low gender diversity in the field. Given this robust and growing body of evidence demonstrating the importance of diversity among leaders, the field of orthopaedic surgery would benefit from improvements in this area.

Research has demonstrated that many barriers exist for women seeking promotions in academic medicine. Subjective barriers include implicit bias and difficulty cultivating mentorships [25, 28, 37], as well as sexual harassment and bullying [4]. Indeed, a recent survey by the American Academy of Orthopaedic Surgeons reported that 81% of members who identify as women stated that they have experienced some level of subjective discrimination, either during training or while in practice [4]. This number is daunting, but these subjective barriers are difficult to analyze scientifically; therefore, their impact on productivity and career trajectory has been difficult to prove and, subsequently, they remain stubbornly intact. While these subjective barriers must be addressed, we believe that identifying and characterizing objective barriers to women's promotion may provide a scientific basis from which we can advocate for targeted interventions that promote increased diversity within the field of orthopaedics. One potential barrier that can be measured objectively, and therefore may be a target for intervention, is the rate of publication by women surgeons. Research demonstrates that, while the number and caliber of publications are often critical to career advancement for academic physicians [17], women consistently publish less frequently than do men across medical specialties, including in general orthopaedics and orthopaedic subspecialties [21, 27, 29, 31, 38]. It is reasonable to presume, then, that if women orthopaedic surgeons are publishing less than men, this may contribute to the overall lack of women in leadership

positions. By identifying this discrepancy, publications and institutions may be able to intervene to promote academic productivity of women orthopaedic surgeons.

We therefore asked: (1) What is the proportion of orthopaedic studies published in six major orthopaedic journals by women first or senior authors from 1987 to 2017? (2) Did men and women orthopaedic surgeons publish in equal proportions during the study period (measured in 5-year intervals)? (3) Are there differences in the characteristics (such as study type or subject focus) of orthopaedic publications authored by women and those authored by men? (4) Has the increased proportion of practicing women orthopaedic surgeons been matched by an equal increase in authorship by women orthopaedic surgeons during the study timeframe?

Materials and Methods

Study Design and Setting

We designed a cross-sectional analysis to characterize trends in authorship of orthopaedic studies by women over time. The study was conducted from December 20, 2017 to January 15, 2018. Articles from six major clinical orthopaedic journals (*Journal of Bone and Joint Surgery*, *Journal of Arthroplasty*, *Journal of Orthopaedic Trauma*, *American Journal of Sports Medicine*, *Journal of Hand Surgery*, and *Journal of Pediatric Orthopaedics*) were evaluated. These journals were selected to represent general orthopaedics, three of the top six largest subspecialties as determined by the number of practitioners (adult reconstruction, trauma, and sports medicine) [6], and two of the three subspecialties with the highest proportion of women in practice (hand and paediatrics [15]). The editorial process of each journal was not considered as part of our selection criteria, but it should be noted that not all included journals state that they employ blinded peer review.

Study Methods

Using a methodology modified from Long et al. [27], we examined a sample of the first (January) issue of each journal at 5-year intervals (1987, 1992, 1997, 2002, 2007, 2012 and 2017) for authorship trends. All original articles published in the selected journals at these time points were included in the study, leading to an initial sample of 1073 articles. The gender of the first and senior author was initially determined by examining the author's first name. Gender, degree, and specialty of practice were then confirmed by reviewing each author's institutional website, searching professional social media resources (LinkedIn and ResearchGate) or general social media resources (Facebook, Twitter), or by general Internet search. Authors of single-author publications were counted as

first authors (158 of 1073 articles, or 15%). Articles were excluded if they were published by a study group (and therefore had no single named author to which a gender could be assigned), or if the gender of the first or senior author could not be determined. We could not determine the gender of the first or senior author of 35 articles (3.3% [35 of 1073]) and these were excluded, leaving a final dataset of 1038 original articles (including 1038 first authors and 880 senior authors) in the final analysis. There was no difference in the proportion of excluded articles across the six journals. All publications were collected manually and evaluated by one of two authors (MAB, MKE), or, in the case of uncertainty, by both.

Variables, Outcome Measures

Our primary study outcome was the proportion of academic publications with women orthopaedic surgeons as either the first or senior author. Our secondary outcomes were (1) the proportion of women versus men authors at each time point; (2) the proportion of women versus men authors of various categories of academic publications; and (3) the rate of change of women authorship compared with that of practicing women orthopaedic surgeons (attending and residents). For each publication, we collected the characteristics of the first and senior author, including gender, academic degree, and medical specialty, as well as the study category. Articles were categorized into one of six groups based on study topic, as assessed by two authors (MAB, MKE): basic science (including biomechanical analyses of implants or constructs, anatomic studies of nonliving human specimens, bench studies involving nonhuman models, etc), case report/technical article, clinical medicine, economics/practice management, editorial content (including true editorials, letters to the editor, commentaries, and book reviews, or any other opinion-based publication), and reviews/meta-analyses.

