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A scientometrics analysis and visualisation of diabetic foot research from 1955 to 2022

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Abstract

Diabetic foot (DF) has become a serious health problem in modern society, and it has been a hotspot of research for a long time. However, little scientometric analysis has been carried out on DF. In the present study, we analysed 8633 literature reports on DF in the Web of Science Core Collection from database inception until April 23, 2022. VOSviewer (Centre for Science and Technology Studies at Leiden University, Leiden, the Netherlands) and CiteSpace (College of Computing and Informatics, Drexel University, Philadelphia, United States) were employed to address high-impact countries and institutions, journals, references, research hotspots, and key research fields in DF research. Our analysis findings indicated that publications on DF have increased markedly since 2016 and were primarily published in the United States of America. The recent studies focus on the amniotic membrane, foot ulcers, osteomyelitis, and diabetic wound healing. The five keyword clusters, which included DF ulcer and wound healing therapies, management and guidelines, neuropathy and plantar pressure, amputation and ischemia, and DF infection and osteomyelitis, are helpful for enhancing prevention, standardising treatment, avoiding complications, and improving prognosis. These findings indicated a method for future therapies and research in DF.

KEYWORDS

CiteSpace, diabetic foot, scientometrics analysis, visualisation, VOSviewer

Key Messages

- this study is the first extensive scientometrics analysis of diabetic foot research
- this work provides insights into the evolution and trends in research on diabetic foot
- publication has increased remarkably since 2016, and papers are primarily from the United States of America
- the recent hotspots of diabetic foot are amniotic membrane, foot ulcer, osteomyelitis, and diabetic wound healing

Jin-Ming Shen and Jie Chen contributed equally to this work.

- five keyword clusters were obtained and included therapies for diabetic foot ulcer and wound healing, management and guidelines, neuropathy and plantar pressure, amputation and ischemia, and diabetic foot infection and osteomyelitis

1 | INTRODUCTION

Diabetic foot (DF) is defined as foot infection, ulceration, or tissue destruction in a person with diabetes mellitus (DM), accompanied by peripheral neuropathy and/or peripheral artery disease (PAD) in the lower extremity.[1] DF is one of the most common complications in patients with DM and directly affects the life quality of patients and leads to a 12% to 15% increase in disease-related costs.[2] DF-related morbidity, mortality, and health care costs have become a significant burden.[3] To summarise the hotspots and difficulties systematically is likely to improve prevention and therapeutic strategies to promote the efficacy of DF treatment.

Scientometrics analysis provides quantitative insights into the development of a given topic, including trends of outputs and focuses, collaboration networks, thematic research clusters, historic evolution patterns, and co-citation networks.[4] Compared with descriptive reviews, scientometrics has the advantage of quickly identifying key issues of interest and guiding future research. In recent years, an increasing number of studies have applied scientometrics methods to investigate various aspects of DM and obtained important information. Studies on diabetic peripheral neuropathic pain have primarily focused on endocrinology, metabolism, and clinical neurology with the recent emerging keywords of "inflammation," "activation," "phenotype," "adult," and "receptor".[5] The hotspots of diabetic neuropathy (DN) studies from 2016 to 2020 include microribonucleic acids, signal transduction pathways, single-nucleotide polymorphisms, mesangial cells and podocytes, plant extracts, and hypoglycemic drug treatment.[6] Bibliometrics analysis revealed that lower limb amputation, diabetic foot infection (DFI), and the treatment and management of diabetic foot ulcer (DFU) were the hotspots of global DFU research.[7] In studies of genome-wide association studies in diabetes, deoxyribonucleic acid methylation and genetic variation are two hotspots, and the identification of genetic phenotypes associated with adiposity, metabolic memory, pancreatic islets, and inflammation is the leading trend in research.[8] An analysis of DF research in New Zealand indicated that the focus on indigenous Māori was limited and that the incidence of diabetes-related amputations was higher for these individuals, which indicates that future research must focus on reducing inequalities in diabetes-related outcomes for the Māori.[9] The findings of all the aforementioned studies suggest that the United States has occupied a leading position in DM studies.[5-9] To date, no analysis has focused on DF; therefore, scientometrics analysis may help scientists understand the current situation and the developing trends of DF and display the hotspot themes, key documents, and key authors.[10]

In this study, we conducted a scientometrics analysis of DF and proposed future research directions. We analysed and summarised the clusters of co-occurring keywords in DF, including management and guidelines, therapies to treat DFU and achieve wound healing, DN and plantar pressure, amputation and ischemia, and DFI and osteomyelitis. This is the first extensive scientometrics analysis of DF research. The results of the present scientometrics analysis help scientists explore key evidence and highlight the emerging trends in DF research.

2 | METHODS

2.1 | Literature source and search strategy

The data utilised in scientometrics analysis were downloaded from the Science Citation Index Expanded database in the Web of Science Core Collection (WoSCC) from database inception until April 23, 2022. The workflow of scientometrics research is shown in Figure 1. We searched WoSCC using the topical retrieval terms: ("diabetic foot" OR "diabetes foot" OR "diabetes feet" OR "diabetic feet") NOT ("comment" OR "commentary"). No language or time refinements were applied. Duplication was removed using CiteSpace.

2.2 | Methods of analysis

We aimed to address the hotspots and future trends of DF by analysing the co-citation of documents and co-occurring keywords. However, we attempted to provide a measure of the DF research network, which included countries, institutions, authors, journals, and publications.

