A Bibliometric Analysis of the Top-Cited Articles on Diabetic Foot Ulcers

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Research

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Abstract

Background: Citation analysis is a bibliometric method for appraising the impact of academic publications in any given scientific discipline. There is a paucity of literature concerning influential works on diabetic foot ulcers (DFUs).

Aims: To determine the top-cited articles in the field of DFU research.

Methods: A bibliometric analysis of citations indexed in the Scopus and the Web of Science databases was conducted in January 2021 to determine all publications related to DFU. The 50 top-cited articles that met the inclusion criteria were ranked. Articles were evaluated for several characteristics including year of publication, country of origin, authorship, publishing journal, topic categories, publishing type and level of evidence.

Results: The median number of citations per article in the list was 442 (interquartile range [IQR], 320-520), with a median of 21.8 citations (IQR, 16.5-34.5) per year since publication. The publication years ranged from 1986 to 2017, with 1998 accounting for the greatest number of studies (n = 7). The citation classics were published in 20 journals and originated from institutions in nine countries. The majority of the studies were clinical, of which expert-opinion/review with Level V evidence and clinical studies with Levels I and II evidence comprised the greater proportion in the list.

Conclusions: This study identified the top-cited articles and provides useful insights into the history and development of DFU research. Our findings may serve as a quick reference for education curriculums and clinical practice, in addition to providing a foundation for further studies on this topic.

Introduction

Diabetic foot ulcer (DFU) is a common and much feared complication of diabetes. Currently, there are 463 million adults living with diabetes worldwide, and approximately 6.3% of them may suffer from foot ulcers.[1] At the initial presentation, more than half of DFUs are clinically infected, leading to substantial morbidity, a significantly impaired quality of life, and prolonged hospitalization, and preceding 80% of all non-traumatic lower extremity amputations.[2,3] The healthcare expenditures associated with the management of DFUs are also considerably high, consuming about one-third of the total cost of diabetic care.[4] Tremendous studies have been conducted and published over the past decades given the serious consequence and huge burden of DFUs on patients, their families, and society. However, such a rapid growth of the DFU literature would be challenging not only with regard to acquainting novice researchers with the most salient topics, but also concerning the thorough identification of this field to guide future studies.

Citation analysis is a quantitative bibliometric method for appraising the impact of academic publications in a particular discipline. Although the number of citations is not the only surrogate for determining the quality of scholarly works, it provides valuable data to determine classics that have

shaped medical practice, fostered new research ideas, and predicted emerging trends and hotspots.[5–7] Several citation analyses have been conducted regarding various medical specialties and subspecialties, including diabetes[8–10] and podiatric medicine.[11–13] While studies on the diabetic foot comprise over a quarter of the top-cited publications in the field of foot and ankle surgery,[12] only a single bibliometric review has specifically addressed DFU to date. However, that citation analysis was limited to few articles retrieved within a short time span from 2007 to 2018, which would be insufficient to reflect the evolution of the DFU research.[14]

Therefore, we performed the current study to compile a comprehensive list of the most cited works that have made key contributions to DFU over the past several decades. With this information, we intend to provide a historical perspective of scientific progress, determine the status quo of research, and highlight future trends in the field of DFU.

Methods

Institutional review board approval was not required given the publicly available nature of the data without protected health information. In January 2021, a search of the Scopus (www.scopus.com) and the Web of Science (www.webofscience.com) databases was conducted as described in previous studies.[15–17] To yield the broadest results, articles were queried in each database by using the following Boolean search phrase: [“diabet* foot” OR (infection AND foot AND “diabetes mellitus”) OR (osteomyelitis AND foot AND “diabetes mellitus”) OR (“foot ulcer*” AND “diabetes mellitus”)]. No restrictions were placed in terms of language, publication date, or journal. All publications were organized in descending order according to the number of citations. Two authors independently evaluated each manuscript to determine whether the contents were dedicated to the diagnosis, therapy, prognosis, or economic analysis of DFU. Since infection and osteomyelitis are progressive and deteriorative conditions associated with DFU, relevant studies on diabetic foot infection and diabetic foot osteomyelitis were also enrolled. Articles were excluded if their primary focus was not DFU, even if the topic was peripherally discussed. Furthermore, publications such as editorials, letters to the editor, commentaries, and meeting abstracts were excluded. This process was repeated until the 50 most cited articles on DFU were retrieved, and any discrepancies between authors were resolved by consensus. The methodology is illustrated as a flowchart in Fig. 1.