Statistical Analysis

We calculated the observed overall proportion of studies authored by women orthopaedic surgeons in the first and senior author positions during our study period. The proportion of publications by women orthopaedic surgeons was subsequently evaluated at each of the seven time points and for each of the six study categories using a Fisher's exact test when the observed raw data were less than 5, and chi-squared analysis when the observed raw data were 5 or more. We calculated odds ratios (OR) and 95% confidence intervals (95% CIs) for each comparison. The expected population proportions for each time point were based on demographic data from the American Academy of Orthopaedic Surgeons' annual census [6] or the American

Medical Association’s annual report [7-12] for attending surgeons, and the Accreditation Council for Graduate Medical Education’s annual data resource book [1-3] for resident surgeons. We compared the rates of change of women authorship, practicing women orthopaedic surgeons, and women orthopaedic residents during the study period using an ANOVA and Tukey’s honestly significant difference (HSD) post-hoc test, and calculated Cohen’s D and 95% CI for effect size. A line of best fit was calculated for each trend, and the slope was used to represent the rate of change. Statistical significance for all analyses was set at $p < 0.05$. All statistical analyses were performed with Microsoft Excel (Microsoft Corp, Redmond, WA, USA).

Results

Proportion of Orthopaedic Studies Published by Women

From 1987 to 2017, 1.7% (15 of 880) of senior authors and 4.4% (46 of 1038) of first authors of published academic orthopaedic studies were women orthopaedic surgeons.

Differences in the Proportion of Publications between Women and Men

Over the 30-year span of our study, based on population proportions (that is, the proportion of practicing orthopaedic surgeons who are women at each time), there were fewer than expected women orthopaedic surgeon senior authors at every time point except for 1987 (2.0% [2 of 101] of senior authors versus 1.9% [326 of 17,333] of surgeons; OR, 1.1, 95% CI, 0.007-0.22; $p = 0.711$). This finding was consistent across three decades, including in 2007, when women orthopaedic surgeons represented only 0.80% (1 of 125) of senior authors compared to 5.2% (1216 of 23,269) of practicing surgeons (OR 0.15, 95% CI, 0.027-0.87; $p = 0.022$), and in 2017, when women orthopaedic surgeons were responsible for only 1.2% (2 of 162) of senior authorships while representing 6.5% (2511 of 36,124) of practicing surgeons (OR 0.18, 95% CI 0.049-0.66; $p = 0.002$). Interestingly, the proportion of women first authors was not different than expected at any time (Table 1).

Characteristics of Orthopaedic Publications Authored by Women Versus Men

Between 1987 and 2017, with the data available, there were no differences in the characteristics of studies published by women versus men authors. Likewise, we observed no differences between women and men in terms of the proportions

Table 1. Proportion of women authors, by role, versus population proportion of practicing women orthopaedic surgeons, from 1987 to 2017

	1987	1992	1997	2002	2007	2012	2017	1987-2017
Women first authors proportion, % (n/N)	0.76 (1/131)	0.038, 3.4 (5/148)	1.2, 2.5 (4/158)	0.74, 5.5 (8/146)	1.4, 4.3 (6/140)	0.82, 8.1 (12/148)	1.2, 5.9 (10/167)	0.86, 4.4 (46/1,038)
OR, 95% CI; p value	0.007-0.22; 0.524	0.51-2.9; 0.770	0.28-1.9; 0.823	0.69-2.8; 0.362	0.37-1.8; 0.553	0.67-2.2; 0.493	0.45-1.6; 0.788	
Women senior authors proportion, % (n/N)	2.0 (2/101)	0, 0 (0/118)	0, 0.85 (1/117)	0.25, 2.3 (3/128)	0.62, 0.80 (1/125)	0.15, 4.7 (6/129)	0.72, 1.2 (2/162)	0.18, 1.7 (15/880)
OR, 95% CI; p value	0.29-4.0; 0.711	0.00-1.2; 0.209	0.044-1.4; 0.191	0.21-1.9; 0.493	0.027-0.87; 0.022	0.32-1.6; 0.478	0.049-0.66; 0.002	
Women orthopaedic surgeons population proportion, % (n/N)	1.9 (326/17,333)	2.8 (565/20,415)	3.4 (756/22,132)	4.0 (882/22,329)	5.2 (1216/23,269)	6.7 (1622/24,048)	6.5* (2511/36,124)	-

*Indicates this data was derived from the 2016 AAOS Census [6]. Calculated values are rounded to two significant figures. P values are reported for comparison between proportion of women authors and population proportion of women orthopaedic surgeons at each time point. Odds ratios indicate odds of being a woman versus man author at each time point. Population proportions are derived from the AMA Annual Report unless otherwise indicated [7-12]. Cumulative data presented in the final column are observational data only and not used for comparison.

