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Hundred top-cited articles focusing on acute kidney injury: a bibliometric analysis

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ABSTRACT

Background: Acute kidney injury (AKI) is a major global health issue, associated with poor short-term and long-term outcomes. Research on AKI is increasing with numerous articles published. However, the quantity and quality of research production in the field of AKI is unclear.

Methods and analysis: To analyse the characteristics of the most cited articles on AKI and to provide information about achievements and developments in AKI, we searched the Science Citation Index Expanded for citations of AKI articles. For the top 100 most frequently cited articles (T100), we evaluated the number of citations, publication time, province of origin, journal, impact factor, topic or subspecialty of the research, and publication type.

Results: The T100 articles ranged from a maximum of 1971 citations to a minimum of 215 citations (median 302 citations). T100 articles were published from 1951 to 2011, with most articles published in the 2000s (n=77), especially the 5-year period from 2002 to 2006 (n=51). The publications appeared in 30 journals, predominantly in the general medical journals, led by *New England Journal of Medicine* (n=17), followed by expert medical journals, led by the *Journal of the American Society of Nephrology* (n=16) and *Kidney International* (n=16). The majority (83.7%) of T100 articles were published by teams involving ≥3 authors. T100 articles originated from 15 countries, led by the USA (n=81) followed by Italy (n=9). Among the T100 articles, 69 were clinical research, 25 were basic science, 21 were reviews, 5 were meta-analyses and 3 were clinical guidelines. Most clinical articles (55%) included patients with any cause of AKI, followed by the specific causes of contrast-induced AKI (25%) and cardiac surgery-induced AKI (15%).

Conclusions: This study provides a historical perspective on the scientific progress on AKI, and highlights areas of research requiring further investigations and developments.

Strengths and limitations of this study

- Two meticulous searches were performed in the Web of Science and consistent results were demonstrated in Scopus data.
- Since some articles were cited more frequently than others because of the differences in time since publication, and this error was adjusted by a citation index determined for each article.
- The language of publication was restricted to English, which would have failed to capture landmark articles published in other languages.
- Findings of the present study would provide a historical perspective on the scientific progress on acute kidney injury.
- Findings of the present study would highlight areas of research requiring further investigations and developments.

INTRODUCTION

Acute kidney injury (AKI) is a major global health issue and its incidence is markedly increasing in developed and developing nations.[1] The reported incidence ranges from 5% to 30–50% in patients under various conditions, such as coronary intervention,[2] cardiac surgery[3] and intensive care unit admission.[4] The development of AKI increases hospital stay and healthcare costs, and results in poor short-term and long-term outcomes.[4] Considering the importance of AKI, researches in this field has been increasing, and numerous articles have been published annually, giving new insights into the mechanism, early recognition and prevention or treatment of AKI.[5 6] However, little is known regarding the quality of scientific achievements in this area.

Citation analysis is a bibliometric process that determines the influence of an article in the scientific community and evaluates the impact factor (IF) of a journal.[7] The number of citations received by an article is a measure of its recognition and influence within the scientific community. A paper with greater citation history may be more valuable in its field.[8 9] Furthermore, citation analysis of the scientific literature may help to identify articles, research topics and

authors of influence.[10] Therefore, academic institutions, funding agencies and the public become increasingly interested in using citation analysis to assess the research quality and productivity of individual researchers.[7] Numerous attempts have been made to identify the most cited articles in various medical disciplines, including psychology,[11] radiology,[12] hypospadiology,[13] hypertension,[14] surgery[15] and cardiac surgery.[16] However, no citation analysis of AKI has been published to date. Therefore, we aimed to analyse the characteristics of the 100 top-cited articles focused on AKI, and to determine achievements and advances in this field during the past century.

METHODS

Search strategy

We conducted a citation search of the Science Citation Index Expanded database of the Thomson Reuters Web of Science Core Collection (Philadelphia, Pennsylvania, USA) from 1945 to 15 July 2015. The following search key words were used: 'acute kidney injury' or 'AKI' or 'acute renal failure' or 'ARF'. All electronic searches were conducted on a single day, 15 July 2015, to avoid changes in citation rate as much as possible. After all identified articles were retrieved, and the results were sorted using the option 'Times cited', which yielded a list of all the articles published in a specific journal ranked by citation number. The papers that had a higher citation density were ranked higher.