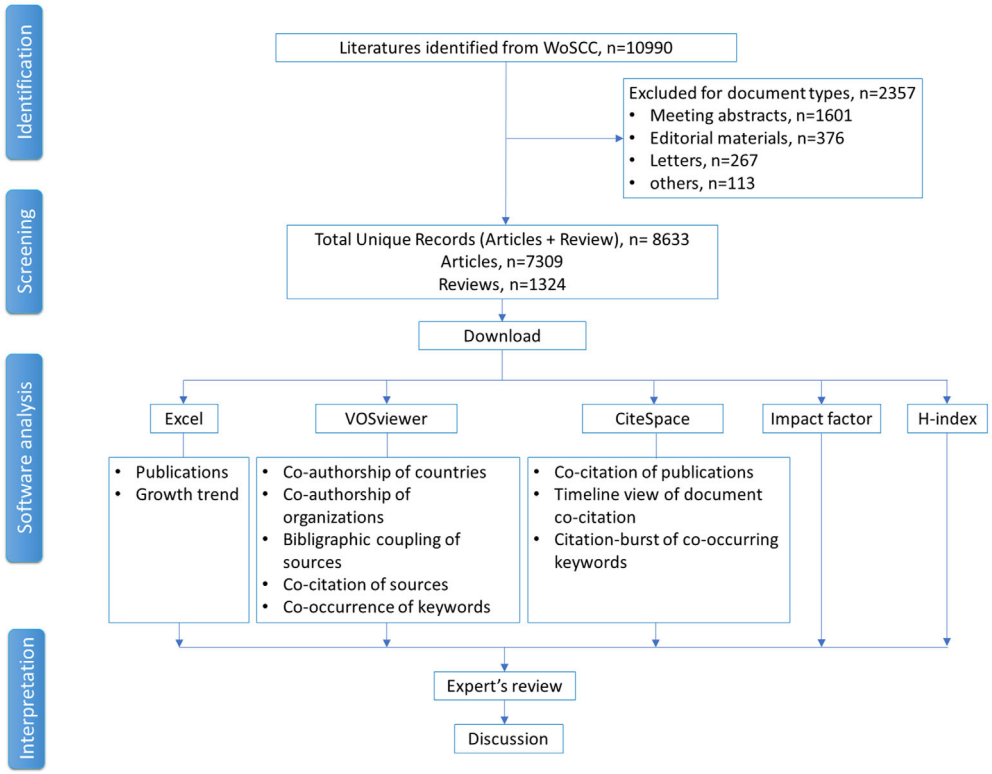

FIGURE 1 Flow chart of the scientometrics analysis

VOSviewer (1.6.18; Centre for Science and Technology Studies at Leiden University, Leiden, the Netherlands) was utilised for bibliometric analysis, including co-authorship of countries and organisations, bibliographic coupling of sources, co-citation of sources, and co-occurrence of keywords. CiteSpace (5.8.R3; College of Computing and Informatics, Drexel University, Philadelphia, United States) was utilised for co-citation of publications, timeline view of document co-citation network, and co-occurring keywords citation-burst analysis. In the visualisation maps, the node size represents the number of publications, and the node colour represents a cluster. The impact factors (IFs) of the journals were extracted from the journal citation report from Web of Science (WoS) (Clarivate, Philadelphia, PA), and the *high citation indexes* (H-indexes) were downloaded from Scimago Journal and Country Rank (https://www.scimagojr.com/journalrank.php).

3 | RESULTS

3.1 | Yearly publication of diabetic foot studies

Literature reports on DF ($n = 8633$) were identified and included 7309 articles and 1324 reviews. Based on the search results of DF in WoSCC, the growth of publications on this topic can be divided into three stages: the beginning stage from 1955 to 1998, the slow growth stage from 1999 to 2015, and the fast growth stage from 2016 to 2022 (Figure 2A). In the first 44 years, 519 papers were published, and the annual publication accounted for less than 1% of the total publications each year. Since 2016, the annual publications on DF have numbered over 500 papers, and the rapid growth in DF can be explained by two factors. First, DM is a leading global health concern in an ageing society,[11] and the incidence of DFU is increasing among elderly patients with DM.[12] Second, in 2021, the World Health Organisation (WHO) launched the Global Diabetes Compact, published during the 100th anniversary of the discovery of insulin, in response to the growing burden of diabetes(https://www.who.int/publications/m/item/the-global-diabetes-compact), and on October 25, 2016, the State Council of China released the Healthy China 2030 plan.[13] Multiple countries have launched a series of plans on public health strategies. For bibliometrics analysis, more data may lead to more reliable results.

As shown in Figure 2B, the top five research fields included surgery, dermatology, endocrinology, metabolism, orthopaedics, and general internal medicine. Among these fields, surgery accounts for 23.8% of the published articles regarding DF. Refractory wounds caused by DF are a challenge for clinical surgery.[14] The current treatment of DF aims to heal the wound,

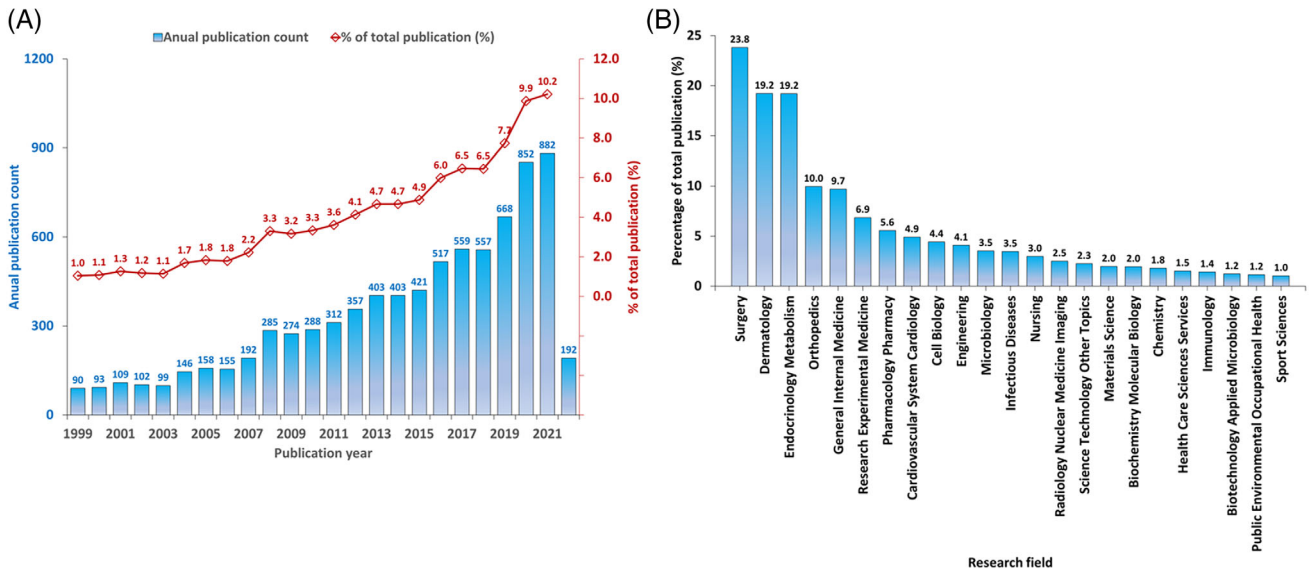

FIGURE 2 Publication data on diabetic foot research from 1955 to 2022. A, Annual publication of diabetic foot studies. B, The research fields of diabetic foot studies

reduce complications, and avoid amputation, and timely surgical treatment of patients with DF may prevent foot ulcers and amputation.[15] Dermatology accounted for 19.2% of publications. The skin protects individuals from the outside environment, and any damage to the skin allows microbes to enter the body and can lead to infection.[16] DFU in diabetics is a wound that penetrates the dermis of the skin below the ankle.[17] Endocrinology, metabolism, and general internal medicine accounted for 28.9% of the publications. The treatment of DF primarily includes blood glucose control, supportive therapy, anti-infection, maintenance of internal environmental stability, and wound management.[18] A systematic analysis of nine randomised controlled trials (RCTs) revealed that intensive glycemic control led to a 35% reduction in amputation risk in patients with DF.[19] These results highlight the complexity of DF and indicate that DF treatment requires comprehensive consideration.

