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Evolution and research trends of fluid therapy related to burn: A bibliometric analysis

Lianjie Cai, Bing Liang, Weilong Peng, Yang Cao
Department of Anesthesiology, Guangzhou Red Cross Hospital, Jinan University, Guangzhou, China

Abstract
Background: Burns represents a frequently encountered and highly debilitating form of trauma. Immediate and judicious fluid resuscitation is imperative in the management of patients with severe burns, aiming to minimize morbidity and mortality. Nevertheless, to date, there has been a paucity of comprehensive bibliometric studies conducted on fluid therapy in the context of burn injuries. The objective of this study is to illustrate the current trends and potential future directions in this field, serving as a valuable reference for future research endeavors and clinical decision-making.
Methods: Relevant studies were collected from the Web of Science Core Collection. Bibliometrics and visual analysis were executed using Histcite, VOSviewer, CiteSpace, and R-bibliometrix.
Results: A total of 1140 documents on fluid therapy related to burn published from 1998 to 2022 were acquired. The annual publications and citations exhibited a gradual growth trajectory. The USA stands as the most productive nation in terms of academic output in this field, boasting a multitude of esteemed institutions. Besides, Cancio Leopoldo C from the US Army Institute emerges as the most prolific author, and Herndon David N from Shriners Hospital for Children garners the highest number of citations. As the foremost academic journals in this field, *Burns* and *Journal of Burn Care & Research* have published a substantial number of articles. Moreover, the most recent clusters of co-cited references include "Enteral fluid" and "Emergency burn care". Notably, the primary keywords encompass "fluid resuscitation", "burns", and "thermal injury".
Conclusion: Since the emergence of the phenomenon known as "fluid creep", there has been a shift in focus within the field from fluid types and volume mechanisms to the urgent care of burn patients. The investigation into fluid resuscitation, with an emphasis on achieving accuracy, will be an area of intense interest for future research.

Keywords: Burn, fluid therapy, bibliometric, VOSviewer, CiteSpace

Introduction

Burn injuries represent a pervasive and devastating form of trauma, constituting a substantial public health concern on a global scale. [1-3]. The World Health Organization reported in 2018 that approximately 180,000 individuals succumb to burn-related fatalities annually. [4, 5]. In particular, the majority of these extensive fatalities were observed in patients with critical burns. The high mortality rate observed during the initial stages of severe burns primarily stems from shock induced by extensive fluid loss, abnormal cardiac function, the release of inflammatory mediators, and heightened vascular permeability within the organism. Failure to adequately replenish intravascular fluid losses in response to shock can lead to generalized or organ-specific hypoperfusion, which serves as a critical risk factor for subsequent complications [6]. Considering the pathophysiologic alterations in burns mentioned above, optimal management of severe burns should primarily focus on fluid resuscitation to restore the depleted effective blood volume and thereby prevent complications and reduce mortality. Consequently, there has been a growing surge of interest among researchers and clinicians in the field of burn injuries towards fluid therapies in recent years. The significant improvement in the survival rate of severe burn patients over recent decades can primarily be attributed to the advancements in fluid therapeutic techniques, which have undergone three distinct stages of development. Initially, it was not until the advent of the 20th century that scholars commenced redirecting their attention from wound treatment to fluid resuscitation as a primary focus in severe burn management [7]. The second stage commenced with the emergence of standardized fluid formulas for burn shock management. One notable formula among these is the Parkland formula, developed by Baxter in 1968, which continues to be extensively employed in numerous burn units to this day [8]. This formula utilizes the total body surface area (TBSA) affected and the patient's weight to estimate the requisite fluid volume for burn patients to restore normal extracellular fluid levels within the initial 24-hour period The implementation of the Parkland formula has led to a significant decrease in the incidence of burn shock. However, the emergence of potential risks associated with excessive fluid resuscitation is becoming evident. The formula solely predicts fluid loss in burn patients with uncomplicated thermal burns and without comorbidities. Nevertheless, clinical scenarios are often more intricate, resulting in actual fluid administration exceeding the calculated amount assumed by the formula. This phenomenon is commonly referred to as "fluid creep". [9]. Excessive fluid resuscitation is a significant risk factor contributing to the emergence of novel post-burn complications [10]. Subsequently, the investigation of fluid therapies related to burns progressed into its third phase, wherein scholars proposed diverse novel strategies for fluid therapy with the aim of mitigating fluid creep and enhancing accurate prediction of burn patients' fluid requirements. Goal-directed fluid therapy has emerged as a noteworthy series of fluid protocols in recent years, garnering significant attention. It entails timely adjustment of fluid therapy for critically burned patients based on pertinent hemodynamic parameters to attain optimal tissue perfusion and oxygenation [11, 12]. In addition, the current forefront of fluid therapy research lies in the fine-tuning of fluid management. Behnood Gholam *et al*. (2021) employed a

closed-loop control system to achieve urine volume-guided fluid resuscitation, enabling accurate completion of early burn resuscitation while minimizing actual fluid requirements. [13]. Collectively, numerous studies have been conducted to determine the optimal fluid therapy for severe burn patients, however, a universally recognized standardized treatment remains elusive. Furthermore, no comprehensive analysis of the research field of fluid therapy related to burn has been identified.

Bibliometric analysis is a literature research methodology employed to elucidate academic trends and the evolutionary development of published works. By comprehensively analyzing scientific publications, it facilitates the presentation of knowledge base, research trajectories, and focal areas within a specific research domain primarily through the core representation of scientific visualization [14]. Related to burn injury, Zhi Cao *et al*. (2022) conducted a bibliometric analysis to identify the focal areas and emerging frontiers of burn sepsis [15]. However, there is a paucity of bibliometric studies focusing on fluid therapy related to burn. In this study, we conducted an analysis of the existing literature on fluid therapy for burns, aiming to provide valuable insights for clinicians in their clinical decision-making process, guide researchers towards future research directions, and assist agencies in formulating rational strategies.

Materials and methods

Search strategy

The literature from January 1998 to December 2022 was systematically searched in the Web of Science Core Collection (WoSCC) using the following search strategy: TS= (fluid therapy OR fluid administration OR hemodynamic therapy OR fluid resuscitation) AND TS= (burn). In addition, all articles and reviews were filtered. Ultimately, a total of 1140 relevant documents were identified. A bibliographic record of this literature was downloaded, including titles, abstracts, institutions, journals, authors, cited references, and keywords (Fig 1).