Study selection

Articles on the list were then reviewed by two independent reviewers (Y-hL and S-qW) by reading the abstracts acquired from Web of Science. When it was necessary, the full texts were acquired from PubMed, EMBASE or ScienceDirect. Only studies focusing on AKI as the main topic and in the English language were included. The exclusion criteria were: (1) articles in languages other than English, (2) articles focused on other topics other than about AKI. Any disagreement between the two reviewers was resolved through discussion with a third reviewer (J-hX).

Assessing the articles and journals

Using the modified approach of the methods by Lim *et al*[17] and Azer and Azer,[18] two reviewers (Y-hL and S-qW) reviewed the top 100 cited (T100) articles and the following data were compiled: (1) citation number, (2) number of authors and authorship (first, second and corresponding authors), (3) title, (4) publication year and (5) country of origin. If there were authors from multiple countries, the country of origin was determined using the country that the corresponding author belonged to. Those from the same country were classified into those from one institute and those from more than one institute. Articles that received funding source were identified. Level of evidence for clinical studies was also identified, and was evaluated based on the levels of evidence introductory document from the Oxford Centre for Evidence-based Medicine.[19] In addition, journal name and IF were also extracted. The journals IFs were cross-referenced with the 2014 edition of Journal Citation Reports (JCR): Science Edition (1945–2014).

Evaluating the included studies

Based on included study design, research setting and goals, the selected articles were grouped into five categories: clinical guidelines, review, meta-analysis, basic research and clinical research (including observational and randomised control trials, RCTs). Prospective, retrospective and case series were all categorised as observational studies. RCTs include both single-blind and double-blind studies.

In addition, according to the causes of AKI, the topics were divided into (1) any cause, (2) contrast, (3) cardiac surgery and (4) others. Since some articles were cited more frequently than others because of the difference in time since publication, this error was adjusted by a citation index determined for each article. The citation index was defined as the mean number of citations per year. For comparison, we searched Scopus (http://www.scopus.com/ search/form.url; retrieved on 15 July 2015) for total citation counts of the T100 articles.

Statistical analysis

Data are represented as median or IQR. The differences between groups were evaluated by the Wilcoxon rank-sum test. The Spearman test was used to evaluate the strength and direction of the linear relationship between journal IF and the number of T100 cited articles or citations, and the correlation of article citations between different databases (Web of Science Core Collection and Scopus). All data analyses were performed with SPSS V.17 software (SPSS, Chicago, Illinois, USA). All probability values were two-tailed, and the threshold for significance was set at $p<0.05$.

RESULTS

Citation count and publication year

A total of 56 830 papers were identified after the initial search in the period from 1945 to present. Among them, articles that focused solely on AKI and were among the top 100 most cited were included. A flow diagram representing the study selection process was presented in online supplementary figure S1. Ultimately, 123 articles (including some duplicate citations) were included in the analysis (table 1 and online supplementary table S1). The median number of citations was 302 (range 215–1971), with only three papers cited over 1000 times. The citation index (median 216, range 5–184) was correlated with number of the citations ($r=0.581$, $p<0.001$) per article. In addition, the number of citation and citations index per article were positively

Table 1 Bibliometric information associated with the top 20 of the top 100 cited articles in acute kidney injury