3.2 | Cooperation of countries/regions and institutions

In the collaboration network obtained through VOSviewer, the node size represents the number of publications, based on the country/region, institution, or author. Based on observation, 52 countries/regions had published more than 20 articles, among which the United States ranked first with 2529 (29.29%) articles (Figure 3A). The United States is followed by England, China, Germany, Italy, the Netherlands, Australia, India, Spain, France, and Turkey with 4558 (52.80%) publications collectively. Furthermore, various countries entered into close collaborations, which emphasises that DF is a global challenge. Developed countries have a larger share of total publications, which may be explained by objective and subjective factors. With regard to objective factors, developed countries spend more money on scientific research. With regard to subjective factors, the incidence of DM in developed countries is higher; thus, it is an urgent problem that needs to be solved.

Sixty institutions have each published more than 30 articles One-half of the top 10 institutions are from the United States, with the University of Washington (Seattle, WA; 163 articles) ranking first (Figure 3C), which indicates the great scientific strength of the United States. Other institutions in the top 10 were the University of Amsterdam (Amsterdam, Netherlands), Queensland University of Technology (Brisbane City, Queensland, Australia), Manchester Royal Infirmary (Manchester, England), the University of Toronto (Toronto, Ontario, Canada), and Complutense University of Madrid (Madrid, Spain). The impact of individual scientific achievements is measured by different bibliometrics such as the H-index, journal impact factor (IF), number of publications, and number of citations.[20] The H-index is accessed from WoS through the "citation report." The H-index of researchers revealed that they have at most H papers cited at least H times.[21] The total H-index of DF studies is 167. The United States has an H-index of 135 and has several world-famous institutions. Compared with other countries/regions, the United States has obvious advantages and makes outstanding contributions to the research on DF. England (H-index = 98), the Netherlands

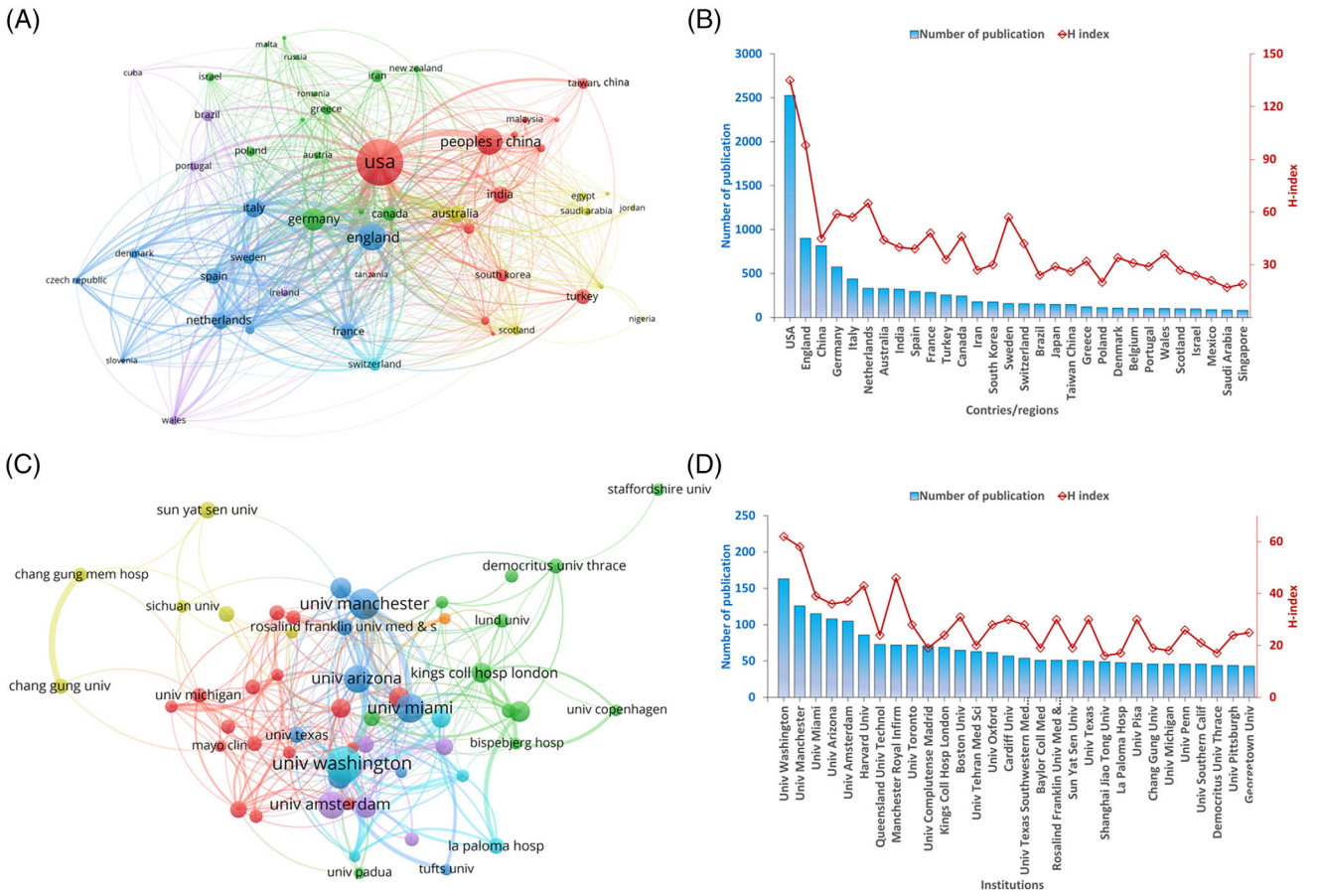

FIGURE 3 Cooperation between countries/regions and institutions. A, The countries/regions co-authorship network contains 52 nodes and 648 links. The size of the nodes and lines represent the number of publications and cooperation, respectively, in a country/region. Different coloured lines represent six different clusters. B, The number of publications and the H-index scores, based on countries/regions. C, The institution co-authorship network contains 55 nodes and 358 links. The node size and line represent the number of publications from the institution and their cooperation, respectively. Different coloured lines represent seven different clusters. D, The number of publications and the H-index scores of the institutions

(H-index = 65), and Germany (H-index = 59) have also made outstanding contributions to the study of DF.