The following details were recorded for each of the top-cited articles that met the inclusion criteria: authorship, year of publication, publishing journal, country and institution of origin, study design (randomized controlled trial, cohort study, case-control study, case series, case report, systematic review, expert-opinion/review, or basic science), and research area. The country of the affiliation was identified based on the geographic location of the corresponding author. If the contact author had two or more affiliations from different countries, the first one was recorded. The research areas were sorted according to the Web of Science categories/classification. The level of evidence for clinical studies was assigned on a scale of I to V based on *the Journal of Bone & Joint Surgery-American Volume* guidelines.[18]

Specifically, the level of evidence for systematic reviews was determined by that of the literature analyzed, whereas review articles in a nonsystematic fashion were coded into the expert-opinion category. Citation density, defined as the number of citations per year, was also extracted for the identified articles.

Results

The initial search yielded 28,049 and 23,594 preliminary results in Scopus and Web of Science, respectively. Table 1 provides a list of the top-cited articles in descending order according to the number of citations in Scopus. This list actually consisted of 56 articles because six unique articles were retrieved from each database.

The top three articles were each cited more than 1,000 times, and the median number of citations per article in the list was 442 (interquartile range [IQR], 320-520). The citation density spanned from 181.3 to 12.6, with a median of 21.8 citations per year since publication (IQR, 16.5-34.5). The publication years ranged from 1986 to 2017, and the greatest number of studies were published in 1998 (*n* = 7). Twenty journals were represented by the citation classics, with *Diabetes Care* having the highest number of publications (*n* = 24; Table 2). Accordingly, the majority of the top-cited articles were published in specialty periodicals, and Endocrinology/Metabolism was the most popular Web of Science research category with 33 studies.

Although all the studies were published in the English language, there was some diversity in terms of the country of origin. More than half of the articles originated from the United States (*n* = 35), followed by the United Kingdom (*n* = 11), the Netherlands (*n* = 3), and Sweden (*n* = 2). China, Germany, Italy, Korea, and Portugal each contributed one article to the list. The University of Washington Veterans Affairs Puget Sound Healthcare System was the most prolific institution for the topic of interest with eight studies, whereas the Manchester Royal Infirmary/University of Manchester produced six articles and was the most prominent institution from outside the United States.

Regarding the corresponding authors, 12 researchers authored two or more of the top-cited articles. Professor Andrew J M Boulton was the most productive contact author with 5 publications, followed by David G Armstrong and Aristidis Veves, who were the corresponding authors in four and three articles respectively. The authorships also included nine committees and panels, of which the Infectious Diseases Society of America, the American Diabetes Association, and the Diabetic Ulcer Study Group each developed two articles.

The majority of the studies were clinical, with six papers representing some type of basic science research. Among the top clinical articles, expert-opinion/review publications (*n* = 15), cohort studies (*n* = 14), and randomized controlled trials (*n* = 12) were the most prevalent study design (Table 3). Accordingly, the most common level of evidence was V. Second to this were Levels I and II, with 13 studies each falling into the categories (Figure 2).

Discussion

In this study, we queried the Scopus and Web of Science databases to rank the top-cited articles with respect to DFU research. Most of the articles were published in specialty journals and originated from academic institutions in the United States. Expert-opinion/review with Level V evidence and clinical studies with Levels I and II evidence comprised a majority of the publications in the list.