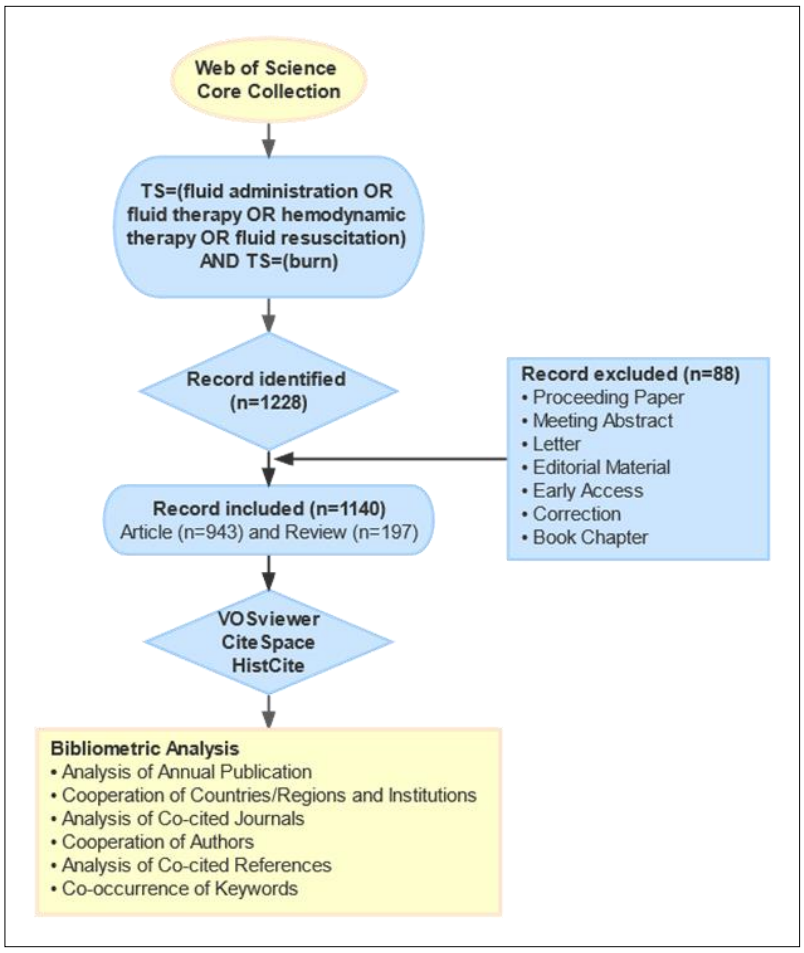

Fig 1: The flow chart of literature search and analysis.

Bibliometric analysis

For the analysis and visualization of the literature, we employed various software tools including Microsoft Excel 2019, HistCite 2.1, VOSviewer 1.6.18, CiteSpace 6.1. R6, and Bibliometrix 4.1.0 Packages.

Microsoft Excel was used to demonstrate the annual trends in publications.

HistCite, a citation map analysis software, is designed to show the relationship between different documents in a particular field in an illustration [16, 17]. In this study, the number and ranking of publications and reference citations were calculated using total local citation score (TLCS), and total global citation score (TGCS). TLCS, the total number of citations in the collection, demonstrates influence in the local field. Conversely, TGCS tends to emphasize influence across the entire WOSCC

VOSviewer, a scientific visualization software, constructs bibliometric connections of academic publications based on citation, co-citation, or co-occurrence relationships [18]. In the present study, it was used to visualize the bibliometric

networks of co-authorship, co-cited journals, and co-occurrence keywords.

Bibliometrix biblioshiny R-software was used to calculate and rank the h-index and g-index of the authors [19]. The h-index is a hybrid quantitative index most commonly used to evaluate scholars' academic influence [20, 21]. Then, the g-index is a scholarly metric that takes into account not only the number of publications and citations but also the performance of the author's top articles [22].

CiteSpace is a Java-based software for bibliometric analysis, in particular the visualization of collaboration networks and research themes within a specific domain [23]. In order to visualize these collaboration networks in a certain domain, it draws on the co-citation theory that 2 papers share a co-citation relation when they are cited together by another paper. In this research, CiteSpace was used in the analysis of countries, institutions and co-cited references to mainly run cluster analysis, compute the between centrality, and perform burst detection. The CiteSpace map of a collaborative network consists primarily of nodes representing each document and links representing the connections between documents. We can derive important results in the research field by network analysis. Citation rings show annual citation patterns, while purple nodes with a centrality value≥0.1 represent landmark theories as bridging roles within a domain [24]. Citation bursts reveal short periods of high scholarly activity as red rings representing significant themes within a domain.

Results

Analysis of publications and citations

Annual publications and citations serve as common indicators to gauge the academic progress of a discipline. A total of 1140 documents related to fluid therapy relative to burn were subjected to analysis. In general, there was an upward trajectory in the number of annual publications from 1998 to 2022, with minor fluctuations observed in certain years such as 2005, 2013, 2014, and 2019 (FIGURE 2a). However, since 2006, over 40 publications on fluid therapies relative to burn have been published annually. In addition, the number of annual citations within a certain domain is more correlated with the degree of interest in relevant themes. As depicted in FIGURE 2b, both TLCS and TGCS exhibited fluctuating patterns over recent years, reaching their peak values in 2007 and 2006 respectively. Moreover, both TLCS and TGCS showed a slight decline in the past 5 years. These findings suggest that this field is progressing at a gradual pace and necessitates groundbreaking research outcomes to attract global attention.

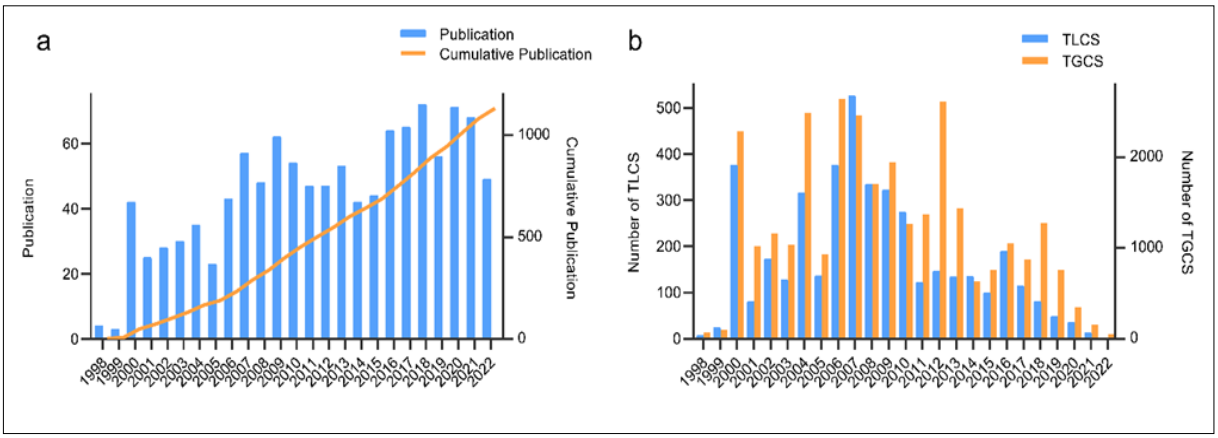

Fig 2: The overall trends of publications and citations. a) Annual and cumulative publications. b) Annual TLCS and TGCS.

Analysis of countries or regions

66 countries were involved in research on fluid therapy relative to burn. FIGURE 3a demonstrates the top 10 most productive countries in the past years. Over the past decade, there has been a consistent upward trend in publication output across these countries, with only slight decreases observed in 2019 and 2022 (FIGURE 3a). The USA exhibited the highest publication output (473), followed by China (108), Germany (101), England (91), and Australia (66) (TABLE 1). On the part of TLCS and TGCS, the USA maintained its leading position globally. Despite having the second-highest number of publications, China's TLCS and TGCS were disproportionately low, suggesting a relatively lower proportion of high-quality articles from China.

Table 1: The top 10 countries distributed by publications and centrality.