3.3 | Journals and journal co-citation

The top 20 journals in the DF field are listed in Table 1. The top journal is the *International Journal of Lower Extremity Wounds* with 336 documents, and the second top journal is the *International Wound Journal* with 269 documents. Of the top 20 journals, 13 journals are from the United States, six journals are from the United Kingdom, and one journal is from Ireland. One-half of the top 20 journals have an IF >3.0, and nine journals have an H-index >100. The journal with the highest IF and an H-index is *Diabetes Care*, with an IF of 19.112 and H-index of 363.

The top 20 co-cited journals in the DF field are listed in Table 2. Based on the number of cited publications, the top three journals are *Diabetes Care* (23 003 citations), *Diabetic Medicine* (8374 citations), and *Wound Repair and Regeneration* (6360 citations). Five journals have an IF >10.0 and eight journals have an IF >5.0. Of the top 20 journals, 11 journals are from the United States; seven journals, from the United Kingdom, one journal, from Germany; and one journal is from Ireland.

Many studies on DF are published in low-IF journals, which suggests that high-quality research is required in DF studies. The cited journals generally have a higher IF, which indicates that the cited research is closer to the basics or the theory is stronger.

3.4 | Analysis of co-cited references

Co-cited references are references that are co-cited in one or more publications. The top 20 commonly cited references

TABLE 1 The top 20 journals publishing articles on diabetic foot

Rank	Journal Name	No. of documents	No. of citations	IF (2020)	H-index (2021)
1	*International Journal of Lower Extremity Wounds*	336	3010	2.057	42
2	*International Wound Journal*	269	5022	3.315	70
3	*Journal of Wound Care*	259	2689	2.072	68
4	*Diabetic Medicine*	230	10 955	4.359	152
5	*Wounds: A Compendium of Clinical Research and Practice*	218	2192	1.546	42
6	*Journal of the American Podiatric Medical Association*	197	2923	0.675	60
7	*Wound Repair and Regeneration*	189	11 433	3.617	117
8	*Diabetes Care*	180	18 882	19.112	380
9	*Diabetes/Metabolism Research and Reviews*	175	8064	4.876	117
10	*Diabetes Research and Clinical Practice*	158	3460	5.602	122
11	*Foot and Ankle International*	109	3194	2.827	114
12	*Journal of Diabetes and Its Complications*	109	2962	2.852	88
13	*Journal of Foot and Ankle Surgery*	105	1190	1.286	70
14	*Journal of Foot and Ankle Research*	94	1077	2.303	45
15	*Advances in Skin and Wound Care*	93	1085	2.347	64
16	*PloS One*	79	2128	3.240	367
17	*Journal of Vascular Surgery*	78	6577	4.268	202
18	*Plastic and Reconstructive Surgery*	69	2910	4.730	188
19	*Ostomy Wound Management*	67	1611	2.629	0
20	*Advances in Wound Care*	62	1876	4.730	31

Abbreviations: H-index, *high citation index*; IF, impact factor.

for DF are listed in Table 3. The highest number of co-citations is 529, seven references are co-cited 100–250 times, and other references are co-cited 70–100 times. Topics covered by highly cited papers include guidelines,[22-25] epidemiology,[26] burden of DF,[27,28] and meta-analysis.[29] Five articles are published in the top journals with an IF >10, and they include the *New England Journal of Medicine*, *the Journal of the American Medical Association (JAMA)*, *Lancet*, *Diabetes Care*, and *Diabetologia*.

Figure 4 shows the timeline map of co-cited references from 1999 to 2022. The reference network map has 1940 nodes and 9923 links. All references form 14 clusters, and positive co-citation exists among the references. The early literature focused on rehabilitation, offloading, dressings, and granulocyte colony-stimulating factor (G-CSF). Co-citations in G-CSF reduced quickly after the year 2004, and a meta-analysis of RCTs using G-CSF therapy demonstrated no benefits in infection eradication.[30] The co-citation of offloading persisted for a longer time. Pressure analyses are required to understand the pressures that result in DF and improve the effectiveness of interventions.,[31] The finite element method has been utilised to study plantar pressure.[32] Proper pressure offloading may stabilise soft tissues and accelerate healing of a DFU.[33]

Later co-cited references were in critical limb ischemia, wound healing, and semelil (Angipars; Pars Roos Drug Company, Tehran, Iran). Angipars is an herbal formulation capable of reducing skin ageing and inducing microvascularization and anti-inflammation.[34] Angipars have been reported to improve the distal latency and amplitude of the motor ulnar nerve in DF,[35] but the evidence remains limited.

Recent co-cited references focused on foot ulcers, amniotic membrane, osteomyelitis, and diabetic wound healing. A multicenter, double-blinded RCT demonstrated that human amniotic membrane preparation is safe and promising for DF treatment.[36] Amniotic membrane allografts could facilitate wound closure with standard therapy in chronic ulcers that are resistant to closure,[37] which indicates that amniotic membrane allografts are promising for improving wound healing. Various modalities such as human amniotic membrane preparations, growth factors, stem cells, cultured fibroblasts, keratinocytes were applied to treat difficult-to-heal ulcers.[38]

TABLE 2 The top 20 co-cited journals for studies on diabetic foot

Rank	Source	No. of citations	IF (2020)	H-index (2021)
1	*Diabetes Care*	23 003	19.112	380
2	*Diabetic Medicine*	8374	4.359	152
3	*Wound Repair and Regeneration*	6360	3.617	117
4	*Diabetes/Metabolism Research and Reviews*	5760	4.876	117
5	*Journal of Vascular Surgery*	5663	4.268	202
6	*Diabetologia*	4880	10.122	241
7	*International Wound Journal*	4280	3.315	70
8	*Clinical Infectious Diseases*	4217	9.079	353
9	*Lancet*	3892	79.321	807
10	*New England Journal of Medicine*	3528	91.245	1079
11	*Plastic and Reconstructive Surgery*	3353	4.730	188
12	*Journal of Wound Care*	3246	2.072	68
13	*Diabetes Research and Clinical Practice*	3033	5.602	122
14	*Foot and Ankle International*	2776	2.827	114
15	*Journal of Foot and Ankle Surgery*	2773	1.286	70
16	*JAMA Journal of the American Medical Association*	2760	56.272	709
17	*Journal of the American Podiatric Medical Association*	2690	0.675	60
18	*PLoS One*	2683	3.240	367
19	*Diabetes*	2401	9.461	345
20	*Journal of Diabetes and Its Complications*	2295	2.852	88

Abbreviations: H-index, high citation index; IF, impact factor.