Currently, several public and commercial databases are available for citation analysis, but none is considered superior.[19,20] Web of Science was the first of its kind and is the most commonly used bibliometric resource, while Scopus covers more expanded scientific fields and focuses on contemporary publications.[6,16,17] Therefore, both databases were queried in this study to ensure comprehensive article coverage. We found that the number of citations per article returned by Scopus was generally greater than that returned by Web of Science, and each contained unique citation classics in the list. A previous analysis also revealed that 80% of the top-cited articles dedicated to obstetrics and gynecology were acquired from both resources.[17] This observation can be explained by the different contents covered and documents cited between the two databases. It has been proposed that Scopus indexes a wider journal range than Web of Science and retrieves a greater proportion of citations from non-English-language sources.[21]

The first three articles in this list, each passing the 1,000-citation mark, were comprehensive reviews published in non-specialty journals, whereas a total of six consensus statements by different expert committees were released in specialty ones. Our findings may imply that non-specialty periodicals have a broader readership and a greater potential to be cited, while specialty ones cater to the specialized needs of audiences within the field.[6] We also found a diversity of Web of Science categories for these specialty periodicals, including Endocrinology/Metabolism, Infectious Diseases/Microbiology, Orthopedics, and Peripheral Vascular Disease. This multidisciplinary nature of publishing journals is in accordance with the modern algorithm for the management of DFU. The deployment of diabetic foot teams has been widely advocated to improve outcomes and processes in patient care.[22] Since these teams are composed of professionals in a variety of disciplines, each member may focus on and preferentially obtain citations from a few reputable journals in their respective fields of expertise.[10,23]

Although 79% of adults with diabetes live in developing countries, academic institutions in developed countries have exerted overwhelming influence on diabetes-related research.[8,10] Our geographic analysis, consistent with previous studies of endocrinology and metabolism topics,[24,25] demonstrated that the United States was the most prolific country by a significant margin with respect to citation classics. A plausible reason for this dominance may be the large size of the US scientific community (e.g., the American Diabetes Association), its abundant research budget and output, and a tendency for American authors to cite material from their own country.[26] Interestingly, we also observed that nine consortiums contributed to 12 top-cited articles in the list, including six clinical practice guidelines, five randomized controlled trials, and one prospective community-based cohort study. Owing to the interdisciplinary and

miscellaneous approaches in the management of DFU, international and regional collaboration is efficient for conducting high-quality research with a large population, in addition to providing robust conclusions and recommendations. It is generally believed that these well-designed studies and latest consensus documents could become heavily cited in the literature.

Preclinical research provides insights into pathophysiological mechanisms and allows the rigorous evaluation of pilot studies in experimental models, which is important for expanding knowledge about a disease. Prior bibliometric analyses revealed a substantial contribution of basic science works in top lists, accounting for 24–42% of citation classics in diabetes,[10] osteoporosis,[27] and orthopedic surgery.[28,29] In contrast, there were only six non-clinical articles in our investigation, including three exhaustive reviews on the molecular biology of DFU healing and recent advances in wound dressing, in addition to two *in vitro* and one *in vivo* study. The explanation for this observation is unknown, but it is probably attributed to the specific locations of the different types of studies. Nolan et al.[23] identified 659 different journals that had published at least one relevant report pertaining to diabetic foot disease in 2012, and found that 17.3% of them were classified into the “basic science/research” category for specialty or primary readership. The value would fall to 3.85% if journals with at least 10 relevant articles were enrolled.[23] This published volume discordance between clinical and non-clinical articles highlights the potential requirements for much development of basic science research in future.