Rank	Authors	Title	Journals	Years	Times cited (web)	Citation index (web)	Times cited (Scopus)	Citation index (Scopus)	PMID
1	Bellomo *et al*	Acute renal failure: definition, outcome measures, animal models, fluid therapy and information technology needs: the Second International Consensus Conference of the Acute Dialysis Quality Initiative (ADQI) Group	*Critical Care*	2004	1971	164.25	2219	184.92	15 312 219
2	Mehta *et al*	Acute Kidney Injury Network: report of an initiative to improve outcomes in acute kidney injury	*Critical Care*	2007	1652	183.56	1725	191.67	17 331 245
3	Uchino *et al*	Acute renal failure in critically ill patients—a multinational, multicenter study	*JAMA—Journal of the American Medical Association*	2005	1297	117.91	1489	135.36	16 106 006
4	Thadhani *et al*	Medical progress—acute renal failure	*New England Journal of Medicine*	1996	963	48.15	1139	56.95	8 618 585
5	Mishra *et al*	Neutrophil gelatinase-associated lipocalin (NGAL) as a biomarker for acute renal injury after cardiac surgery	*Lancet*	2005	949	86.27	1079	98.09	15 811 456
6	Chertow *et al*	Acute kidney injury, mortality, length of stay, and costs in hospitalized patients	*Journal of the American Society of Nephrology*	2005	893	81.18	1035	94.09	16 177 006
7	Ronco *et al*	Effects of different doses in continuous veno-venous haemofiltration on outcomes of acute renal failure: a prospective randomised trial	*Lancet*	2000	816	51.00	1032	64.5	10 892 761
8	Paller *et al*	Oxygen free radicals in ischemic acute renal failure in the rat	*Journal of Clinical Investigation*	1984	814	25.44	575	17.97	6 434 591
9	McCullough *et al*	Acute renal failure after coronary intervention: incidence, risk factors, and relationship to mortality	*American Journal of Medicine*	1997	799	42.05	1016	53.47	9 375 704
10	Levy *et al*	The effect of acute renal failure on mortality—a cohort analysis	*JAMA—Journal of the American Medical Association*	1996	793	39.65	998	49.9	8 622 223
11	Rihal *et al*	Incidence and prognostic importance of acute renal failure after percutaneous coronary intervention	*Circulation*	2002	691	49.36	877	62.64	12 010 907
12	Solomon *et al*	Effects of saline, mannitol, and furosemide to prevent acute decreases in renal function induced by radiocontrast agents	*New England Journal of Medicine*	1994	684	31.09	905	41.14	7 969 280

Continued

Table 1 Continued

Rank	Authors	Title	Journals	Years	Times cited (web)	Citation index (web)	Times cited (Scopus)	Citation index (Scopus)	PMID
13	Mehran *et al*	A simple risk score for prediction of contrast-induced nephropathy after percutaneous coronary intervention—development and initial validation	*Journal of the American College of Cardiology*	2004	677	56.42	844	70.33	15 464 318
14	Mishra *et al*	Identification of neutrophil gelatinase-associated lipocalin as a novel early urinary biomarker for ischemic renal injury	*Journal of the American Society of Nephrology*	2003	645	49.62	735	56.54	14 514 731
15	Chertow *et al*	Independent association between acute renal failure and mortality following cardiac surgery	*American Journal of Medicine*	1998	630	35.00	747	41.5	9 576 407
16	Parfrey *et al*	Contrast material-induced renal failure in patients with diabetes mellitus, renal insufficiency, or both. A prospective controlled study	*New England Journal of Medicine*	1989	618	22.89	635	23.52	2 643 041
17	Aspelin *et al*	Nephrotoxic effects in high-risk patients undergoing angiography	*New England Journal of Medicine*	2003	575	44.23	758	58.31	12 571 256
18	Brivet *et al*	Acute renal failure in intensive care units—causes, outcome, and prognostic factors of hospital mortality: a prospective, multicenter study	*Critical Care Medicine*	1996	538	26.90	632	31.6	8 605 788
19	Togel *et al*	Administered mesenchymal stem cells protect against ischemic acute renal failure through differentiation-independent mechanisms	*American Journal of Physiology—Renal Physiology*	2005	524	47.64	625	56.82	15 713 913
20	Merten *et al*	Prevention of contrast-induced nephropathy with sodium bicarbonate—a randomized controlled trial	*JAMA—Journal of the American Medical Association*	2004	513	42.75	714	59.5	15 150 204

PMID, PubMed Identifier.
See online supplementary table S1 for a complete list of T100.

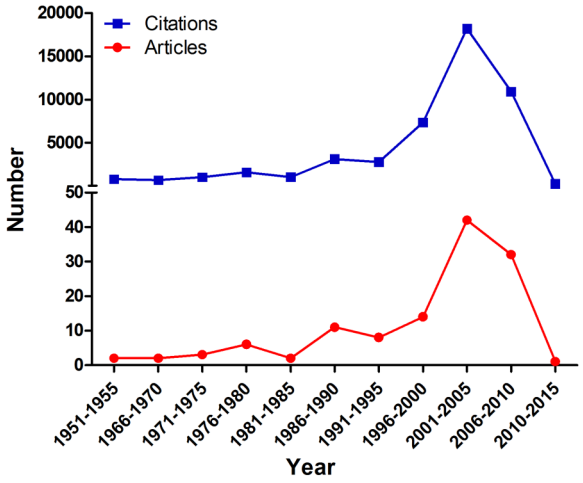

Figure 1 Numbers of articles published and number of citations in 5-year periods.

correlated between the Web of Science and Scopus database (r=0.770, p<0.001; r=0.791, p<0.001, respectively).