3.5 | Keywords analysis and citation burstness

Keywords indicate the hot spots and future trends in the DF research field. Keyword clustering is formed by keywords with similar research topics, and each cluster is marked by frequently used keywords in the articles. Keywords with a co-occurrence >50 were included in the keyword clustering map (Figure 5A). The keywords were classified into five clusters, which included 218 nodes and 13 991 links. Cluster 1 (75 items) referred to DFU and wound healing; cluster 2 (48 items) referred to prevention, care, management, and guidelines of diabetes complications; cluster 3 (35 items) referred to risk of DF; cluster 4 (32 items) referred to amputation; and cluster 5 (28 items) referred to osteomyelitis and infections. We summarised the top 15 keywords of each cluster to systematically understand DF and provide suggestions for future research (Figure 6).

Keywords with citation bursts have a higher citation rate within a certain period, which can test whether a research area is popular at that time. In all, 270 keywords had citation bursts in the field of DF from 1999 to 2022. The top 20 are listed in Figure 5B. Much burstness occurred in the earlier times and included DFU amputation and limb salvage. The type of DFU was classified as neuropathic ischemic or neuroischemic ulcers based on the International Working Group on the Diabetic Foot (IWGDF) consensus.[39] Hyperbaric oxygen therapy combined with standard management to treat DFU may promote wound healing and decrease the risk of major amputation.[40] Recent bursts focused on the burden of DF on society and IWGDF guidance. Recent studies have tended to adopt the IWGDF guidelines for risk evaluation.[41,42] IWGDF DFI guidelines were published in 1999 and were utilised to classify FD states with the Perfusion Extent Depth Infection and Sensation classification, which can be utilised to assess clinical practise and help improve patient care[43]

4 | DISCUSSION

In this study, we conducted a scientometrics analysis of DF and analysed clusters of co-occurring keywords in DF, including management and guidelines, therapies to treat DFU and achieve wound healing, DN and plantar pressure, amputation and ischemia, and DFI and osteomyelitis.

TABLE 3 The top 20 cited articles related to diabetic foot

Rank	Cited number	Title of the article	Year	Journal name	Impact factor (2020)	H-index (2021)
1	529	Diabetic foot ulcers and their recurrence	2017	*New England Journal of Medicine*	91.245	1079
2	250	Global epidemiology of diabetic foot ulceration: a systematic review and meta-analysis	2017	*Annals of Medicine*	4.709	117
3	237	Executive summary: 2012 infectious diseases society of America clinical practice guideline for the diagnosis and treatment of diabetic foot infections	2012	*Clinical Infectious Diseases*	9.079	353
4	187	IWGDF guidance on the diagnosis and management of foot infections in persons with diabetes	2016	*Diabetes-Metabolism Research and Reviews*	4.876	117
5	124	Preventing foot ulcers in patients with diabetes	2005	*JAMA Journal of the American Medical Association*	56.272	709
6	118	Medical treatment of diabetic foot infections	2004	*Clinical Infectious Diseases*	9.079	353
7	116	The management of diabetic foot: a clinical practice guideline by the society for vascular surgery in collaboration with the American podiatric medical association and the society for vascular medicine	2016	*Journal of Vascular Surgery*	4.268	202
8	113	Association of diabetic foot ulcer and death in a population-based cohort from the United Kingdom	2016	*Diabetic Medicine*	4.359	152
9	98	Practical guidelines on the management and prevention of the diabetic foot 2011	2012	*Diabetes-Metabolism Research and Reviews*	4.876	117
10	97	The global burden of diabetic foot disease	2005	*Lancet*	79.321	807
11	96	Burden of diabetic foot ulcers for Medicare and private insurers	2014	*Diabetes Care*	19.112	380
12	90	The 2015 IWGDF guidance documents on prevention and management of foot problems in diabetes: development of an evidence-based global consensus	2016	*Diabetes/Metabolism Research and Reviews*	4.876	117
13	88	IWGDF guidance on the prevention of foot ulcers in at-risk patients with diabetes	2016	*Diabetes/Metabolism Research and Reviews*	4.876	117
14	85	Practical guidelines on the prevention and management of diabetic foot disease (IWGDF 2019 update)	2020	*Diabetes/Metabolism Research and Reviews*	4.876	117
15	83	Prevention and management of foot problems in diabetes: a summary guidance for daily practice 2015, based on the IWGDF guidance documents	2016	*Diabetes/Metabolism Research and Reviews*	4.876	117

(Continues)

TABLE 3 (Continued)

Rank	Cited number	Title of the article	Year	Journal name	Impact factor (2020)	H-index (2021)
16	83	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	*Diabetologia*	10.122	241
17	80	The society for vascular surgery lower extremity threatened limb classification system: risk stratification based on wound, ischemia, and foot infection (WIFI)	2014	*Journal of Vascular Surgery*	4.268	202
18	78	Guidelines on the diagnosis and treatment of foot infection in persons with diabetes (IWGDF 2019 update)	2020	*Diabetes/Metabolism Research and Reviews*	4.876	117
19	74	Burden of infected diabetic foot ulcers on hospital admissions and costs	2016	*Annals of Vascular Surgery*	1.466	75
20	72	Challenges in the treatment of chronic wounds	2015	*Advances in Wound Care*	4.73	31

Abbreviations: H-index, high citation index; IF, impact factor.