Limitations

This citation analysis has inherent limitations that require consideration. Similar to previously described methods, first and possibly the most significant is that we were unable to account for self-citations, citations in textbooks and lectures, and authors’ predilection to cite articles from journals where they sought to publish.[29–31] The second weakness is related to two biases in citation practice, namely “obliteration by incorporation phenomenon” and the “snowball effect”. The main idea behind the former is that classic papers are gradually being cited less as their substances become integrated into current knowledge,[32] and the latter indicates a tendency to cite articles because of an abundance of previous citations.[33] Third, a query for 50 articles, as within any other number, is arbitrary and may exclude other influential works from the list. However, some authors[34–36] believed that 50 represents a reasonable number of articles to offer a framework for physicians, researchers, and trainees in a specific subject area. Finally, this cross-sectional study acquired the count profiles at a time point, and the most recent articles were at a disadvantage because of the clear time effect in bibliometric analysis.[37] Therefore, it would be necessary to update this list as the field continues to progress. Since the primary aim of our study was to rank highly influential works on DFU research by using total citation counts, these limitations should not significantly affect our conclusions.

Conclusion

This study identified the top-cited DFU articles and provided useful insights into the history and development of DFU research. This list could serve as a quick reference for the educational purposes and clinical practice, in addition to providing a foundation for further studies on this topic.

Declarations

Ethics approval and consent to participate

Not applicabl

Consent for publication

Not applicable

Availability of data and material

All data, models, or code generated or used during the study are available from the corresponding author by request.

Competing interests

The authors declare that they have no competing interests

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Authors' contributions

Dr. Hongye Li and Dr. Lin Li had full access to all of the data in the study and take responsibility for the integrity of the data and the accuracy of the data analysis.

Concept and design: H.L., L.L.

Acquisition, analysis, or interpretation of data: J.Y., C.L., H.L. Y.C. W.Z.

Drafting of the manuscript: J.Y., L.L., C.L.

Tables and Figures construction: Y.C., W.Z.

Administrative, technical, or material support: S.W., L.L.

Supervision: S.W., H.L., L.L.

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Tables

Table 1. Top 50 cited articles on diabetic foot ulcers according to the number of citations in Scopus

Citations, Scopus, n (citation density)	Citations, Web of Science, n (citation density)	Authors	Title	Year
1661 (110.7)	1510 (100.7)	Singh et al.	Preventing foot ulcers in patients with diabetes	2005
1297 (86.5)	1208 (80.5)	Boulton et al.	The global burden of diabetic foot disease	2005
1207 (80.5)	1171 (78.1)	Falanga	Wound healing and its impairment in the diabetic foot	2005
795 (99.4)	762 (95.3)	Lipsky et al.	2012 Infectious Diseases Society of America clinical practice guideline for the diagnosis and treatment of diabetic foot infections	2012
782 (37.2)	685 (62.3)	Ramsey et al.	Incidence, outcomes, and cost of foot ulcers in patients with diabetes	1999
758 (47.4)	637 (39.8)	Lipsky et al.	Diagnosis and treatment of diabetic foot infections	2004
720 (34.3)	628 (29.9)	Reiber et al.	Causal pathways for incident lower-extremity ulcers in patients with diabetes from two settings	1999
694 (31.5)	600 (27.3)	Armstrong et al.	Validation of a diabetic wound classification system. The contribution of depth, infection, and ischemia to risk of amputation	1998
660 (36.7)	553 (30.7)	Abbott et al.	The North-West Diabetes Foot Care Study: incidence of, and risk factors for, new diabetic foot ulceration in a community-based patient cohort	2002
655 (43.7)	576 (38.4)	Armstrong et al.	Negative pressure wound therapy after partial diabetic foot amputation: a multicentre, randomised controlled trial	2005
588 (34.6)	546 (32.1)	Jeffcoate and Harding	Diabetic foot ulcers	2003
561 (21.6)	419 (16.1)	Caputo et al.	Assessment and management of foot disease in patients with diabetes	1994
544 (181.3)	524 (174.7)	Armstrong et al.	Diabetic foot ulcers and their recurrence	2017
520 (27.4)	487 (25.6)	Veves et al.	Graftskin, a human skin equivalent, is effective in the management of noninfected neuropathic diabetic foot ulcers: a prospective randomized multicenter clinical trial	2001
518 (15.2)	369 (10.9)	Edmonds et al.	Improved survival of the diabetic foot: the role of a specialized foot clinic	1986