The selected T100 articles were published between 1951 and 2011, with most articles published in the 2000s (n=77), and particularly the 5-year period from 2002 to 2006 (n=51), followed by the 1990s (n=22; figure 1). The most cited articles in a single year were 2004 and 2006 (each n=13). The number of citations was also the highest in the 2000s (30 537) followed by the 1990s (9510). Spearman test indicated an uptrend between the citation index and time (r=0.315, p<0.001). There is no correlation between time and number of citations (r=−0.003, p=0.975), but there was a positive correlation between time and citation index (r=0.347, p<0.001).

Publishing journals of T100 articles

The T100 articles were published in 30 journals (table 2), predominantly in general medical journals, led by the *New England Journal of Medicine* (n=17), followed by expert medical journals, led by the *Journal of the American Society of Nephrology* (n=16) and *Kidney International* (n=16; table 2). In addition, *Journal of Clinical Investigation*, *Lancet*, *Journal of the American Medical Association*, *American Journal of Medicine* and *Critical Care Medicine* contributed 11, 7, 5, 5 and 5 most cited articles, respectively. The journals IFs of T100 articles ranged from 2.1 to 55.9. Many of the T100 articles were published in the high-IF journals, while the journal IF was significantly correlated with the number of T100 articles (r=0.439, p=0.017), and the number of citations (r=0.476, p=0.009).

Authorship, origins and institutions

The majority (83.7%) of T100 articles were produced by teams involving ≥3 authors. A list of the most frequently appearing authors is presented in table 3. It is clearly dominated by JV Bonventre, who authored 10 T100 articles (first author: 5; corresponding author: 9) with a

Table 2 Journals in which the T100 articles were published

Journal	Number of articles (citations)	Impact factor	5-year impact factor
New England Journal of Medicine	17 (7249)	55.87	54.39
Journal of the American Society of Nephrology	16 (5470)	9.34	5.47
Kidney International	16 (5157)	8.56	7.89
Journal of Clinical Investigation	11 (3930)	13.22	14.05
Lancet	7 (3194)	45.22	42.72
JAMA—Journal of the American Medical Association	5 (3095)	35.29	31.03
American Journal of Medicine	5 (2138)	5.00	5.26
Critical Care Medicine	5 (1935)	6.31	6.29
American Journal of Physiology—Renal Physiology	4 (1252)	3.25	3.51
Critical Care	4 (4379)	4.48	5.14
Archives of Internal Medicine	4 (1079)	17.33	13.10
Journal of the American College of Cardiology	3 (1238)	16.50	14.10
Medicine	3 (971)	5.72	5.29
Annals of Internal Medicine	3 (864)	17.8	17.47
Proceedings of the National Academy of Sciences of the United States of America	2 (683)	9.67	10.56
American Journal of Kidney Diseases	2 (627)	5.90	5.56
Clinical Journal of the American Society of Nephrology	2 (604)	4.61	5.47
American Journal of Cardiology	2 (482)	3.28	3.35

The journals that only published one of the T100 articles were shown below. Values given in parentheses were number of articles, impact factors and the corresponding citations, respectively. *Circulation* (1, 14.43, 691); *Intensive Care Medicine* (1, 7.21, 349); *Nephrology Dialysis Transplantation* (1, 3.58, 304); *Anesthesiology* (1, 5.88, 263); *Circulation Research* (1, 11.02, 243); *Journal of Thoracic and Cardiovascular Surgery* (1, 4.17, 229); *International Journal of Molecular Medicine* (1, 2.09, 228); *American Journal of Physiology* (1, NA, 227); *Clinical Infectious Diseases* (1, 8.89, 226); *Annals of Surgery* (1, 8.33, 226); *Annals of Thoracic Surgery* (1, 3.85, 221); *European Radiology* (1, 4.01, 220).