Rank	Country	Publications	TLCS[a]	TGCS[b]	Average citations	Rank	Country	Centrality
1	USA	473	1380	14273	30.17548	1	USA	0.4
2	China	108	103	1530	14.16667	2	England	0.12
3	Germany	101	273	2064	20.43564	3	Australia	0.12
4	England	91	98	2357	25.9011	4	Germany	0.1
5	Australia	66	110	1685	25.5303	5	Sweden	0.1
6	Canada	56	356	2531	45.19643	6	China	0.08
7	Switzerland	34	15	903	26.55882	7	Belgium	0.05
8	Italy	31	10	1987	64.09677	8	Austria	0.04
9	Japan	31	175	860	27.74194	9	Singapore	0.04
10	Belgium	29	21	737	25.41379	10	Saudi Arabia	0.04

The close academic cooperation between countries or regions can be intuitively observed in the collaboration network. FIGURE 3b demonstrates the links between the 20 most productive countries or regions of the globe. The USA exhibited the highest number of publications and established strong relationships with other nations in this field. In FIGURE 3c, the size of the nodes depends on the number of publications, the lines between nodes indicate the cooperation between countries or regions, and the thicknesses of the lines represent the strength of connections. From a centrality greater than 0.1, the USA, Germany, Australia, and England marked with purple circles seemed to hold significant influence on global collaborations in this field. These countries serve as key contributors of groundbreaking research and play pivotal roles in international cooperation.

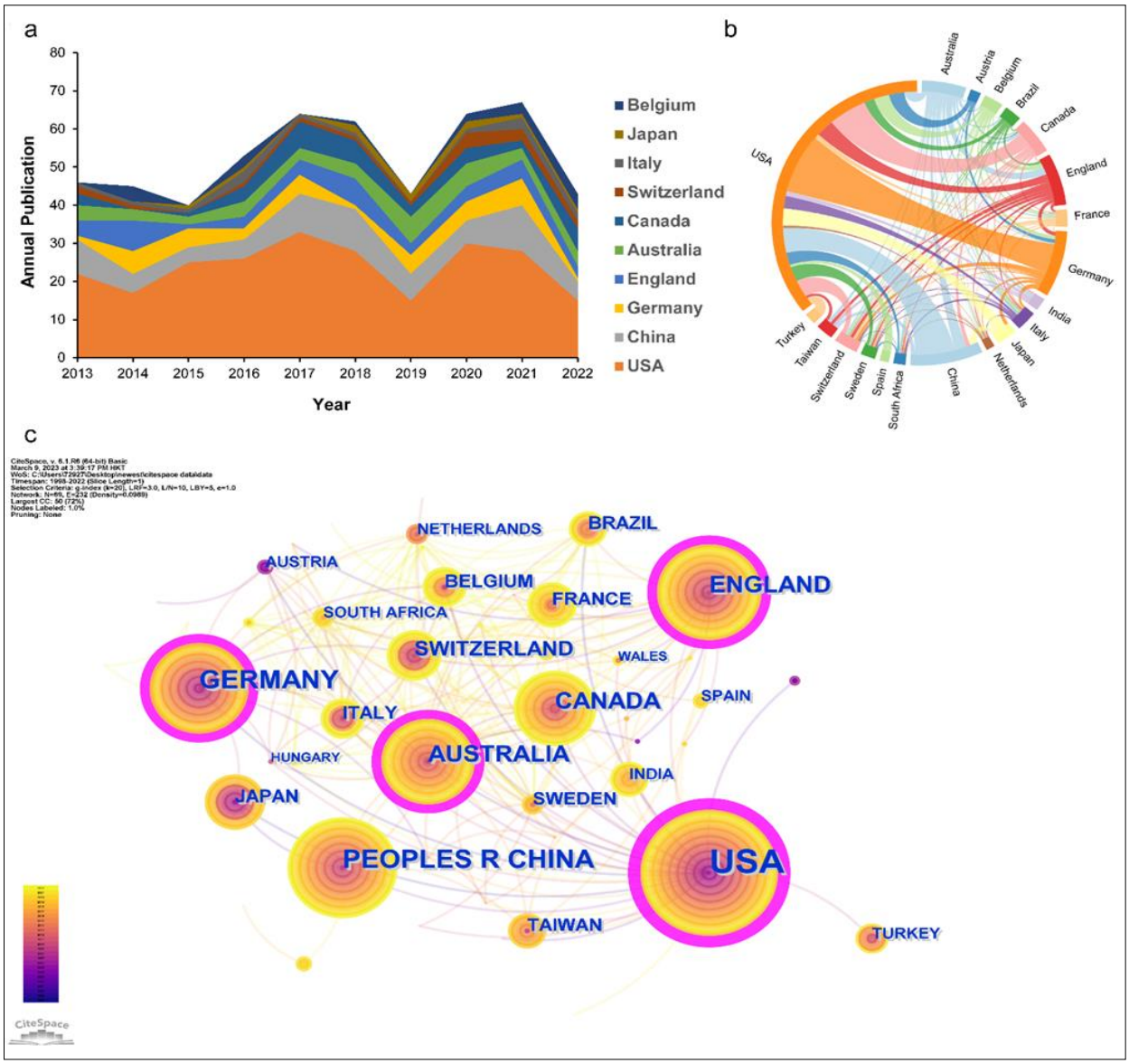

Fig 3: Analysis of countries or regions. a) The temporal trends of publications from the top 10 countries. b) The chord diagram of cooperation between the top 20 countries or regions with the number of publications. c) Collaboration network of countries or regions with centrality.

The aforementioned results collectively demonstrate a strong interconnection among countries in the research domain, with the United States exerting significant influence.

Analysis of institutions

Table 2: The top 10 institutions distributed by publications and centrality.

Rank	Institution	Publications	TLCS	TGCS	Original country	Rank	Institution	Centrality	Original country
1	US Army Inst Surg Res	68	217	1702	USA	1	Univ Toronto	0.08	Canada
2	Univ Texas	49	249	2334	USA	2	US Army Inst Surg Res	0.05	USA
3	Univ Texas Med Branch	34	91	592	USA	3	Univ Texas Med Branch	0.04	USA

4	Univ Toronto	32	142	701	Canada	4	Univ Western Australia	0.04	Australia
5	Shriners Hosp Children	31	52	1069	USA	5	Shriners Hosp Children	0.03	USA
6	Univ Calif Davis	28	53	996	USA	6	Univ Sydney	0.03	Australia
7	Uniformed Serv Univ Hlth Sci	26	26	350	USA	7	Univ Texas	0.02	USA
8	Univ Washington	21	223	1194	USA	8	Univ Washington	0.02	USA
9	Harvard Univ	20	84	690	USA	9	Univ Colorado	0.02	USA
10	Loyola Univ	17	86	713	USA	10	Univ Queensland	0.02	Australia

The influential institutions that have been key motivations for the evolution of the academic field can be identified by institutions' number of publications, TLCS, TGCS, centrality and partnerships with others. TABLE 2 presents the top 10 institutions in terms of productivity and centrality. The majority of productive institutions are based in the USA, with the exception of the University of Toronto from Canada. Notably, the US Army Institute of Surgical Research emerged as the most prolific institution with a total of 68 publications, while Texas University achieved the highest scores for both TLCS (249) and TGCS (2334) As for the between centrality, six of the top 10 institutions were from the USA, three are from Australia. Notably, Toronto University in Canada had the highest centrality score of only 0.08, indicating a lack of overall collaboration among institutions and an absence of an authoritative research center. Inter-institutional academic collaboration is considered a crucial driver for development in the field. FIGURE 4 demonstrates the inter-institutional cooperation network from various countries and regions. Coupled with the between centrality of the institutions noted in TABLE 1, it can be seen from FIGURE 4 that the network is relatively straightforward. In conclusion, American institutions are still predictably prolific while there is no close connection between institutions.