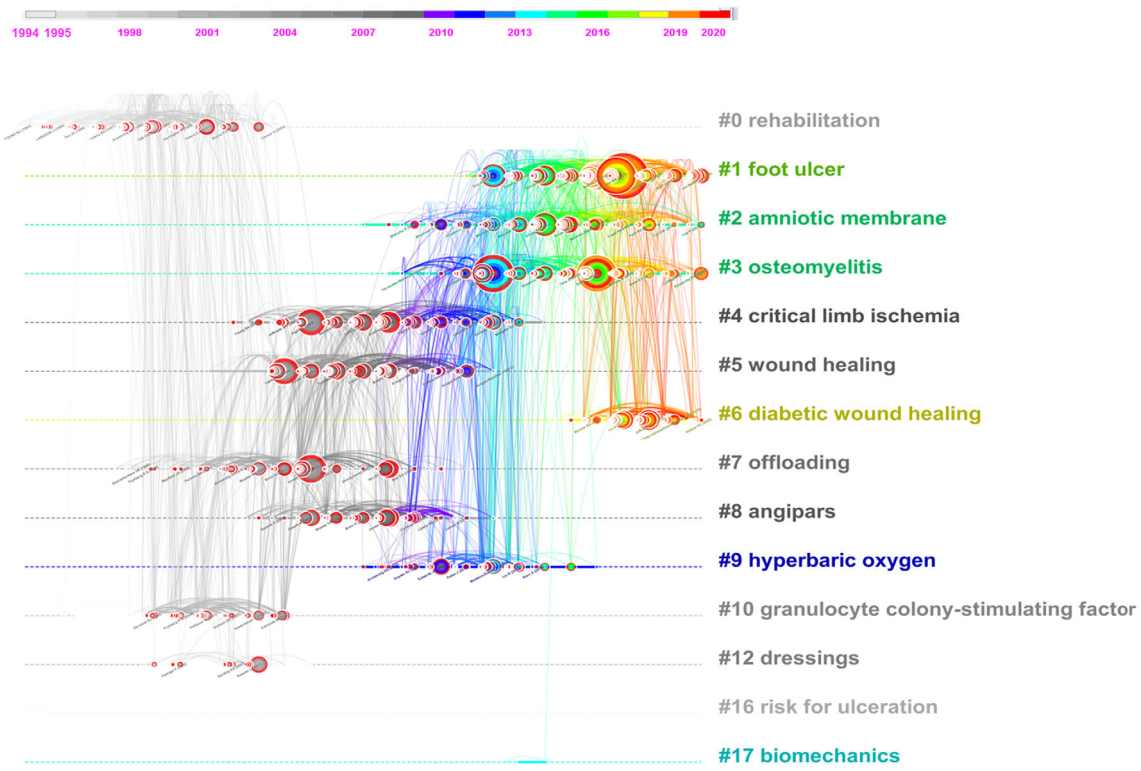

FIGURE 4 Timeline view of co-cited references. The node size represents the total number of references, and the node colour represents the time slice. Different coloured lines indicate that two articles were co-cited in one article

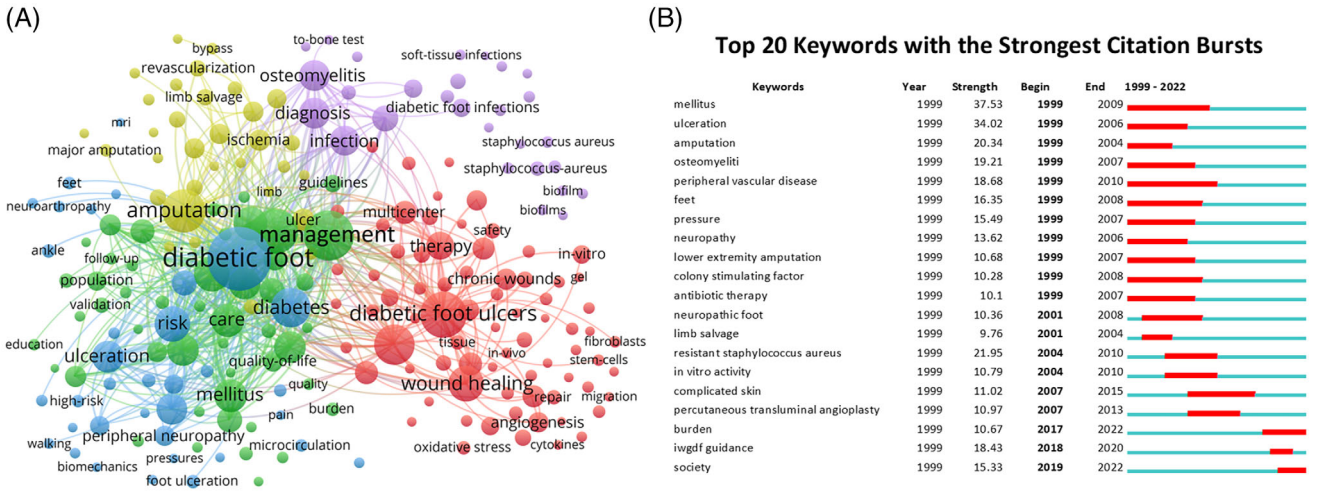

FIGURE 5 Co-occurrence of keywords. A, The keywords co-occurrence clustering network. Node size and node colour represent the number of keywords and clusters. Different coloured lines indicate that the two keywords appeared in an article. B, The top 20 keywords with the strongest citation bursts. The red bars indicate that certain keywords are frequently referenced at a certain time

4.1 | Therapies of DFU and wound healing

Epidemiological studies have revealed that 15% to 25% of diabetics develop DFU during their lifetime.[44] DFU is a major health risk for DM patients and leads to limb loss and mortality. In the absence of intact skin covering, these wounds can be reopened and gradually spread, which may result in sepsis and amputations.[45] Thus, the treatment of chronic wounds to promote healing is a major area of research in DFU.[46] The top 15 keywords related to therapies for DFU are shown in Figure 6A.

The standard therapies of DFUs include offloading and controlling the blood glucose level, thorough wound debridement, negative pressure drainage, and infection management.[47,48] Offloading is the primary intervention for healing DFUs.[49] Debridement removes necrotic debris, senescent cells, infected tissue, and biofilms to transform chronic ulcers into biologically active acute wounds and accelerate healing.[50]

Furthermore, strategically designed wound dressings can facilitate wound healing. Therefore, a series of new dressings have been reported recently for treating DF, such as an injectable glucose-responsive multifunctional metal–organic drug-loaded hydrogel,[51] an asiaticoside-loaded multifunctional biomimetic nanofibrous scaffold,[52] and bioactive agent-loaded polymer-based wound dressing materials.[53] Three-dimensional scaffolds can be fabricated through bioprinting and electrospinning, offer excellent biocompatibility and mechanical properties, and promote cell adhesion and proliferation.[54] Natural polymers such as collagen, gelatin, alginate, and fibrin, and synthetic polymers are employed for bioprinting. Antibiotics, growth factors,[55] colony-stimulating factors,[56] stem cells,[57] fibroblasts,[58] keratinocytes,[59] endothelial progenitor cells,[60] and platelet-rich plasma[61] can be supplemented to stimulate healing. Furthermore, some systems have been developed to incorporate and release bioactive nanoparticles on demand.[62]