of basic science and case reports, or technique papers they published (6.7% [1 of 15 each] versus 17% [150 of 865 and 147 of 865, respectively], OR 0.31, 95% CI, 0.049-2.0; $p = 0.460$ for both categories), nor in the proportion of clinical studies (67% [10 of 15] versus 54% [470 of 865]; OR 1.8, 95%

CI 0.59-5.6; $p = 0.344$) or systematic reviews or meta-analyses they published (13% [2 of 15] versus 4.5% [39 of 865], OR, 4.7, 95% CI, 0.082-27; $p = 0.175$). There were also no differences between publication categories of studies authored by women versus men first authors (Table 2).

Table 2. Authorship trends by gender, author position, and study category

	Women first authors	Men first authors	All included first author studies
Basic science			
Proportion, % (n/N)	11 (5/46)	15 (149/992)	15 (154/1038)
OR, 95% CI; p value			0.7, 0.18-1.7; 0.453
Case report/technical			
Proportion, % (n/N)	13 (6/46)	16 (156/992)	16 (162/1038)
OR, 95% CI; p value			0.66, 0.23-1.9; 0.633
Clinical medicine			
Proportion, % (n/N)	57 (26/46)	47 (466/992)	47 (492/1038)
OR, 95% CI; p value			2.0, 0.92-4.5; 0.215
Economic/practice management			
Proportion, % (n/N)	0.0 (0/46)	1.3 (13/992)	1.3 (13/1038)
OR, 95% CI; p value			0, 0.00-3.5; 1.000
Editorial			
Proportion, % (n/N)	11 (5/46)	16 (155/992)	16 (160/1038)
OR, 95% CI; p value			0.54, 0.18-1.6; 0.395
Review/meta-analysis			
Proportion, % (n/N)	8.7 (4/46)	5.3 (53/992)	5.2 (57/1038)
OR, 95% CI; p value			3.3, 0.59-18; 0.463
	Women senior authors	Men senior authors	All included senior author studies
Basic science			
Proportion, % (n/N)	6.7 (1/15)	17 (150/865)	17 (151/880)
OR, 95% CI; p value			0.31, 0.049-2.0; 0.460
Case report/technical			
Proportion, % (n/N)	6.7 (1/15)	17 (147/865)	17 (148/880)
OR, 95% CI; p value			0.31, 0.049-2.0; 0.460
Clinical medicine			
Proportion, % (n/N)	67 (10/15)	54 (470/865)	54 (480/880)
OR, 95% CI; p value			1.8, 0.59-5.6; 0.344
Economic/practice management			
Proportion, % (n/N)	0 (0/15)	1.5 (11/865)	1.5 (13/880)
OR, 95% CI; p value			0, 0.00-15; 1.000
Editorial			
Proportion, % (n/N)	6.7 (1/15)	5.3 (46/865)	5.3 (47/880)
OR, 95% CI; p value			1.3, 0.19-9.9; 0.576
Review/meta-analysis			
Proportion, % (n/N)	13 (2/15)	4.5 (39/865)	4.7 (41/880)
OR, 95% CI; p value			4.7, 0.82-27; 0.175

This table details the authorship trends by gender and author position regarding each study classification.

Calculated values are rounded to two significant figures.

P values reported for comparison between women versus men authorship per category. Odds ratios (OR) indicate odds of being a woman versus man author for each study category.

Proportion of Women Orthopaedic Surgeons Compared with Proportion of Women Authors

From 1987 to 2017, the proportion of women who were attending orthopaedic surgeons increased from 1.9% to 6.5% [6, 7-12], and from 2007 to 2017, the proportion of women orthopaedic residents increased from 12% to 16.7% [1-3]. During this time, the proportion of practicing women orthopaedic surgeons grew more quickly than did the proportion of women senior authors (0.83% per 5-year period versus 0.25% per 5-year period; $d = 5.3$, 95% CI, 4.8-5.6; $p = 0.023$), but not compared with the proportion of women first authors (0.93% per 5-year period; $d = 0.18$, 95% CI, -0.34 to 0.84; $p = 0.900$); and the growth of women senior authorship was also slower than that for women first authorship ($d = -4.3$, 95% CI -4.6 to -3.6; $p = 0.030$; pooled estimated mean for comparison was 3.3, $p = 0.014$) (Fig. 1). In the last decade of the study, the proportion of women orthopaedic residents increased from 12% to 17% [1-3], at a rate of 2.5% per 5-year period; this

was faster than the growth of both women senior authorship (0.23% per 5-year period, $d = -11$, 95% CI, -13 to -9.7; $p = 0.001$) and women first authorship (0.79% per 5-year period, $d = -7.5$, 95% CI, -8.7 to -5.9; $p = 0.008$; pooled estimated mean for comparison was 7.3, $p = 0.001$) (Fig. 2). Finally, there were no differences between journals in the rate of growth of women first authorship (pooled mean 0.018, $p = 0.436$) or senior authorship (pooled mean 0.075, $p = 0.472$; no post hoc tests were performed for either comparison) across the study time period (Fig. 3).