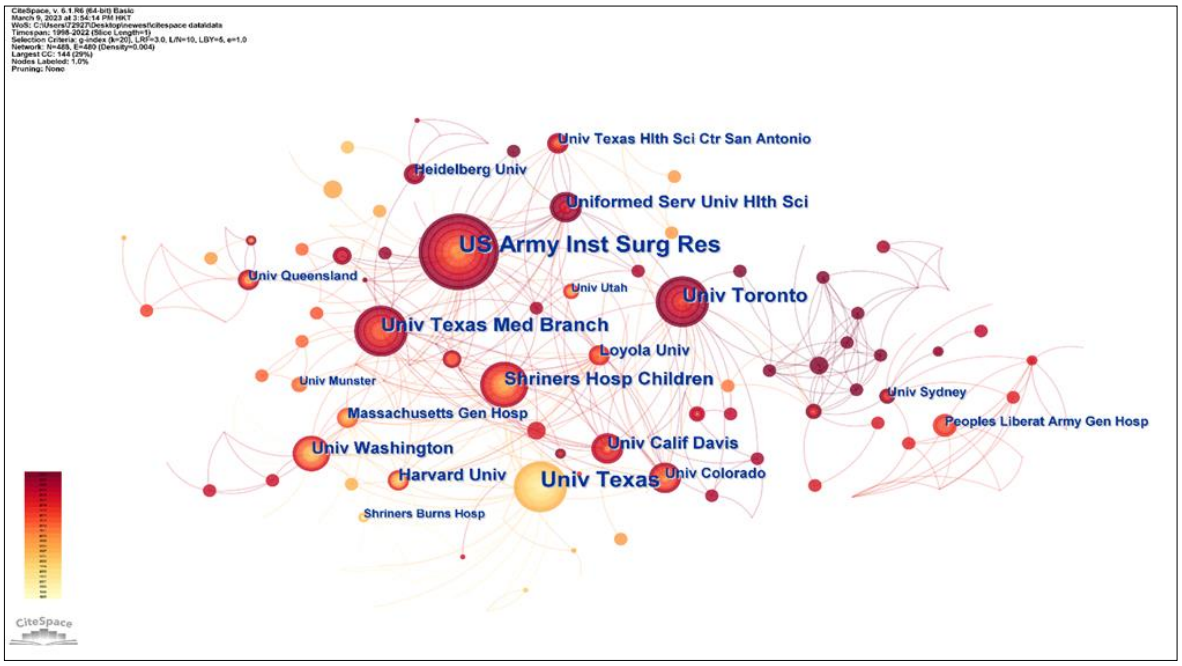

Fig 4: Collaboration network of institutions.

Analysis of authors

The bibliometric analysis of authors enables us to identify eminent research collectives within a specific field. The ranking of authors based on their publication output reveals the most influential experts in the field, and Table 3 displays the top 10. Leopoldo C Cancio from the USA has produced the largest number of publications with a first TLCS score of 30,501, followed by David N Herndon (29,370) and Kevin K Chung (25,284). However, David N Herndon holds the highest TGCS score at 1342. Among the top 10 most prolific authors, excluding Hu Sen from China and Cartotto Robert from Canada, the remaining individuals are affiliated with institutions in America. Furthermore, 6 researchers among these top 10 authors are associated with the US Army Institute of Surgical Research and the Texas University Medical Branch.

Table 3: The top 10 authors distributed by publications.

Rank	Author	Publications	TLCS	TGCS	Institution	Country
1	Cancio Leopoldo C	30	501	1067	US Army Inst Surg Res	USA
2	Herndon David N	29	370	1342	Shriners Hosp Children	USA
3	Chung Kevin K	25	284	756	US Army Inst Surg Res	USA

4	Wolf Steven E	24	283	742	Univ Texas Med Branch	USA
5	Kramer George C	19	220	505	Univ Texas Med Branch	USA
6	Hu Sen	19	31	212	Chinese Peoples Liberat Army Gen Hosp	China
7	Salinas Jose	18	118	331	US Army Inst Surg Res	USA
8	Traber Daniel L	18	70	631	Univ Texas Med Branch	USA
9	Gibran Nicole S	16	456	1006	Univ Washington	USA
10	Cartotto Robert	16	158	314	Univ Toronto	Canada

H-index and g-index are novel scientific metrics employed for assessing academic accomplishments. FIGURE 5a demonstrates the h-indices and g-indices of the top 10 most prolific authors in the field. Herndon David N achieved the highest h-index (18), while Cancio Leopoldo C attained the highest g-index (30). Notably, Gibran Nicole S from the USA exhibited a relatively modest publication count, however, he ranked third in terms of h-index, indicating exceptional article quality."

The authors were classified into 7 clusters in the collaboration network analysis (FIGURE 5b), mainly including Herdon David N *et al*, Cancio Leopoldo C *et al*, Traber Daniel L *et al*, and Horton Jureta W *et al*. Based on these findings, it is evident that these investigators possess a robust academic standing within the field of fluid therapy related to burn.

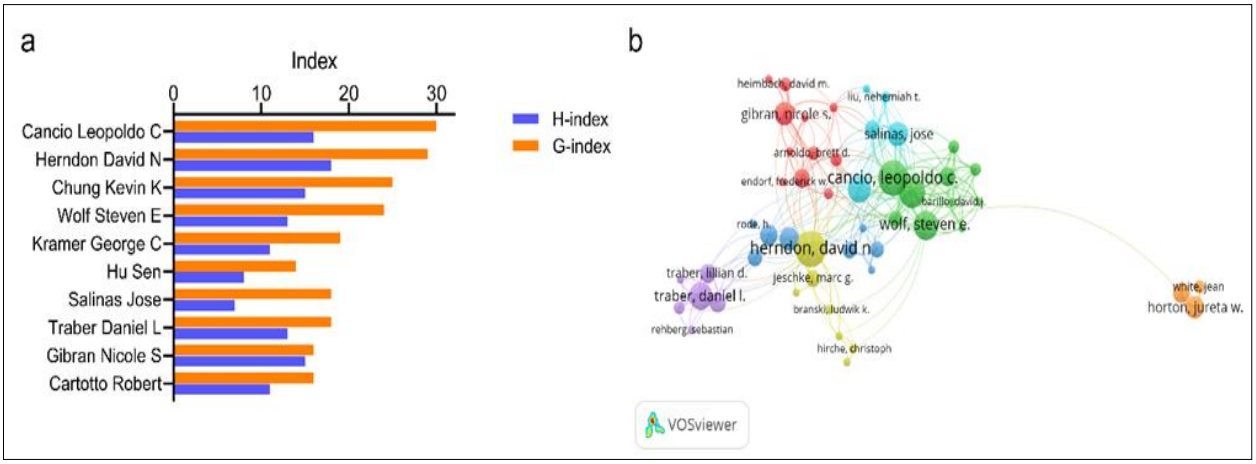

Fig 5: Analysis of authors. a) H-index and g-index of the top 10 prolific authors. b) Collaboration network of authors.