Table 3 Authors with two or more top-cited articles

Rank	Author	Number of articles	First	Correspond	Other	Citations (first and correspond)	Total citations
1	Bonventre	10	5	9	1	4263	4527
2	Devarajan	8	1	5	3	2464	3428
3	Chertow	6	3	5	1	2353	2579
4	Mehta	6	4	3	1	2757	4728
5	Parikh	4	2	4		996	813
6	Marenzi	3	3	3		813	1095
7	Schrier	3	2	3		1095	1634
8	Camussi	2		2		452	452
9	Dangas	2	1	2		934	934
10	Kellum	2				1788	1788
11	McCullough	2	2	2		1101	1101
12	Schiffl	2	2	2		677	677
13	Westenfelder	2		2		761	761
14	Parfrey	2	1	2	1	892	892
15	Bates	2	1	1	1	226	1119
16	Coca	2	2			486	486

total of 4527 citations, and P Devarajan, who authored 8 T100 articles with 3428 citations.

The T100 articles originated from 15 countries, led by the USA (n=81) followed by Italy (n=9), Germany (n=7), France (n=5) and the UK (n=5), with all other countries having <5 publications, as shown in figure 2. Articles originating from the USA also had the highest mean number of citations (mean 384 citations per article). Of the total T100 articles, the leading institutions with the most productive articles were Brigham and Women's Hospital (Boston, Massachusetts, USA), Cincinnati Children's Hospital Medical Center (Cincinnati, Ohio, USA) and the University of California, San Francisco (San Francisco, California, USA), with five articles each. The institution ranking next is the Yale University (West Haven, Connecticut, USA; table 4).

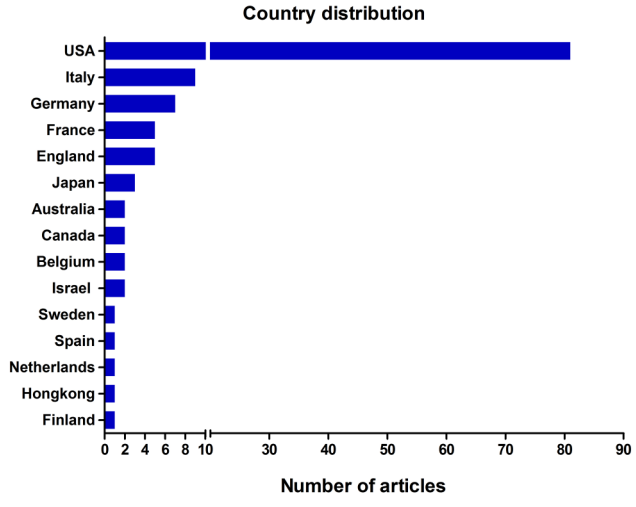

Figure 2 Countries of origin of the top 100 cited articles on acute kidney injury.

Publication type and areas of study

The T100 articles included 69 clinical studies, 25 basic science studies, 21 reviews, 5 meta-analyses and 3 clinical guidelines (figure 3). The number of total citations per article ranged from 218 to 1652 (median, 303) for clinical studies, and from 215 to 814 (median, 257) for basic science. Of the 69 clinical articles, the most common type was prospective observational studies (n=35), followed by RCTs (n=16), retrospective studies (n=16) and case reports (n=2). In addition, 75% of the 16 RCTs were published in the journals with high IF, 8 in *New England Journal of Medicine*, 2 in *Lancet* and 2 in *JAMA*. Only 18% of the 51 observational studies were published in journals with high IF, and most of them (47%) presented open access options, and all of them were from prospective observational studies, including 4 in New *England Journal of Medicine*, 2 in *Lancet* and 3 in *JAMA*. Furthermore, prospective observational studies had a higher median citation of per article than the retrospective studies (median 298 vs 292).

The primary purpose of these clinical studies included evaluation of a therapy strategy (n=16), description of biomarkers or risk model to prevent AKI (n=9 and n=3, respectively), description of epidemiology (n=27), evaluation of a diagnostic modality (n=5) and others (n=9). With regard to the causes of AKI in clinical researches, most articles (55%) included patients with any cause of AKI, followed by specific contrast-induced AKI (25%) and cardiac surgery-induced AKI (15%). Only one study reported on drug-induced AKI, and the rest were non-traumatic rhabdomyolysis-induced AKI (n=3). In addition, ischaemia-induced AKI was the most common type of AKI (64%) assessed in basic science studies, followed by drug-induced AKI models (32%) and only one basic research study concerned surgery-induced AKI.