Discussion

Background

In 2018, the American College of Physicians announced its dedication to achieving gender equity in physician compensation and career advancement [14], and the American Academy of Orthopaedic Surgeons (AAOS) made

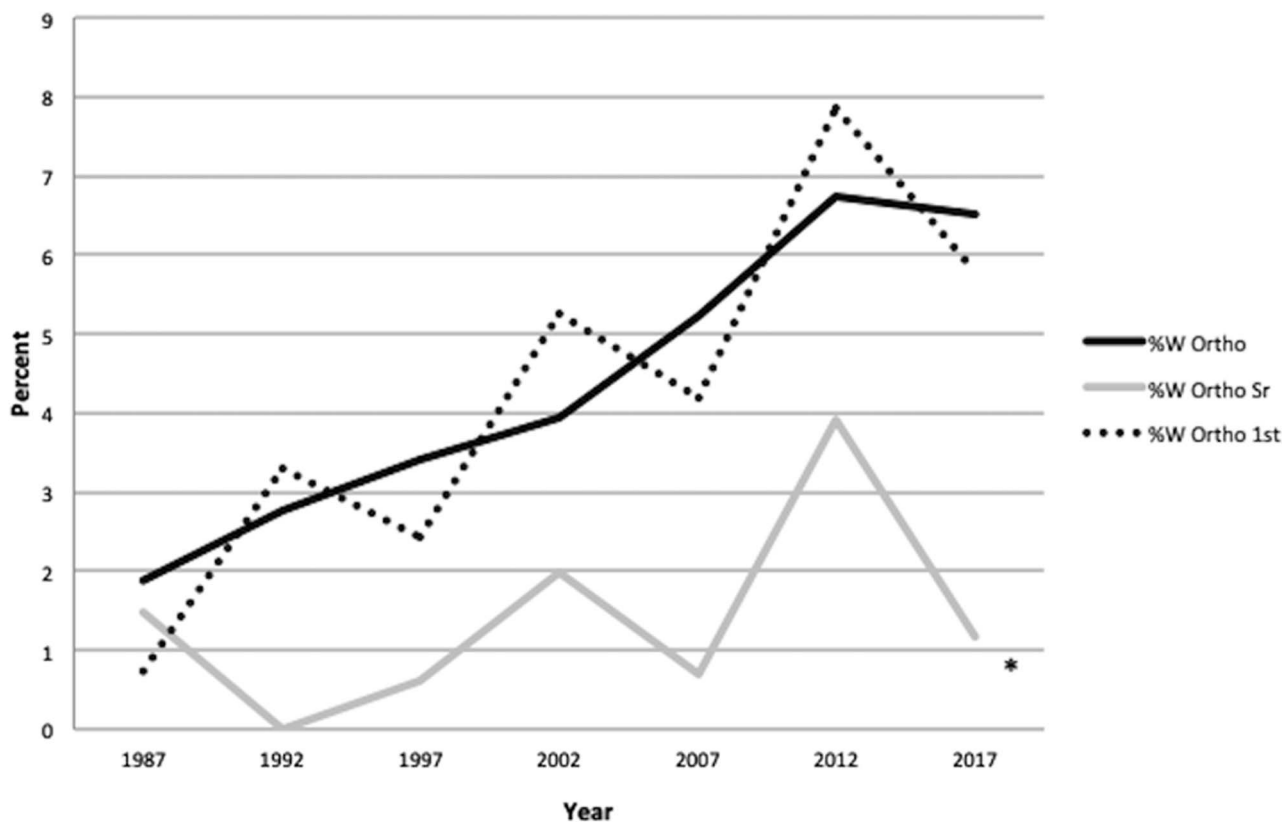


Fig. 1 This figure details the growth of practicing women orthopaedic surgeons versus women orthopaedic first and senior authorship from 1987 to 2017. *Indicates that the rate of growth of women orthopaedic senior authorship was less than that of practicing women orthopaedic surgeons ($d = 5.3$, 95% confidence interval [CI], 4.8-5.6; $p = 0.023$) and of women orthopaedic surgeon first authorship ($d = -4.3$, 95% CI -4.6 to -3.6; $p = 0.030$); pooled estimated mean for comparison was 3.3, $p = 0.014$). %W Ortho = the proportion of practicing women orthopaedic surgeons, slope of best fit line, $m = 0.84$; %W Ortho 1st = the proportion of women orthopaedic surgeon first authors, slope of best fit line, $m = 0.93$; %W Ortho Sr = the proportion of women orthopaedic surgeon senior authors, slope of best fit line, $m = 0.25$.