Analysis of journals and co-cited journals

TABLE 4 listed the 10 journals with the largest publication output, all of which were distributed in Q1, Q2, and Q3. Moreover, only two journals *Burns* and *Journal of Burn Care & Research* published more than 100 articles, together accounting for more than a quarter of the total number of publications. *Burns* exhibited the highest TGCS, while *Journal of Burn Care & Research* had the greatest TLCS. In terms of the IF, *Critical Care* reached the highest IF of 19.334, followed by *Cochrane Database of Systematic Reviews* (12.008) and *Critical Care Medicine* (9.296).

Table 4: The top 10 journals distributed by publications.

Rank	Journal	Publications	% of 1140	TLCS	TGCS	IF (JCR 2021)	JCR quartile
1	Burns	186	16.32%	639	3978	2.609	Q2
2	Journal of Burn Care & Research	162	14.21%	771	3611	1.819	Q3
3	Journal of Trauma and Acute Care Surgery	50	4.39%	268	1873	3.697	Q2
4	Critical Care Medicine	26	2.28%	98	1494	9.296	Q1
5	Shock	25	2.19%	30	682	3.533	Q3
6	Critical Care	15	1.32%	2	458	19.334	Q1
7	Cochrane Database of Systematic Reviews	14	1.23%	0	1065	12.008	Q2
8	Burns & Trauma	12	1.05%	0	198	5.711	Q2
9	Journal of Surgical Research	12	1.05%	26	75	2.417	Q3
10	Annals of Plastic Surgery	10	0.88%	39	277	1.763	Q2

In addition, co-citation analysis reflects the interrelationships among different journals with their significance within a research field determined by the frequency of citations they receive. The top 3 co-cited journals were *Burns*, *Journal of Trauma and Acute Care Surgery*, and *Journal of Burn Care & Research*, the same as the top 3 most prolific journals (FIGURE 6a, b). These results indicate that *Burns* and *Journal of Burn Care & Research* enjoy widespread popularity in the academic community, while *Critical Care* and *Cochrane Database of Systematic Reviews* demonstrate exceptional scholarly performance in this domain.

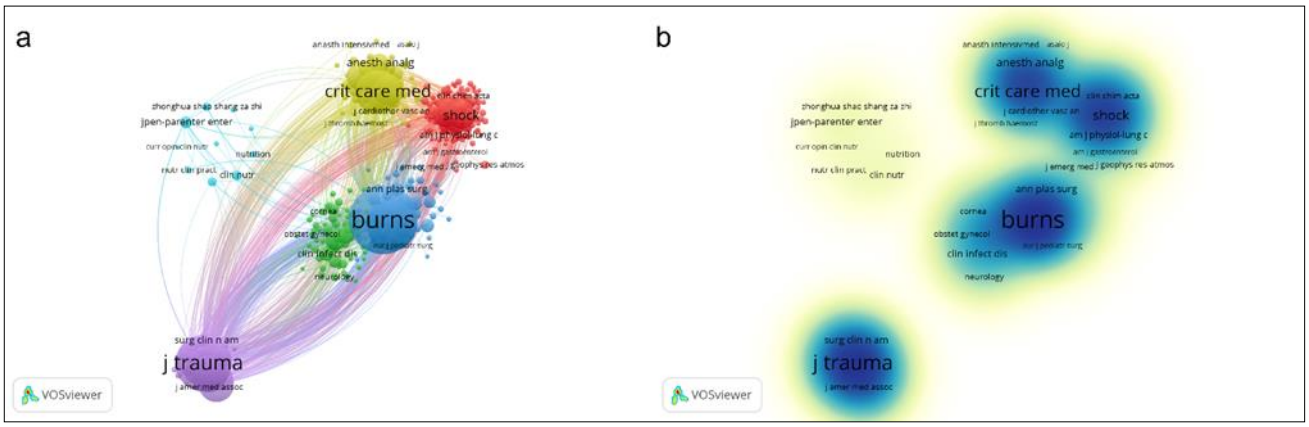

Fig 6: VOSviewer visualization map of most commonly cited journals related to fluid therapy related to burn. a) Co-citation network of journals. b) The density map of the most commonly cited journals. The dark blue nodes represent journals with large numbers of citations.

Analysis of highly cited articles and co-cited references

TLCS is a widely adopted academic metric that quantifies the frequency of citations received by a paper from other papers within the dataset since its publication. Compared with TGCS, TLCS displays more about the influence of articles in the current research field. Among the top 10 articles with the highest TLCS shown in TABLE 5, the top 3 were as follows: 1) Saffle JR in 2007 (109), this review summarized mechanisms, influence factors, and prevention of fluid creep, a phenomenon in which severely burned patients required far more fluid than that predicted by the Parkland formula [25]. 2) Klein MB in 2007 (97), this article conducted a multicenter study concluding that the TBSA% burn, patient age, weight, and intubation status before admission were found to significantly influence fluid requirements in the first 24 hours following burn injury [26]. 3) Pham TN in 2008 (85), the article was a clinical guideline on burn shock resuscitation and provided practical information and evidence for researchers and doctors [27]. However, it should be taken into account that TLCS is not a perfect measure index of the quality of an article, as the number of citations always grows over time.

Table 5: The top 10 articles with the highest TLCS.

Rank	Title	Year	Journal	Corresponding author	TLCS	DOI
1	The phenomenon of "fluid creep" in acute burn resuscitation	2007	Journal of Burn Care & Research	Saffle, JR	109	10.1097/BCR.0B013E318053D3A1
2	The association between fluid administration and outcome following major burn - A multicenter study	2007	Annals of Surgery	Klein, MB	97	10.1097/01.sla.0000252572.50684.49
3	American burn association practice guidelines burn shock resuscitation	2008	Journal of Burn Care & Research	Pham, TN	85	10.1097/BCR.0b013e31815f3876
4	How well does the Parkland Formula estimate actual fluid resuscitation volumes?	2002	Journal of Burn Care & Rehabilitation	Cartotto, RC	84	10.1097/00004630-200207000-00006
5	A biopsy of the use of the Baxter formula to resuscitate burns or do we do it like Charlie did it?	2000	Journal of Burn Care & Rehabilitation	Engrav, LH	78	10.1097/00004630-200021020-00002
6	Predicting increased fluid requirements during the resuscitation of thermally injured patients	2004	Journal of Trauma-Injury Infection and Critical Care	Cancio, LC	69	10.1097/01.TA.0000075341.43956.E4
7	Is supra-Baxter resuscitation in burn patients a new phenomenon?	2004	Burns	Engrav, LH	67	10.1016/j.burns.2004.01.021
8	A clinical randomized study on the effects of invasive monitoring on burn shock resuscitation	2004	Burns	Holm, C	66	10.1016/j.burns.2004.06.016
9	Reduction of resuscitation fluid volumes in severely burned patients using ascorbic acid administration - A randomized, prospective study	2000	Archives of Surgery	Tanaka, H	61	10.1001/archsurg.135.3.326
10	The burn edema process: Current concepts	2005	Journal of Burn Care & Rehabilitation	Demling, RH	55	10.1097/01.BCR.0000162151.71482.B3