Table 4 Institutions with two or more top-cited articles on acute kidney injury

Rank	Institution	Number of articles	Citations
1	Brigham and Women's Hospital, Boston, Massachusetts, USA	9	4263
2	Cincinnati Children's Hospital Medical Center, Cincinnati, Ohio, USA	5	2464
3	University of California, San Francisco, California, USA	5	2353
4	Yale University, West Haven, Connecticut, USA	4	996
5	University of California, San Diego, California, USA	3	2757
6	The University of Milan, Milan, Italy	3	813
7	University of Colorado, Denver, Colorado, USA	3	1095
8	University of Torino, Torino, Italy	2	452
9	Columbia University, New York, New York, USA	2	934
10	William Beaumont Hospital, Royal Oak, Michigan, USA	2	1101
11	University of Munich, Munich, Germany	2	677
12	Veterans Affairs Medical Center, Salt Lake City, Utah, USA	2	761
13	Memorial University of Newfoundland, City of Saint John, Canada	2	892

Funding source and level of evidence

Among the T100 articles (original articles), 60 were funded by public foundations, 3 received support from commercial companies, 8 were supported by both and the remaining 52 did not specify the funding source (figure 4). More than half of studies that disclosed funding (95.8%) were supported by the public, and pharmaceutical companies only supported 15.5%. Funding supported most of the basic science T100 studies (96%, 24/25), but only 43.5% of clinical articles.

All of the clinical articles were assigned a level of evidence from 1 to 5 (figure 5). Level 2b (47.3%) was the most frequent level of evidence, with a median of 298 citations per article. There were 16 studies each at levels 1b and 3b. Only one and four T100 cited articles were assigned to level 1a and 2a, respectively. There was no significant association between the citation index and level of evidence (p=0.847). In addition, the evidence level was not strongly correlated with the overall number of citations (r=−0.11, p=0.345), citation index (r=−0.08, p=0.500) or year of publication (r=−0.16, p=0.174).

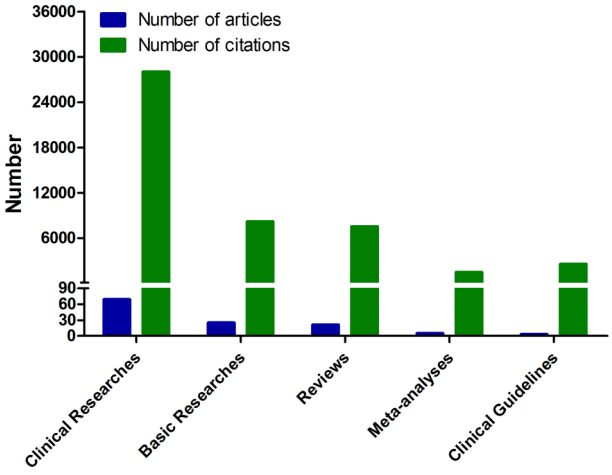

Figure 3 Distributions of research type of the top 100 cited articles on acute kidney injury.

DISCUSSION

The present study is the first to identify, rank and characterise the T100 articles in the field of AKI. The results reveal important advances and prevalent areas of interest in research about AKI, and may help physicians and scientists to understand and design future research. The present study also provides quantitative information about

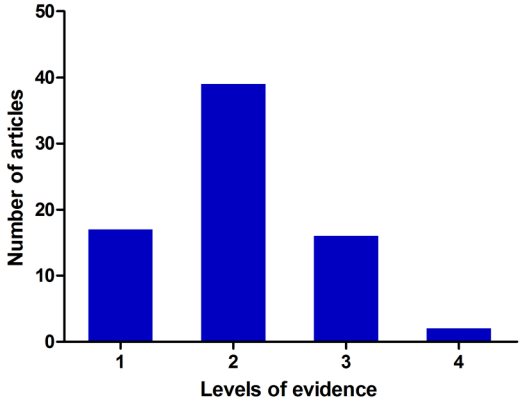

Figure 4 Funding source of the top 100 cited research studies.

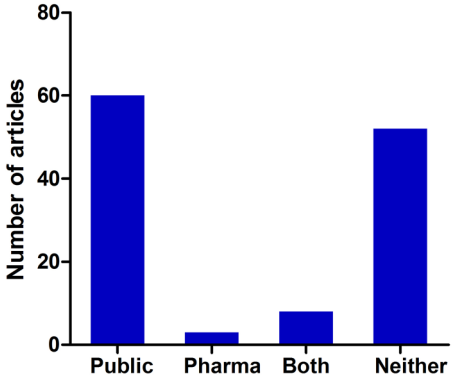

Figure 5 Levels of evidence of the top 100 cited clinical articles.

authors, institutions and journals that help to identify classic studies and high-impact journals.