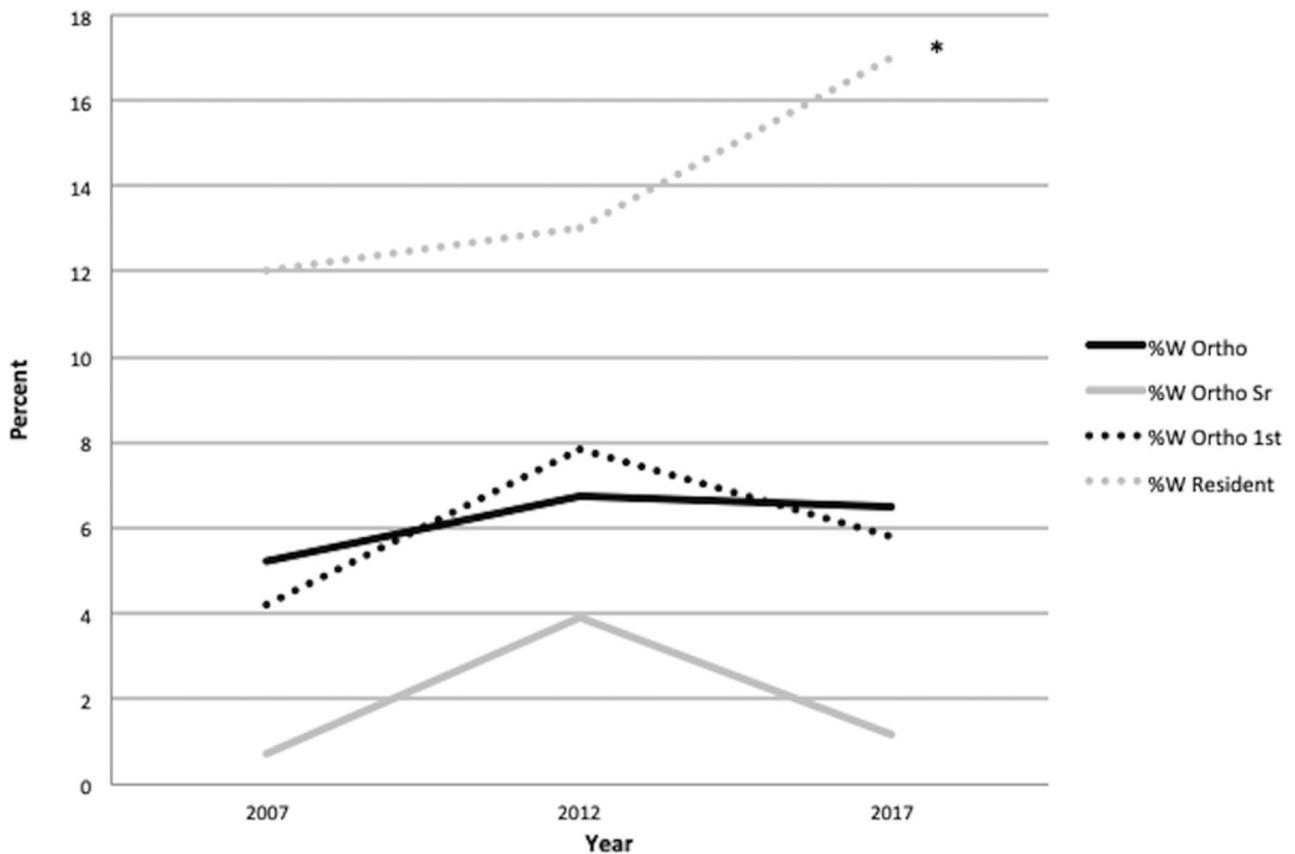


Fig. 2 This figure details the growth of women orthopaedic first and senior authorship versus practicing women orthopaedic surgeons and women orthopaedic residents from 2007 to 2017. *Indicates that the rate of growth of women orthopaedic residents was more than that of both women orthopaedic first authorship ($d = -7.5$, 95% confidence interval [CI], -8.7 to -5.9 ; $p = 0.008$) and of women orthopaedic surgeon senior authorship ($d = -11$, 95% CI, -13 to -9.7 ; $p = 0.001$); pooled estimated mean for comparison was 7.3, $p = 0.001$). %W Ortho = the proportion of practicing women orthopaedic surgeons, slope of best fit line, $m = 0.64$; %W Ortho 1st = the proportion of women orthopaedic surgeon first authors, slope of best fit line, $m = 0.79$; %W Ortho Sr = the proportion of women orthopaedic surgeon senior authors, slope of best fit line, $m = 0.23$; %W Resident = the proportion of women orthopaedic residents, slope of best fit line, $m = 2.5$.