The exploration of the literature co-citation network enables a comprehensive investigation into the developmental trajectory and evolutionary dynamics of a specific field. The co-cited references map in Figure 7a illustrates that a total of 31,908 references were cited across 1,140 articles. “Saffle JR (2007)”, “Klein MB (2007)”, “Pham TN (2008)”, “Cartotto R (2017)”, and “Cancio LC (2004)” were frequently co-cited references. Notably, the top 3 locally cited articles, “Saffle JR (2007)”, “Klein MB (2007)”, and “Pham TN (2008)”, appeared again in the list of highly co-cited references. In the cluster analysis, relevant terms related to fluid therapy relative to burn were divided into 16 categories (FIGURE 7b). The top 5 clusters were noted in TABLE 6 as follows, “fluid creep”, “resuscitation protocol”, “enteral fluid”, “ill patient”, and “hypertonic saline dextran”. The silhouette (s) refers to the average value of the cluster contour. For an s > 0.5 the clustering is generally

considered rational, while for an s > 0.7 the clustering turns out to be convincing [14]. All silhouette values for the top 10 clusters in our study were greater than 0.7 (TABLE 6), indicating that the clusters were compelling. “Fluid creep” (Cluster ID 0#) was the largest cluster including 104 references, and the articles on the theme of fluid creep might have significant implications in the field. In addition, FIGURE 7c demonstrates the timeline view of clusters. Combined with FIGURE 7b, it is predictable that “enteral fluid” and “emergency care” might be the latest hotspots.

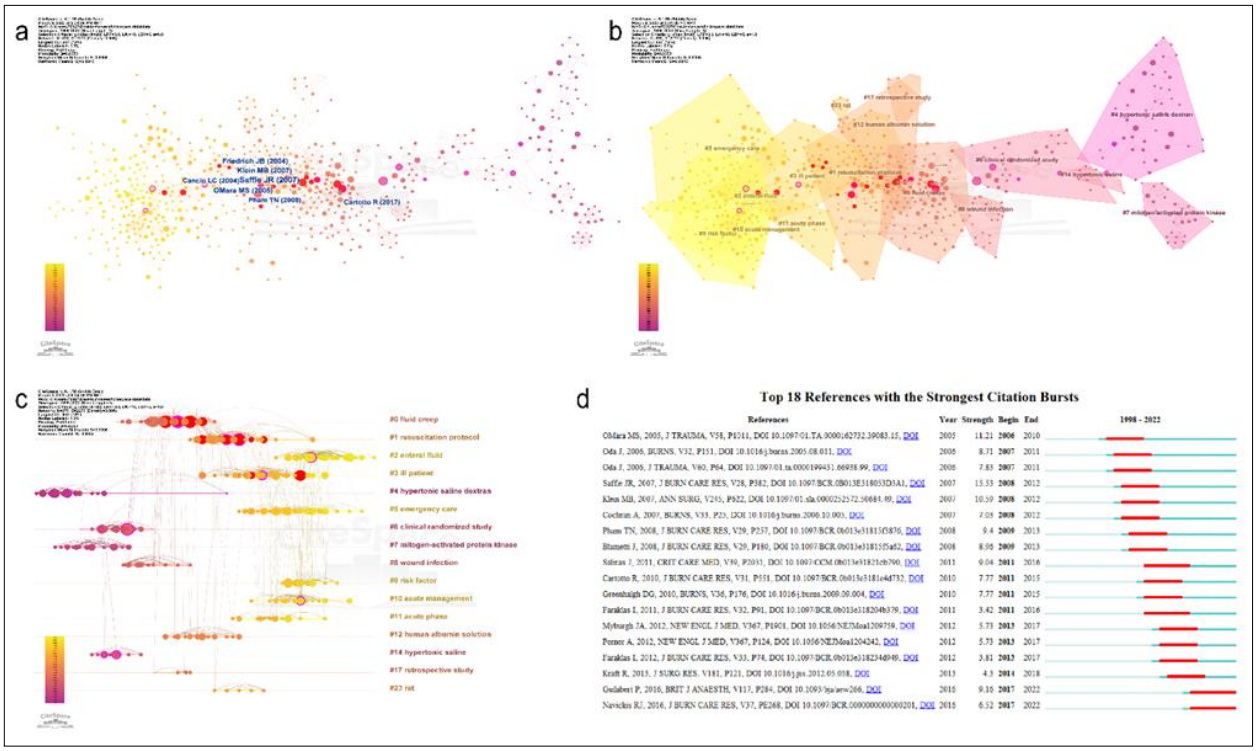

Fig 7: Analysis of most commonly cited references. a) Visualization of co-cited references. b) Cluster analysis of co-cited references. c) Timeline view of cluster analysis. d) Top 18 references with the strongest bursts.

The emergent analysis detects significant changes in the number of literature citations in a period which helps explore the frontiers of a research field [14]. The top 18 references with the strongest burst were noted in FIGURE 7d. The article with the strongest citation burst was written by Saffle JR in 2007. Based on the burst time, the articles written by Guilabert P in 2016 and Navickis RJ in 2016 had the latest explosions covering 2017 to 2022. Guilabert P in 2016 conducted a non-systematic review to clarify how to quantify the amount of fluids needed, what the current evidence said about the available solutions, and which solution was the most appropriate for burn patients based on the available knowledge [28]. Navickis RJ in 2016 conducted a meta-analysis suggesting that albumin could improve outcomes of burn shock resuscitation [29]. The above findings suggest that the exploration of fluid therapy relative to burn is a topic with constant widespread concern.

Table 6: The Top 10 largest clusters of co-cited references.

ClusterID	Label (LLR)	Size	Silhouette	Average Year
#0	fluid creep	104	0.892	2005
#1	resuscitation protocol	93	0.951	2010
#2	enteral fluid	74	0.903	2017
#3	ill patient	67	0.896	2013
#4	hypertonic saline dextran	53	0.984	1997
#5	emergency care	46	0.923	2015
#6	clinical randomized study	40	0.952	2001
#7	mitogen-activated protein kinase	33	1	1999
#8	wound infection	29	0.974	2003
#9	risk factor	28	0.966	2017

Analysis of keywords

The core theme and essential content of a paper can be succinctly summarized through the identification of keywords. By conducting keyword analysis, we are able to identify the research hotspots and frontiers in the field of burn fluid resuscitation. FIGURE 8a shows the co-occurrence analysis of keywords derived from both “author keywords” and “keywords”. The keywords used most frequently were “fluid resuscitation”, “burns”, “resuscitation”, “burn”, “injury”, “management”, “thermal injury”, “mortality”, “inhalation injury”, and “sepsis”. In addition, the cluster analysis revealed that keywords were primarily divided into 4 categories according to the co-occurrence relationship. The red cluster mainly included

"thermal injury", "burn", "sepsis", "septic shock", and "inflammation", mostly related to sepsis, the primary common complication of burn injuries. It was because of the high mortality from sepsis that fluid therapies for burn injuries were paid much attention to. In addition, "burns", "management", "outcome", "accuracy" and "emergency" were visible in the green cluster. This category mostly focused on clinical emergency treatment and accurate fluid management of major burns. Moreover, the yellow cluster primarily consisted of "fluid therapy", "severe sepsis", "hydroxyethyl starch", "randomized trial", and "hypertonic saline". Finally, the blue cluster mainly included "fluid resuscitation", "shock resuscitation", "creep", "abdominal compartment syndrome", and "inhalation injury".