Bibliometric analysis is a tool that quantifies the characteristics and scholarly impact of citation classics. Citation analysis, a common bibliometric method, can help authors to recognise important advances, and add a useful perspective on historical developments in a specific field. Understanding the characteristics inherent to highly cited studies could help researchers who wish to publish effectively.[20] However, we also should notice that the citations number might be poorly related to merit, it is strongly affected by the journal in which the paper is published.[8 21] In addition, the number of citations would be influenced by factors such as the geographic origin of the authors, whether they are English speaking[22] and the gender of the authors.[23] Despite some disadvantages in the assessment of article quality based simply on citation rating, it remains the most widely accepted method currently available to judge the merits of a paper or journal.[24] Citation analysis is often used by journals to attract manuscripts with high citation potential. Currently, citation analysis of top-cited articles is widespread and reported in various medical disciplines. However, there has been no citation analysis of AKI, which is a major global health issue associated with increased medical cost, and poor short-term and long-term outcomes. In addition, the prevention, diagnosis and treatment of AKI have become a rapidly developing specialty in recent years. This development is evidenced by the increasing number of related studies in the scientific literature. Identifying the classic articles that have contributed to progress in AKI research will help to understand the history and development of AKI and design future studies. However, little work has been conducted to recognise these important papers. The present study is the first to analyse the top article citations in AKI, and will help readers or authors to recognise the quality of the research, discoveries and the trends steering AKI.

An article has more time to be cited with increasing age, and 'older' articles are more likely to attain more citations, purely because of their longer citable period. However, in this analysis, most of the T100 articles (67%) were published between 2001 and 2009. This result is not consistent with most other citation analyses, in which the peak period for citation is from 1980 to 1995. However, it is consistent with recent research in the field of cardiovascular diseases.[25] In addition, to overcome the effect of publication time on citations, we also assessed the citation index as a measure of the true impact of an article independent of short-lived trends. The results remained consistent indicating that the number of AKI articles increased, and this field attracted more resources and materials in the past 10 years, with the growing incidence of AKI, because of increasing exposure to contrast media or cardiothoracic surgery.

Some previous studies have demonstrated that high IF journals are attractive to authors, which in turn preferentially attract more submissions from the authors. Therefore, the IF of a journal is the strongest indicator for citations, and most top-cited articles are published in high IF journals.[26–28] The present study also demonstrated that IF was positively correlated with the number of T100 articles, and the number of citations. However, other than the high-IF general medical journal the-New England Journal of Medicine, which published 17 T100 articles, the most productive journals were the *Journal of the American Society of Nephrology and Kidney International*, which have relatively low IFs. This result indicates an increasing trend of publishing highly influential articles in specialty journals dedicated solely to research into renal diseases such as AKI rather than general medical journals (eg, *Lancet* or *JAMA*). These results are consistent and agree with previous studies focusing on other diseases.[14 25] Our results also revealed that no T100 basic research study focusing on AKI was published in *Nature*, *Cell* or *Science*, journals with the highest influence on basic research. This result is in contrast to hypertension studies, among which highly cited basic research is published more frequently in *Nature* (six articles) and *Cell* (four articles).[14]

Fifteen countries contributed to the T100 cited articles, led by the USA, which is similar to the T100 articles in the fields of cardiac surgery,[16] sepsis[29] and others.[25 30 31] This finding confirms the influence of the USA in relation to AKI research worldwide and may be related to the large population and abundant financial resources available to the scientific community in the USA. In addition, among the top 13 institutions, 9 (69%) are in the USA. The leading institution is Brigham and Women's Hospital, which published 9 T100 cited articles with total citations number of 4263. Furthermore, American authors tend to cite local papers and European authors tend to publish in American journals and US reviewers prefer US papers.[28 32] In addition, European countries, like Italy and the UK, also demonstrated higher productivity. However, despite the rapid development of scientific research in recent years, Asian authors have not played a dominant role in AKI research since their contribution to research productivity is relatively low. This finding seems to conform to the phenomenon that 'a country with better economic ranking has the higher quantity and quality of biomedical publications'.[33] A number of first or corresponding authors were represented more than once on the list. This list of frequently cited authors highlights some of the world's best recognised experts in the field of AKI research. The most frequently cited authors JV Bonventre and P Devarajan, with five and six articles, respectively, were associated with clinical articles.