DFU involves damage to multiple tissues. Therefore, distraction osteogenesis is utilised to induce new bone, angiogenesis, and local perfusion, and proximal tibial cortex transverse distraction is a promising surgical method.[47,48] Hyperbaric oxygen therapy may increase cell proliferation, collagen deposition, angiogenesis, and host defence to reduce cases of infection and promote the healing of chronic or severe wounds.[63]

4.2 | Management and guidelines

One study reviewed 22 DM clinical practise guidelines and summarised the recommendations for DF complications, such as DFU, Charcot neuropathy (CN), and diabetic foot osteomyelitis.[64] The four recommendations for standard care for DFU and six recommendations for diagnosis and treatment of CN are consistent.[64] The care standard for DFU involves four principles—decompression, debridement, infection management, and revascularization—and adjuvant therapies such as negative pressure wound therapy and hyperbaric oxygen therapy.[65] Five clinical practise guidelines were developed by five independent working groups of the IWGDF,[66,67] which covered the five aspects of DF: prevention,[68] offloading,[69] infection,[70] peripheral arterial disease,[71] and wound management.[14] Multidisciplinary guidelines for the prevention and management of

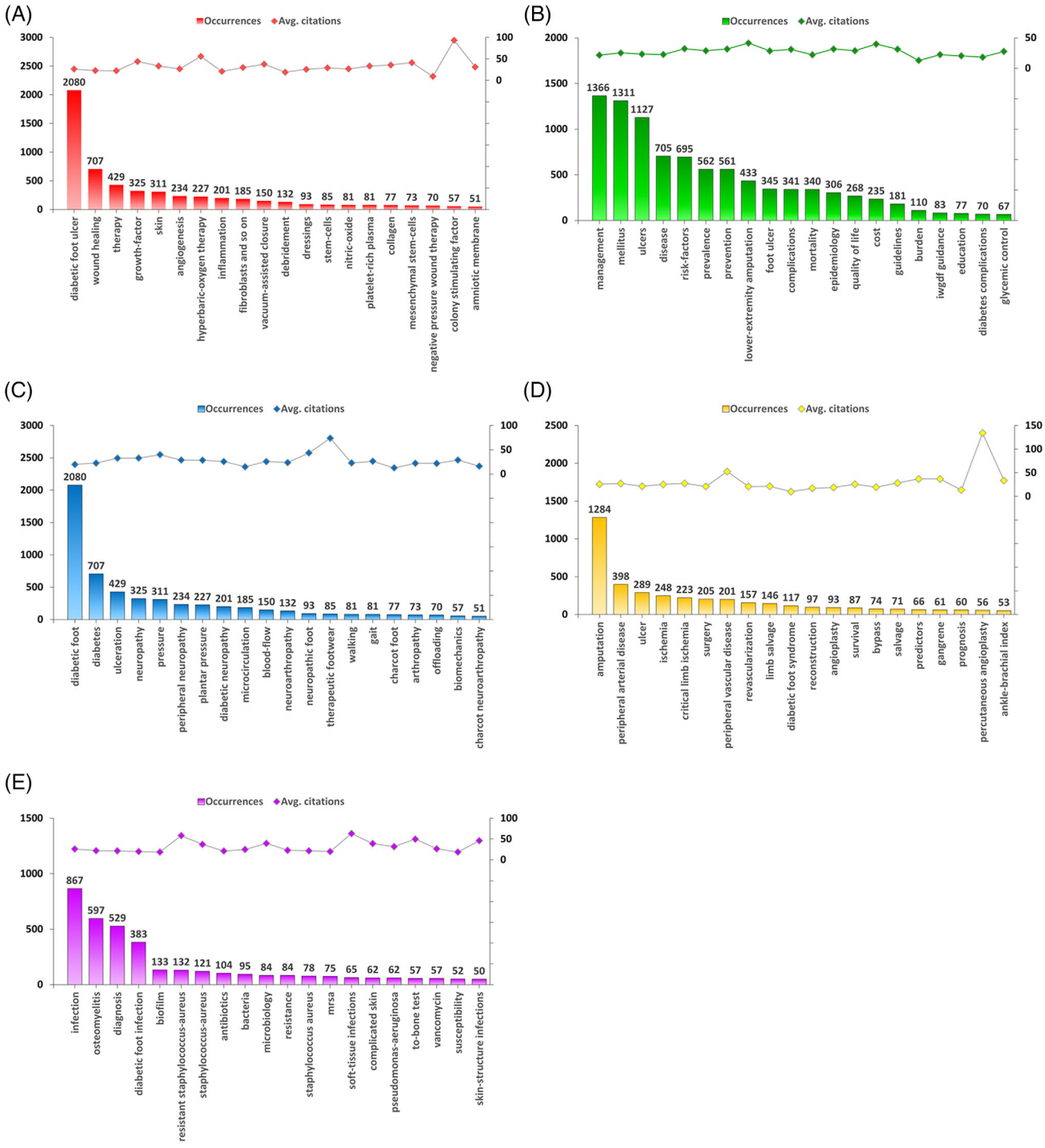

FIGURE 6 The top 20 keywords of five co-occurrence keywords clusters. A, Therapies to achieve wound healing. B, Management and guidelines. C, Neuropathy and plantar pressure. D, Amputation and ischemia. E, Infection and osteomyelitis

DF suggest a whole course of patient care and multidisciplinary teamwork, which includes endocrinology, burns, vascular surgery, orthopaedics, foot and ankle surgery, and cardiology.[72]

The risk of DF has always been a research hotspot. A study[73] in New South Wales (Australia) found that, among people with DM aged ≥45 years, the prevalence of diabetes-related foot disease was 10.8%; DFU, 5.4%; DFI, 5.2%; diabetic gangrene, 0.4%; and diabetes-related lower extremity amputation (DLEA), 0.9%. Older age, male sex, single status, having an ethnicity from English-speaking countries, a low socioeconomic position, low physical activity, history of diabetes for >15 years, and cardiovascular disease were risk factors for diabetes-related foot

disease, DFU, and DFI.[74] A case–control study[75] from Egypt found that three or more comorbidities, two or more diabetic complications, callus, and flatfoot are risk predictors of DFUs, whereas diet control, oral hypoglycemic drugs, insulin, and an intact vibration sense are protective predictors. A cohort study[76] in South Korea found that DFU among people of low socioeconomic position was strongly associated with increased rates of amputation and mortality. A systematic review suggested that barefoot plantar pressure and adherence were associated with DFU.[77] A meta-analysis suggests that in Ethiopia, socio-demographic factors, body weight, and health care practise are risk factors for DFU.[78] Identifying the risk factors is helpful for the effective prevention and treatment of DF.