diversity one of its strategic goals for 2018 to 2022 [5]. To achieve these goals, however, it is important to recognize and dismantle barriers to matriculation to training programs and subsequent career advancement for women physicians. One possible barrier to advancement for women orthopaedic surgeons is a lack of publication and academic productivity. From 1987 to 2017, the proportion of women in orthopaedic practice increased at both the attending and resident level; however, our study demonstrates that this was not matched by an equal increase in authorship by women orthopaedic surgeons. We found that, although there was a concurrent increase in the proportion of women first authors of academic orthopaedic publications, the proportion of senior authorship by women orthopaedic surgeons was lower than should be expected based on population proportions throughout our study period, and that the rate of increase in publication by women senior authors lagged behind the rate of increase in

women attending orthopaedic surgeons. Furthermore, the increased proportion of women residents outpaced the increase in both first and senior authorship by women during the past decade. These findings warrant further exploration because a discrepancy in publication productivity may negatively impact the career advancement of women orthopaedic surgeons and contribute to the overall lack of gender diversity within orthopaedics.

Limitations

Our study had several limitations. First, because this was an observational, cross-sectional analysis, we were only able to report on trends and are unable to determine the cause of the lower-than-expected rate of women authors that we observed. However, we believe that by comparing the proportion of women authors to the population proportion

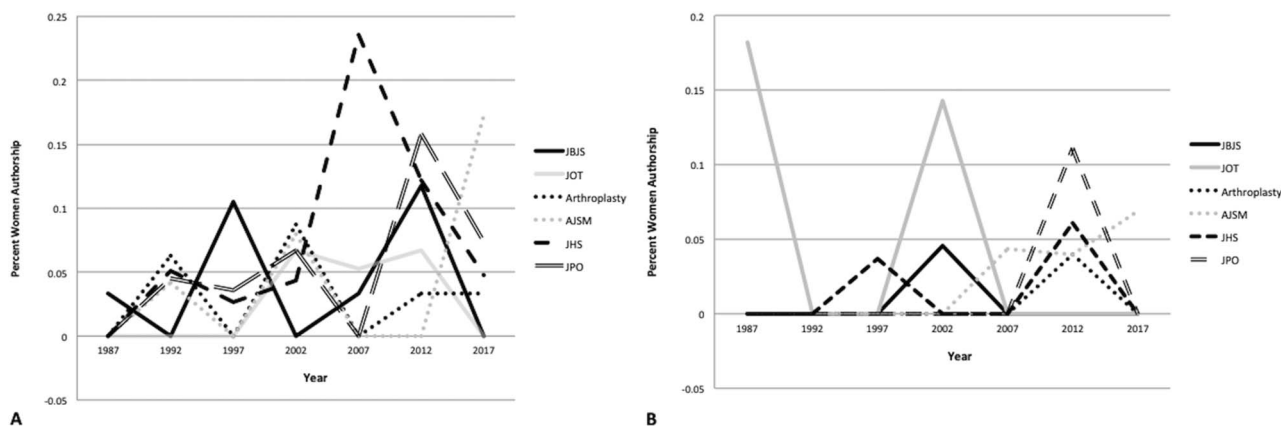


Fig. 3 This figure demonstrates the change in the proportion of (A) women who were first authors and (B) women who were senior authors between 1987 and 2017, by journal. By journal, there were no differences in the proportion of women who were first authors (pooled mean 0.075, $p = 0.435$), or senior authors (pooled mean 0.018, $p = 0.472$). *JBJS* = *Journal of Bone and Joint Surgery*; *JOT* = *Journal of Trauma*; *Arthroplasty* = *Journal of Arthroplasty*; *AJSM* = *American Journal of Sports Medicine*; *JHS* = *Journal of Hand Surgery*; *JPO* = *Journal of Pediatric Orthopaedics*.

of women orthopaedic surgeons at each time point, our study design allowed us to demonstrate that women are publishing less than would be expected despite the low absolute numbers of practitioners, and that our data should encourage further research into the nature and cause of these discrepancies. Second, we observed a very low raw number of women authors in our study sample, especially in the senior author role, and our study was subsequently underpowered to identify differences between men and women authors based on our secondary endpoints. We did not examine all articles published across the 30-year study period in all of the included journals; instead, we investigated a sample that consisted only of the January issue of each journal in 5-year intervals, which may have contributed to the low raw numbers we observed. This may have also resulted in an over- or underestimation of the true publication rates of women orthopaedic surgeons during the past 30 years. We based our design on several published studies examining gender discrepancies in medical peer-reviewed research, which used similar sampling techniques and adequately estimated their respective population characteristics [21, 27, 31, 38]; however, it remains possible that selection bias and sampling error could affect our results.