511 (23.2)	433 (16.7)	Wieman et al.	Efficacy and safety of a topical gel formulation of recombinant human platelet-derived growth factor-BB (becaplermin) in patients with chronic neuropathic diabetic ulcers. A phase III randomized placebo-controlled double-blind study	1998
511 (18.3)	417 (14.9)	Veves et al.	The risk of foot ulceration in diabetic patients with high foot pressure: a prospective study	1992
497 (19.1)	421 (16.2)	Young et al.	The prediction of diabetic neuropathic foot ulceration using vibration perception thresholds. A prospective study	1994
492 (41.0)	427 (35.6)	Boulton et al.	Comprehensive foot examination and risk assessment: a report of the task force of the foot care interest group of the American Diabetes Association, with endorsement by the American Association of Clinical Endocrinologists	2008
483 (20.1)	401 (16.7)	Steed et al.	Effect of extensive debridement and treatment on the healing of diabetic foot ulcers	1996
481 (40.1)	455 (37.9)	Prompers et al.	Prediction of outcome in individuals with diabetic foot ulcers: focus on the differences between individuals with and without peripheral arterial disease. The EURODIALE Study	2008
475 (33.9)	337 (24.1)	Frykberg et al.	Diabetic foot disorders. A clinical practice guideline (2006 revision)	2006
473 (18.9)	403 (16.1)	Steed et al.	Clinical evaluation of recombinant human platelet-derived growth factor for the treatment of lower extremity diabetic ulcers	1995
466 (27.4)	430 (25.3)	Marston et al.	The efficacy and safety of Dermagraft in improving the healing of chronic diabetic foot ulcers: results of a prospective randomized trial	2003
464 (22.1)	363 (17.3)	Boyko et al.	A prospective study of risk factors for diabetic foot ulcer. The Seattle Diabetic Foot Study	1999
460 (18.4)	339 (13.6)	Grayson et al.	Probing to bone in infected pedal ulcers. A clinical sign of underlying osteomyelitis in diabetic patients	1995
458 (35.2)	411 (31.6)	Prompers et al.	High prevalence of ischaemia, infection and serious comorbidity in patients with diabetic foot disease in Europe. Baseline results from the Eurodiale study	2007
442 (22.1)	382 (19.1)	Pham et al.	Screening techniques to identify people at high risk for diabetic foot ulceration: a prospective multicenter trial	2000
442 (21.0)	124 (5.9)	American Diabetes Association	Consensus Development Conference on Diabetic Foot Wound Care: 7-8 April 1999, Boston, Massachusetts. American Diabetes Association	1999
406 (21.4)	329 (17.3)	Armstrong et al.	Off-loading the diabetic foot wound: a randomized clinical trial	2001