4.3 | Neuropathy and plantar pressure

DN is the presence of certain physical signs or specific symptoms suggestive of neuropathy in DM patients after excluding other causes of neuron damage. The risks of DN increase with age and diabetes duration, poor glycemic control, hyperlipidemia, hypertension, obesity, and reduced physical activity. Early diagnosis and management of DN may limit or delay disease progression.[79] The temperature perception test and pinprick pain perception test are utilised to evaluate thin nerve fibre function, and the vibration perception test, monofilament touch perception test, and ankle reflexes test are utilised to evaluate long nerve fibre function. A DN diagnosis requires at least two semi-quantitative tests.[80] A nerve conduction study is one of the gold standards of DN diagnosis, and quantitative sensory measurement, the neurological function scoring system, confocal microscopy, and high-frequency ultrasound may be utilised for early DN screening.[81]

Patients with DN tend to have an increased forefoot-to-rearfoot plantar pressure ratio[82] and plantar pressure.[83] Owing to the loss of the protective sensation of pain in the feet, patients with DM may load their feet too heavily, which leads to the development of DFU. Therefore, increased plantar pressure is a main mechanical trigger for DF, and the reduction of plantar pressure is an important part of the management of DF. In patients with DM, weight-bearing exercise is associated with better plantar microcirculation and lower plantar tissue hardness and is not associated with the risk of DFUs.[84] Monitoring temperature and pressure as a whole may help predict DFU in clinical practice; various technologies have been developed to measure in-shoe plantar pressures and skin temperatures.[85] Smart wearable devices have been developed to prevent DF by monitoring pressure, humidity, and temperature.[86] Some researchers tried to employ a low-cost three-dimensional printing technique to monitor overloading of the foot in daily life.[87] Suitable exercises and footwear may provide effective offloading interventions to prevent the occurrence of DF.

4.4 | Amputation and ischemia

DFU is a serious health care problem worldwide, and minor traumas can have catastrophic consequences.[88] Patients with diabetes should be classified based on their risks of developing DFU and should be screened for risk factors for DFU at least annually. The risk classification system developed by the IWGDF is very useful in daily clinical practise.[89] The healing of a DF wound is frequently complicated by critical limb-threatening ischemia, which may require amputation. Imminent arterial revascularization is an option to avoid amputation.[90] More than 80% of lower extremity amputations are secondary to dysvascular disease resulting from PAD, DM, or both.[91]

The incidence of dysvascular lower extremity amputation has not decreased greatly, though the treatment of DM has improved. A multidisciplinary team approach is critical for amputation prevention.[88] Limb-preservation teams are believed to be beneficial for DF management, and a team comprises vascular surgeons, podiatrists, foot and orthopaedic surgeons, vascular medicine specialists, endocrinologists, infectious diseases specialists, plastic surgeons, physical medicine specialists, pedorthists and orthotists, dietitians, and nurses experienced in wound care.[92]

4.5 | DFI and osteomyelitis

The top 15 keywords related to DFI are shown in Figure 6E. Approximately 2.2% to 6.3% of patients with DM may experience DFI annually, 50% to 60% cases of DFU may progress to DFI, and 20% to 66% cases of DFI are complicated with diabetic foot osteomyelitis.[22] The Infectious Diseases Society of America (IDSA) classification system is commonly used to classify DFI and includes four grades: "no infection," "mild infection," "moderate infection," and "severe infection." Patients with osteomyelitis have worse outcomes.[93,94] Therefore, the IDSA classification has been modified and now includes group 1 ("no infection"), group 2 ("mild soft tissue infection"), group 3 ("moderate or severe soft tissue infection"), and group 4 ("moderate or severe bone infection").[94]

The management of DFI relies on a combination of effective surgical and antimicrobial treatment.[95] The microbiology of DFI is diverse. *Staphylococcus aureus* (*S. aureus*) is the organism most commonly identified,

and methicillin-resistant *S. aureus* (MRSA) represents 18.0% of *S. aureus* infection cases.[96] The incidence of *Pseudomonas aeruginosa* and multidrug-resistant gram-negative bacilli is growing.[97] The choice of antibiotics to treat DFI is highly individualised, based on the site, extent, severity of infection, pathogens involved, presence of concomitant osteomyelitis, and comorbidities.[95] Ten principles for antimicrobial stewardship exist and include preventing DFI, diagnosing DFI correctly, excluding non-infectious causes of DVI, identifying causative pathogens, differentiating between soft tissue and bone infection, ensuring specialist consultation for most moderate and all severe infections, choosing an effective antibiotic regimen with the narrowest spectrum, optimising patient-related effectiveness of antibiotic therapy, medical therapy, and surgical treatment.[98] For diabetic foot osteomyelitis treatment, using antibiotics that penetrate the bone and are active against biofilms is important.[99] Researchers have suggested that the maximum duration of antibiotic therapy should be no more than 4 to 6 weeks.[100]

4.6 | Strengths and limitations

Data from the WoSCC were analysed in the present study. The literature in the WoSCC provides high-quality research results on DF; therefore, it is ideal for bibliometric analysis.[101] The WoSCC database covers a substantial amount of data to study the topic of DF, which ensured the results obtained in this study were highly reliable. However, at present, the bibliometrics software is unable to distinguish between authors with the same abbreviations; therefore, some incorrect conclusions about authors may be included in this paper. This scientometrics study helps researchers to quickly understand the research hotspots and future trends in the field of DF.

5 | CONCLUSIONS

In the present study, we utilised scientometrics to analyse DF research in the Science Citation Index Expanded database. Our results revealed the high-impact countries and institutions, journals, references, research hotspots, and key research fields in DF research. Following the increasing incidences of DM and the health strategies in response to the growing burden of DM, publications on DF have increased remarkably since 2016. The United States leads the research on DF. The recent studies focus on the amniotic membrane, foot ulcers, osteomyelitis, and diabetic wound healing. The hotspots of DF studies include DFU and wound healing therapies, management and guidelines, neuropathy and plantar pressure, amputation and ischemia, DFI, and osteomyelitis. Our results revealed the high impact countries and institutions, journals, references, research hotspots, and key research fields in DF research and the directions for further research.

DATA AVAILABILITY STATEMENT

Data derived from public domain resources. [Web of Science (https://www.webofscience.com/); Scimago Journal & Country Rank (https://www.scimagojr.com/journalrank.php)].

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