We used the American Medical Association (AMA) annual report to estimate the population proportion of women and men orthopaedic surgeons at each time point (except 2016, for which we used the AAOS annual census). The AMA annual reports are generated from the AMA Masterfile of physician data and include member and nonmember data. We used the AMA dataset because of its large size and consistency of publication over our study time period; however, our sample of orthopaedic surgeons may represent a larger proportion of community or

nonacademic surgeons than would a survey of the membership of the AAOS or another subspecialty organization. Therefore, our study may be used with caution when characterizing orthopaedic academia; we note, though, that for the years available for comparison, the AAOS membership population proportions of men and women practicing orthopaedic surgeons did not differ substantially from those of the AMA reports.

In our study, we did not examine factors relating to quality of research, including level of evidence or number of citations per each study, or the H-index of each author. Our data, therefore, should not confuse higher quantity of publications with higher quality, and further studies may be warranted to better assess this distinction. Finally, we were unable to identify the gender of the first or senior author of 35 articles, and we did not attempt to contact the authors of these articles. These exclusions may have led to an underestimation of authorship by women. There was no difference in the proportion of excluded papers between the six journals, and we believe that, given the general low proportion of women authors in our study, the excluded articles are unlikely to over-represent women orthopaedic surgeons or dramatically change our findings.

Proportion of Orthopaedic Studies Published by Women

From 1987 to 2017, only 1.7% (15 of 880) of senior authors and 4.4% (46 of 1038) of first authors of published academic orthopaedic studies were women orthopaedic surgeons. These data represent authorship across six major peer-reviewed orthopaedic publications, and the proportion of authorship by women orthopaedic surgeons was

equally low across all journals (including *the Journal of Hand Surgery* and the *Journal of Pediatric Orthopaedics*, which represent two of the three subspecialties with the most practicing women surgeons [15]). Our results are consistent with prior data that demonstrate low numbers of publications by women authors across a wide range of medical specialities [21, 27, 29, 31, 38], but are lower than reported rates of women authors of orthopaedic studies [31]. We believe that the differences in our data can be explained by the fact that we considered only women authors who are or were practicing orthopaedic surgeons at the time of publication in our final analysis. When we identified all women authors of any degree or specialty who published articles within our sample, we found that only 48% (46 of 96) of women who were first authors were orthopaedic surgeons, and that only 18% (15 of 82) of women who were senior authors were orthopaedic surgeons (data not presented). To avoid overrepresentation of their contributions in our final analysis, we specifically included only women orthopaedic surgeons to better identify barriers to career advancement specific to this group. Notably, a full one-third of studies published by the included women first authors and those published by included women senior authors were written by practitioners outside the United States (data not presented); while these were not excluded in our final analysis, this fact emphasizes that the true proportion of publications by US women orthopaedic surgeons is critically low and may still be overrepresented by our data.

Differences in the Proportion of Publications between Women and Men

We found that not only was there a low overall proportion of publications by women orthopaedic surgeons in the past 30 years, but that women in the senior author position also published less than would be expected based on the population of women in practice at all time points after 1987 (Table 1). We demonstrate that women orthopaedic surgeons surpassed 2% of senior authors only once in the past 30 years (2012, 4.7% [6 of 129]). This low number persists despite the overall growth of women practitioners and challenges the so-called “pipeline theory” (the lower raw number of women authors and leaders is due to the lower raw number of women in orthopaedic practice [14, 27, 31]). Instead, our findings indicate that external barriers contribute to lower-than-expected publication productivity. If all opportunities were equal, women surgeons should represent a proportion of authors similar to or greater than their overall population proportion, since women are more likely than men to pursue academic medicine [30]; yet we did not observe this in our study, and

it is consistently not borne out [20, 21, 27, 31, 38, 39]. Instead, our study contributes to a growing body of evidence that suggests objective measures of career productivity are impacted by external forces and supports the need for a comprehensive examination of what these other barriers may be.

Characteristics of Orthopaedic Publications Authored by Women versus Men

We found that there were no differences in the types of studies published by men and women authors during our study period. As earlier suggested, our study may have been underpowered to fully elucidate differences on this secondary endpoint, and future, larger studies may find a difference where we did not. We believe this may be the case for several reasons. First, we suspect that mentorship plays a less important role in the production of meta-analyses or reviews and some types of clinical research (for example, retrospective chart analyses), compared with basic science and technical studies (which often require substantial infrastructure and funding). These studies may therefore be more feasible for women authors who are known to have more difficulty obtaining academic mentors, a problem that has paradoxically worsened recently in the wake of high-profile workplace sexual harassment scandals [25, 28, 37]. Bias and the so-called Matilda effect (the general and systemic under-recognition of contributions by women scientists [35]) may also affect which types of studies by women authors are published and which are rejected [16, 18, 22, 35]. Particularly troubling research by Knobloch-Westerwick et al. [22] found that journal reviewers judged abstracts to have the lowest scientific quality if the author was a woman and the subject of the study pertained to a topic perceived to be “masculine” (such as computing). This finding suggests that women authors may be perceived as less qualified to produce high-quality research on topics that are traditionally dominated by men, and highlights a fundamental concern for women in orthopaedics, a field typically perceived as “masculine.” This may be especially problematic for those hoping to publish biomechanical studies, which play a critical role in advancing the field of orthopaedics and device design and may contribute to the low proportion of women publishing basic science and technical papers.