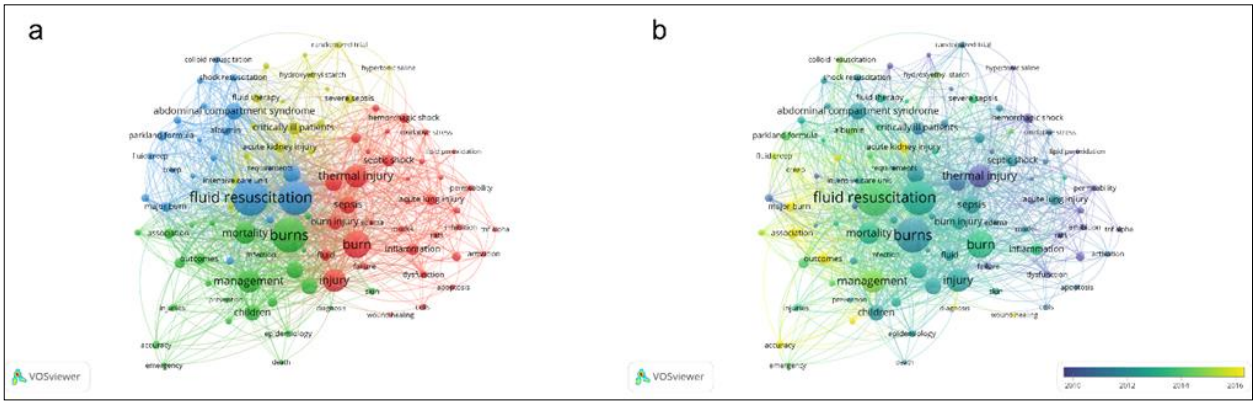

Fig 8: Analysis of all keywords in studies related to fluid therapy related to burn. a) VOSviewer visualization map of co-occurring keywords. b) The overlay visualization of keywords. The later the average publication year in which a keyword appears, the lighter the color of its node.

Based on the overlay visualization of keywords, the color intensity of a node corresponds to the average publication year in which a keyword appears, with lighter shades indicating later years. As shown in FIGURE 8b, the most recent keywords encompassed "outcomes", "accuracy", and "emergency".

Discussion

General information

In this study, we conducted a comprehensive bibliometric analysis on the literature pertaining to burn-related fluid therapy. Our findings reveal a gradual increase in publication output within this field, despite fluctuations in citation activity from 1998 to 2022. Notably, the year 2007 witnessed an unprecedented surge of scholarly attention worldwide, as evidenced by the peak TLCS. This remarkable interest can be attributed to the seminal work by Saffle JR *et al* in 2007, which extensively reviewed potential etiologies, mechanisms, and consequences associated with fluid creep [25]. The article established the theoretical framework for contemporary research on fluid therapy related to burn.

The publication outputs and collaborations of countries and institutions serve as compelling evidence of their academic excellence and capacity to disseminate scientific achievements in a specific field [30]. The USA emerged as the most prolific country, closely followed by China, likely attributed to the robust scientific research capacity of the former and the vast population size of the latter. Moreover, among the top 10 prolific institutions, an overwhelming majority of 9 were affiliated with American organizations, with notable leadership from both the US Army Institute of Surgical Research and Texas University. The USA possesses the highest number of prolific institutions, which partially elucidates its potential to spearhead research in the field of fluid therapy related to burn. The centrality of a specific entity within collaborative networks may serve as a superior indicator of advancements achieved in a particular domain. In this respect, the USA, England, Australia, and Germany appear to exert a substantial influence in this particular domain. The chord diagram suggests that the USA exhibits the highest degree of collaboration with other nations. The collaboration map actually corroborates a transfer of technology and expertise which contributes significantly to the global development of the field. The regional patterns of severe burn morbidity are evident, with a higher incidence observed in low and middle-income countries, leading to increased mortality rates attributed to inadequate healthcare provision. Moreover, the transfer of technology and expertise from countries with robust scientific research capacity to developing regions not only fosters scientific advancements but also enhances their practical application in clinical settings, thereby improving patient care in these nations. However, it is worth noting that all institutions scored less than 0.1 in terms of centrality, indicating a lack of authoritative research centers within this field. Therefore, there is a pressing need to strengthen collaboration among various institutions. key indicators for evaluating prominent researchers in a specific field contain the number of publications, global or local citation score, h-index, and g-index [21]. In this study, we have identified three representative experts who have substantial academic impacts in the research field of fluid therapy related to burn. The first author, Cancio Leopoldo C from the US Army Institute of Surgical Research, emerges as the most prolific researcher with the highest TLCS. Cancio Leopoldo C primarily focuses on elucidating the pathophysiology and advancing treatment strategies for burn wounds, including fluid resuscitation protocols for severe burns. [27, 31]. Furthermore, he is dedicated to investigating contemporary diagnostic approaches for hemorrhagic shock [32, 33], as well as the inhalation injury and airway management associated with burns [34]. Leveraging the extensive burn case database at the US Army Institute of Surgical Research, Cancio Leopoldo C has made noteworthy contributions to this field. Secondly, we found that Herndon David N from Shriners Hospital for Children is the most cited author also with the highest TGCS and h-

index. His research primarily focuses on investigating the intricate interplay between nutritional support, body metabolism, and morbidity among critically burned patients [35-37]. The third researcher, Gibran Nicole S, has garnered over 1000 global citations with a mere 16 publications, underscoring the exceptional caliber and extensive industry recognition of his research. Initially focusing on the pathophysiology and wound healing of burns, he subsequently engaged in clinical studies and contributed to guideline development pertaining to fluid therapy for burn patients. The remarkable excellence of his papers can be attributed to the production of authoritative academic accomplishments. These aforementioned experts all possess significant academic standing within the field of burn-related fluid therapy

In the present study, we identified the leading journals in the field based on their publication frequency, citation count, and impact factor. *Burns* (IF2.609) and *Journal of Burn Care & Research* (IF1.819) accounted for over a quarter of all publications on fluid therapy related to burn injuries, demonstrating commendable performance in terms of co-citations. The aforementioned findings substantiate the authoritative nature of these two journals. *Burns* and *Journal of Burn Care & Research* are both highly respected journals in the field of burns, renowned for their expertise and authority. However, while *Burns* was classified as Q2, *Journal of Burn Care & Research* was classified as Q3. The fact that both journals had IF values below 3 does not necessarily imply a lack of academic quality and influence. Burns injury, as a specialized branch of surgery, is distinct from conventional diseases due to its direct association with accidental trauma. Consequently, being a relatively small and highly specialized discipline, it often garners more attention within the local field but receives less recognition globally. This could potentially explain why these top two journals were not classified as Q1 and obtained a low IF score. As for the prestigious journals, *Critical Care* (IF 19.334) and *Cochrane Database of Systematic Reviews* (IF 12.008) each contributed over 1% of the number of publications. Their high IF stands for high-quality and mature studies with wide recognition. In conclusion, the four journals mentioned above are undoubtedly regarded as cornerstones supporting the development of the field of fluid therapy related to burn. The future publications from these journals are likely to shape the trajectory of this field.