Financial support from public foundations or commercial companies has greatly contributed to medical and public health research. In our study, more than half (57.7%) of the T100 articles reported a source of funding support. Among them, 84.5% received funding

from public institutions or national foundations, 4.2% from industry and 11.3% from both. Although, industry-funded research has been widely debated because of susceptibility to various biases, it has played and will continue to play a critical role in the research process.[34] In another recent study, 24% of funding was from industry, which is higher than in the present study. However, 30% of reported funding was from public agencies, which is lower than ours.[29] This comparison indicates that government-funded entities have prioritised AKI, a global health issue impacting medical costs. The cost per 6-month AKI survivor was calculated to be $80 000.[35] Another reason for this discrepancy might be the lack of new drug development research in the present T100 articles, resulting in little funding from pharmaceutical companies. In addition, only 44% of clinical research received funding, while 96% of basic research received funding. These results confirm the key role of public funding in the generation of influential basic research. However, clinical research has bridged the gap between basic science and human health improvement, is heavily weighted towards biomedical science, and plays a special role in the fight against AKI by providing evidence for its treatment and diagnosis. High-quality clinical research is expensive, and in future, it should receive more funding support.

Based on the advantages of clinical research aforementioned, more clinical studies have been performed to provide new insights into the prevention, biomarkers, diagnosis or treatment of AKI. In addition, a recent detailed bibliometric analysis suggests the rapid dissemination of clinical findings.[36] Thus, it is not surprising that most of the T100 articles (58%) in the present study are clinical research, consistent with analyses in other fields.[37–39] The mean citation number per clinical research article was higher than that of basic research articles (404 vs 328). Among clinical studies, the most frequent type was prospective observational study (n=35), followed by RCT (n=16). Our limited survey, based on the analysis to identify the citation source for the top 3 T100 clinical studies, revealed that most of their citations (2/3) came from other original articles (both clinical and preclinical studies), with the rest of citations (1/3) in subsequent reviews, editorials or meta-analyses. This distribution suggests that the conclusions of these highly cited clinical studies have stimulated much subsequent original research. Guidelines, reviews and meta-analyses (with 852, 362 and 267 mean citations per article, respectively) accounted for a high proportion (22%) of the list, which is a common finding in top citation assessments for any medical specialty. Authors frequently cite such publications as they convey outcome generalities of many single-site studies. It is well recognised that levels of evidence will vary depending on the study designs. The goal of rating study designs and levels of evidence is to indicate the best available evidence for use in patient care. Among the various study designs, RCTs provide the highest quality evidence for most clinical or interventional trials. The T100 articles included 16 RCTs, a lower proportion than other top medical articles, such as hypertension (24 RCTs).

A majority of clinical research studies in the T100 cited articles included patients with AKI from any cause admitted to an intensive care unit. Among the research on specific causes of AKI, contrast-induced AKI in patients after cardiac catherisation was the most common. It is not surprising that researchers have been increasingly interested in the field of biomarkers,[40] or therapy for contrast-induced AKI,[41] with a large number of papers published, in parallel with the increasing use of cardiac catherisation. Additionally, previous studies demonstrated that contrast-induced AKI is a common complication after procedures requiring contrast media, responsible for 11% of in-hospital AKI cases, and also associated with poor short-term and long-term outcomes.[2 42] In our T100 RCT studies, 50% focused on the therapy of contrast-induced AKI. However, more high-quality RCTs for other causes of AKI, such as cardiac surgery, are needed in the future.

This study also has some limitations. First, despite a meticulous search of Web of Science and consistent results, also demonstrated in Scopus data, some studies might have been missed. Second, this type of study usually favours older published articles, but excludes some recently published high-quality studies, a limitation related to the effect of time on citations. Third, using the number of citations alone cannot quantify the value of contributions to the field. Therefore, papers that are important and influential, but have a lower citation frequency, might have been missed. Fourth, the minimal effect of self-citation was also not considered in our study. Finally, the language of publication was restricted to English, which would have failed to capture landmark articles published in other languages.

CONCLUSIONS

Our analysis summarised most of the influential studies on AKI, and highlights research areas that require further investigation and development. Our analysis also provides an insight into the citation frequencies of the top-cited articles on AKI and sheds light on the quality of the studies, discoveries and trends steering AKI research globally.

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