383 (27.4)	363 (25.9)	Lavery et al.	Risk factors for foot infections in individuals with diabetes	2006
360 (30.0)	347 (28.9)	Choi et al.	In vivo wound healing of diabetic ulcers using electrospun nanofibers immobilized with human epidermal growth factor (EGF)	2008
360 (20.0)	334 (18.6)	Lobmann et al.	Expression of matrix-metalloproteinases and their inhibitors in the wounds of diabetic and non-diabetic patients.	2002
352 (20.7)	311 (18.3)	Moulik et al.	Amputation and mortality in new-onset diabetic foot ulcers stratified by etiology	2003
352 (16.0)	266 (12.1)	Reiber et al.	The burden of diabetic foot ulcers	1998
341 (12.6)	287 (10.6)	Apelqvist et al.	Long-term prognosis for diabetic patients with foot ulcers	1993
340 (17.9)	299 (15.7)	Oyibo et al.	A comparison of two diabetic foot ulcer classification systems: the Wagner and the University of Texas wound classification systems	2001
334 (19.6)	330 (19.4)	Sheehan et al.	Percent change in wound area of diabetic foot ulcers over a 4-week period is a robust predictor of complete healing in a 12-week prospective trial	2003
329 (13.2)	265 (10.6)	McNeely et al.	The independent contributions of diabetic neuropathy and vasculopathy in foot ulceration. How great are the risks?	1995
326 (13.6)	272 (11.3)	Gentzkow et al.	Use of dermagraft, a cultured human dermis, to treat diabetic foot ulcers	1996
322 (21.5)	284 (18.9)	Cavanagh et al.	Treatment for diabetic foot ulcers	2005
322 (15.3)	285 (13.6)	Smiell et al.	Efficacy and safety of becaplermin (recombinant human platelet-derived growth factor-BB) in patients with nonhealing, lower extremity diabetic ulcers: a combined analysis of four randomized studies	1999
319 (14.5)	251 (11.4)	Lavery et al.	Practical criteria for screening patients at high risk for diabetic foot ulceration	1998
318 (26.5)	325 (27.1)	Dowd et al.	Polymicrobial nature of chronic diabetic foot ulcer biofilm infections determined using bacterial tag encoded FLX amplicon pyrosequencing (bTEFAP)	2008
316 (14.4)	239 (10.9)	Frykberg et al.	Role of neuropathy and high foot pressures in diabetic foot ulceration	1998
315 (22.5)	326 (23.3)	Blakytny and Jude	The molecular biology of chronic wounds and delayed healing in diabetes	2006
311 (14.1)	256 (11.6)	Abbott et al.	Multicenter study of the incidence of and predictive risk factors for diabetic neuropathic foot ulceration	1998

310 (12.9)	246 (10.3)	Faglia et al.	Adjunctive systemic hyperbaric oxygen therapy in treatment of severe prevalently ischemic diabetic foot ulcer. A randomized study	1996
309 (14.0)	263 (12.0)	Mayfield et al.	Preventive foot care in people with diabetes	1998
307 (43.9)	311 (44.4)	Moura et al.	Recent advances on the development of wound dressings for diabetic foot ulcer treatment–a review	2013
306 (15.3)	264 (13.2)	Apelqvist and Larsson	What is the most effective way to reduce incidence of amputation in the diabetic foot?	2000
298 (14.2)	272 (13.0)	Margolis et al.	Healing of diabetic neuropathic foot ulcers receiving standard treatment. A meta-analysis	1999
283 (31.4)	279 (31.0)	Lu et al.	Comparison of bone marrow mesenchymal stem cells with bone marrow-derived mononuclear cells for treatment of diabetic critical limb ischemia and foot ulcer: a double-blind, randomized, controlled trial	2011
263 (32.9)	269 (33.6)	Bakker et al.	Practical guidelines on the management and prevention of the diabetic foot 2011	2012
254 (15.9)	331 (20.7)	Boulton et al.	Neuropathic diabetic foot ulcers	2004
231 (19.2)	347 (28.9)	Blume et al.	Comparison of negative pressure wound therapy using vacuum-assisted closure with advanced moist wound therapy in the treatment of diabetic foot ulcers: a multicenter randomized controlled trial	2008