Proportion of Women Orthopaedic Surgeons Compared with Proportion of Women Authors

To further examine the “pipeline” effect on publication productivity, we examined the rates of growth of women authorship versus practicing women orthopaedic surgeons.

If the pipeline effect adequately explained the publication discrepancies we observed at each time point, we would expect that the raw number of women authors might be lower than practitioners at any given time, but that the overall rate of increase should mirror that of matriculation. This was not the case. In fact, the proportion of women in the senior author position in 2017 was 1.2% (2 of 162), less than the proportions of both women senior authors (2.0% or 2 of 101) and practicing women orthopaedic surgeons in 1987 (1.9%) [7]. Given that the average length of a woman orthopaedic surgeon's academic career is approximately 10 years [17], our 30-year study time period should have captured an increase in academic productivity reflected as an increase in senior authorship. Instead, we demonstrate a dropoff of productivity between first and senior authorship across the study timeframe (Fig. 1). Furthermore, we found an increased rate of matriculation of women orthopaedic residents in the past decade, but slower rates of growth of both women first and senior authors during the same time (Fig. 2). These findings are concerning, and directly contradict the "pipeline" theory as the sole explanation for persistent discrepancies in academic productivity. Some suggest that women's predisposition to leave their practice to raise a family contributes to this plateau in growth of women in senior positions, a tendency exacerbated by the fact that several large research grants are limited to practitioners within the first decade of their career [28], which often coincides with childbearing age. However, attributing the discrepancies we observe to motherhood alone is too simplistic an explanation and fails to acknowledge the complex factors impacting women's careers. Previous authors have reported that difficulties in obtaining and fostering relationships with academic mentors [25, 28, 37], discrepancies in allocation of research grants (despite parental status) [20], and experiences with harassment and bullying [4] all contribute to low productivity and physician burnout among women and contribute to the "leaky pipeline" of women (both mothers and nonmothers) leaving orthopaedics before becoming principal investigators or leaders. Our findings are consistent with those of the American College of Physicians, which recently issued a call to action to better understand these and other barriers to full gender parity across fields [14].

Conclusions

From 1987 to 2017, women orthopaedic surgeons authored a paucity of published orthopaedic studies, publishing less than would have been expected based on the total number of practicing women orthopaedic surgeons after 1987. While the total proportion of women in orthopaedic practice increased during the studied time period, the rate of increase of women senior authors lagged behind the overall increase in women surgeons. Though we cannot definitively identify the

cause of this discrepancy, we believe our study provides evidence that the "pipeline effect" is an insufficient explanation for this phenomenon, and that external barriers contribute to the persistent gender disparity within orthopaedic surgery. While a multifaceted and multidisciplinary approach is needed to dismantle both objective and subjective barriers for women orthopaedic surgeons, there are concrete actions that publishers of orthopaedic journals can take to improve the academic productivity and visibility of women orthopaedic surgeons. First, orthopaedic journals can perform internal reviews of their editorial processes and encourage a truly blinded review processes to minimize the Matilda effect and other biases (as exemplified by *Clinical Orthopaedics and Related Research*[®] and *Nature Publishing Group* [16, 24]). Alternatively, or in addition to evaluating their review processes, journals could actively seek out publications by women and underrepresented minorities to amplify their perspectives and visibility within the field. Encouraging young women orthopaedic surgeons' participation in communities such as the Ruth Jackson Orthopaedic Society and other professional women's groups may also foster mentorship, encourage collaboration, and lead to increased productivity and job satisfaction. Together, these actions may improve academic productivity and impact the recruitment and retention of the next generation of women orthopaedic surgeons.

Acknowledgments We would like to thank Maile Thayer Phillips MS, of the Department of Epidemiology of Microbial Diseases, Yale School of Public Health, New Haven, CT, USA, Dayna Olivia Walker PhD, of the Department of Management, San Francisco State University College of Business, San Francisco, CA, USA, and Hyunwoo Paco Kang MD, of the Department of Orthopaedic Surgery, Keck School of Medicine of USC, Los Angeles, CA, USA, for their assistance with our statistical analyses.

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