Hotspots and frontiers

TLCS is a highly regarded bibliometric indicator that accurately reflects the scholarly significance of an article. Among the top 10 most locally cited studies, there are 8 articles focused on clinical research and 2 reviews, indicating a strong preference among researchers for clinically relevant topics. One possible explanation for this emphasis on clinical items could be attributed to the ongoing controversy surrounding the selection of fluid therapy for burn injuries in clinical practice. The optimal type, quantity, and administration of resuscitation fluids for severely burned patients remain critical issues faced by clinical physicians; however, a universally accepted gold standard has yet to be established.

Co-citation clustering analysis reflects the development trends and prominent issues within a specific field [38]. In this study, we will discuss the largest cluster and the recent clusters through a literature co-citation analysis. First, the largest cluster is “fluid creep” (Cluster ID 0#) with 104 references, a phenomenon in which severely burned patients required far more fluid than that predicted by the Parkland formula. Pruitt noticed this phenomenon in 2000 and named it "fluid creep" [9]. Saffle JR *et al*. (2007) provided a comprehensive overview of the potential causes, mechanisms, and implications of fluid creep in contemporary practice. Additionally, they proposed evidence-based therapeutic strategies to mitigate or eliminate excessive fluid resuscitation in burn care. [25]. In the same year, Klein MB *et al*. conducted a multicenter study that demonstrated that “fluid creep” was associated with an increased risk of injury complications and mortality among patients [26]. For fluid requirements, TBSA, age, body weight, and intubation status on admission should be taken into account. In conclusion, the introduction of "fluid creep" marked a pivotal milestone in the evolution of burn-related fluid therapy, as scholars shifted their focus from achieving "adequate" to "accurate" fluid administration. Moreover, the later clusters include “enteral fluid” (Cluster ID 2#), “emergency care” (Cluster ID 5#), “risk factor” (Cluster ID 9#), “acute management” (Cluster ID 10#), and “acute phase” (Cluster ID 11#). It can be observed that the majority of these findings are primarily associated with emergency burn care, which represents a current focal point in this field. In the cluster view and timeline view, initial cluster labels such as: “hypertonic saline dextran” (Cluster ID 4#), “clinical randomized study” (Cluster ID 6#), “mitogen-activated protein kinase” (Cluster ID 7#), and “hypertonic saline” (Cluster ID 14#) predominantly concentrate on elucidating the mechanisms, fluid types, and clinical investigations pertaining to fluid resuscitation for burn injuries. However, burn shock differs from other types of shock due to its pronounced temporal regularity, posing challenges in determining the optimal fluid administration for severe burn patients with shock. Implementing a well-designed early fluid resuscitation protocol in accordance with the temporal regularity of burn injuries can significantly mitigate the occurrence of shock and complications among patients with severe burns. The temporal regularity of body volume in burns underscores the critical importance of early fluid resuscitation as a primary treatment for severe burns [39]. Consequently, with a deeper understanding of the mechanisms behind burn shock, scholars shifted their focus towards improving emergency burn care. Furthermore, a study performed by Guilabert P *et al*. (2016) related to emergency burn care showed a high-intensity burst in this research field. The research group summarized recent advancements in the management of fluid resuscitation for burn patients, concluding that timely administration of fluids is crucial for the survival of severely burned individuals. This conclusion was drawn after an extensive study on the pathophysiology and outcomes of burn patients [28]. In conclusion, emergency burn care has emerged as a prominent research area and has garnered significant scholarly attention across different nations.

The analysis of keywords can provide insights into the prominent research areas within a specific field [40]. The overlay visualization of keywords unveils the temporal transmission of research content within the field from an alternative perspective. In conjunction with literature co-citation analysis, emergency burn care continues to be a prominent area of research within the keyword co-occurrence network, thus highlighting its significance in the

field. Moreover, based on the timeline view of keyword co-occurrence analysis, we infer that precise fluid resuscitation for burn injuries has emerged as a prominent academic trend in this particular domain. The concept of burn fluid resuscitation accuracy gained prominence following the emergence of the fluid creep phenomenon. To avoid the complications of over-resuscitation and fluid creep, scholars and physicians began to stop aiming for adequacy and instead aim for accuracy in fluid resuscitation for severe burn. Accurate fluid therapy protocols are based on traditional weight-related formulas using different basic or advanced hemodynamic parameters with the goal of minimizing fluid intake while maintaining an effective circulation volume. These hemodynamic primarily encompassed parameters such as urinary output, mean arterial pressure, cardiac output, stroke volume, and microcirculatory perfusion mark [41]. In recent studies on precise fluid resuscitation, Jianglin Tan *et al*. (2021) proposed a novel resuscitation formula based on the burn index to enhance the accuracy of estimating fluid requirements following major burns [42]. The study proved that the Third Military Medical University (TMMU) formula widely used in fluid resuscitation in China showed low accuracy in predicting fluid requirements among major burn patients. The novel resuscitation formula incorporates burn index, body weight, and inhalation as key factors associated with the volume requirements for postburn fluid resuscitation. In addition, Jianping Ye *et al*. (2021) have developed a highly precise weighing system to enhance the accuracy of the Parkland formula and establish a dependable foundation for early burn resuscitation [43]. The accumulation of novel fluid therapy protocols has highlighted the growing emphasis on "accuracy" in burn fluid resuscitation in recent years, garnering significant attention from scholars worldwide.

Limitations

The publications on fluid therapy related to burn evaluated in this study were extracted from the WoSCC database and were analyzed primarily using three recognized bibliometric software, resulting in a more accurate and objective data analysis. Nevertheless, this study has certain limitations. Firstly, we solely relied on data extracted from WoSCC while excluding other databases like Scopus or PubMed, potentially impacting the comprehensiveness of our findings. Secondly, due to the dynamic nature of fluid therapy literature in relation to burn injuries, the obtained publications may not accurately reflect the true number, potentially leading to fluctuations in bibliometric parameters such as citation count and h-index. Finally, we extensively reviewed the available literature on fluid therapy for burns from the WOSCC database, however, it is important to acknowledge that the heterogeneous quality of these studies may impact the overall authority and credibility of our findings.

Conclusion

This study employs scientific visualization analysis to investigate the research progress, hotspots, and frontiers in fluid therapy related to burn. The research in this field is experiencing a notable surge; nevertheless, there exists an imminent necessity to disseminate more groundbreaking research findings in order to captivate scholarly attention. The USA and the US Army Institute of Surgical Research are the most prolific country and institution. Cancio Leopoldo C from the US Army Institute is the most productive author and Herndon David N from Shriners Hospital for Children is the most cited author. *Burns* and *Journal of Burn Care & Research* are the most productive and commonly cited journals. The document with the highest number of local citations is “The Phenomenon of ‘Fluid Creep’ in Acute Burn Resuscitation” by Saffle JR in 2007. Additionally, the focus within the field has transitioned from early-stage research on fluid type and mechanisms to recent emphasis on emergency burn care. The investigation of fluid resuscitation with a goal of accuracy will be an area of intense interest for future research. In general, this study systematically analyzed the literature on fluid therapy related to burn, providing a comprehensive perspective on the developmental process in this field from multiple dimensions. Our findings revealed prominent authors and institutions, summarized key research achievements and offered valuable references for clinical decision-makers and scientific scholars regarding research directions and clinical applications.

Data availability statement

The original contributions involved in the study have been included in the paper/supplement material, and additional queries can be presented to the corresponding authors.

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