Table 2 Journal of origin

Journal	Web of Science categories/classification	Number of Articles
Diabetes Care	Endocrinology & Metabolism	24
Lancet	General & Internal Medicine	5
Diabetologia	Endocrinology & Metabolism	4
The New England Journal of Medicine	General & Internal Medicine	3
Clinical Infectious Diseases	Immunology; Infectious Diseases; Microbiology	2
Diabetes/Metabolism Research and Reviews	Endocrinology & Metabolism	2
Diabetic Medicine	Endocrinology & Metabolism	2
JAMA-Journal of the American Medical Association	General & Internal Medicine	2
Wound Repair and Regeneration	Cell Biology; Dermatology; Research & Experimental Medicine; Surgery	1
Diabetes Research and Clinical Practice	Endocrinology & Metabolism	1
Acta Biomaterialia	Engineering; Materials Science	1
Biomaterials	Engineering; Materials Science	1
Archives of Internal Medicine	General & Internal Medicine	1
Journal of Internal Medicine	General & Internal Medicine	1
QJM: An International Journal of Medicine	General & Internal Medicine	1
Journal of Foot & Ankle Surgery	Orthopedics; Surgery	1
Plos One	Science & Technology - Other Topic	1
American Journal of Surgery	Surgery	1
Journal of the American College of Surgery	Surgery	1
Journal of Vascular Surgery	Surgery; Cardiovascular System & Cardiology	1

Table 3 Articles classified by study type

Study type	Number of articles
Basic science	6
Randomized controlled trial	12
Cohort study	14
Case-control study	3
Case series	4
Case report	0
Systematic review	2
Expert-opinion/review	15

Figures

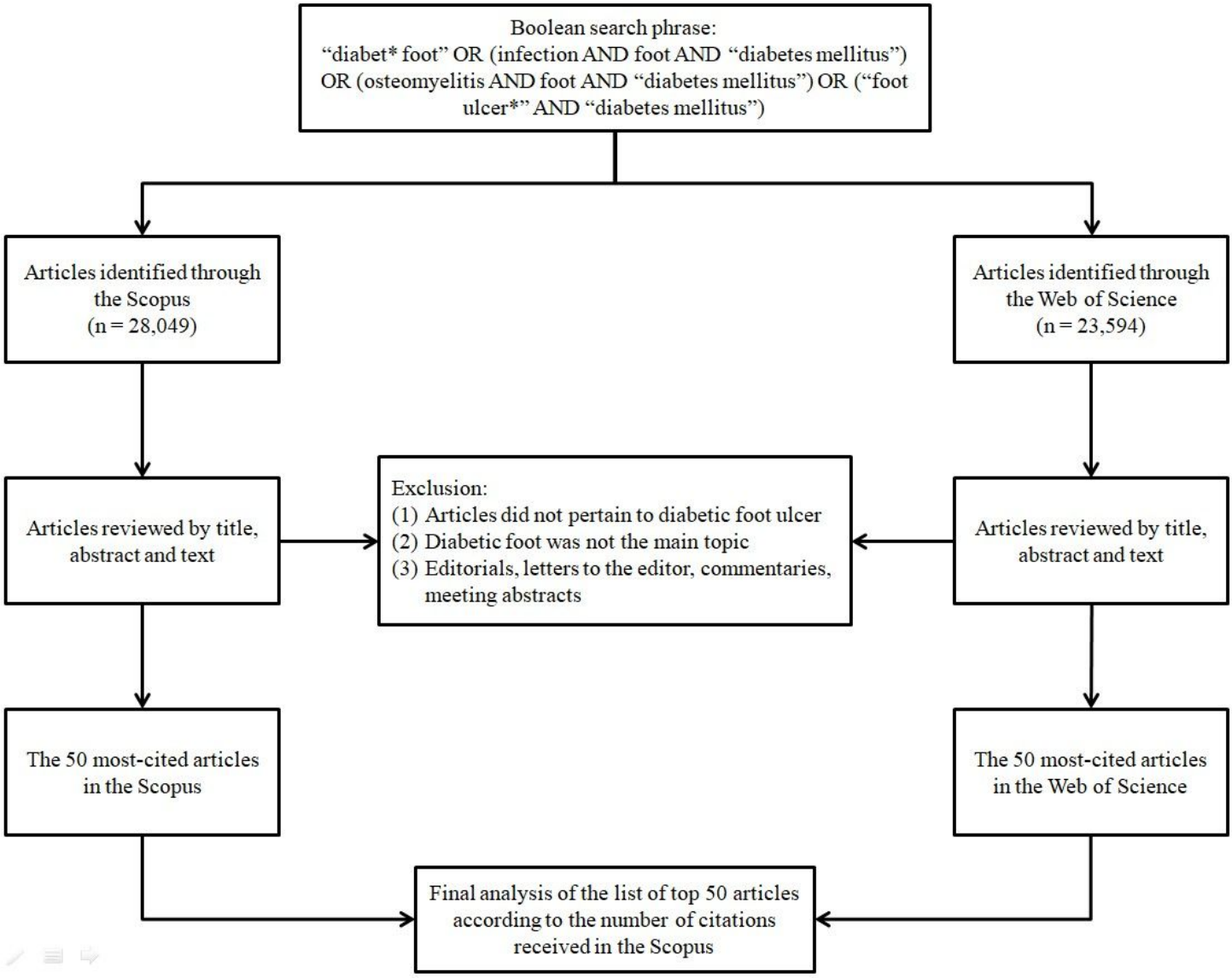

Figure 1

Study Flow Diagram

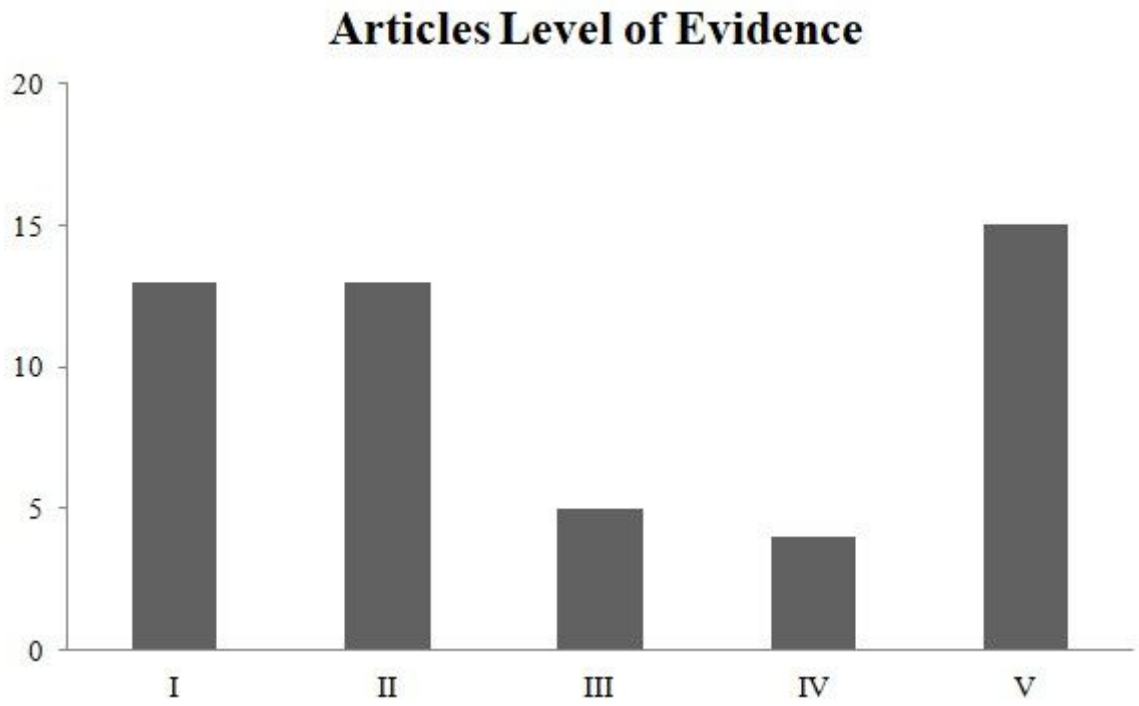

Figure 2

Total Number of Articles by Level of Evidence