Top 100 cited articles on hemodialysis
A bibliometric analysis

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Abstract
Introduction: This study was conducted to better understand hemodialysis by reviewing the most-cited articles related to it.

Methods: We searched articles on the Web of Science and selected the 100 most frequently cited articles. Subsequently, we reviewed these articles and identified their characteristics.

Results: The 100 most frequently cited articles were published in 21 journals. The majority of these papers were published in the following journals: Kidney International (26 articles), New England Journal of Medicine (18 articles), Journal of the American Society of Nephrology (14 articles), and the American Journal of Kidney Disease (13 articles). The 100 most-cited articles were published in 25 countries. The United States of America was the country with the highest number of publications (65 articles). The University of Michigan was the institution with the highest number of articles (14 articles). FK Port was the author with the largest number of publications (13 articles).

Conclusions: This is the first study in the field of nephrology that provides a list of the 100 most-cited articles on hemodialysis. Through this study, clinicians will be able to recognize major academic interests and research trends in hemodialysis.

Abbreviations: ESRD = end-stage renal disease, HD = hemodialysis.

Keywords: analysis, hemodialysis, publications

1. Introduction

A progressive stage of chronic kidney disease with a glomerular filtration rate of less than 15 mL/min/1.73 m² is defined as end-stage renal disease (ESRD). ESRD is one of major global health problems. Its prevalence is gradually increasing worldwide and in Korea.[1,2] ESRD patients often experience various complications including multiorgan dysfunction. In ESRD, hemodialysis (HD) and peritoneal dialysis are mainly used for renal replacement therapy. As both therapies have their advantages and disadvantages, the choice of the treatment method can be decided by the physical condition, patient’s preference, or comorbidities. The number of patients requiring HD continues to increase annually. According to research by the National Health Insurance Service on medical aid, the number of HD patients increased by 31.9% from 44,136 in 2006 to 58,232 patients in 2010.[3,4]

The Science Citation Index was explained by 1964 at the Institute for Scientific Information. This was used to confirm that the academic contribution of the journal was high. It was also used to collect citation information and build indexes for database screening of scientific articles. Science Citation Index has become one of the most widely and frequently used databases for searching journals and assessing research outcomes. In the area of science, by increasing the number of articles, the availability of these articles in the form of compact discs or books was limited. This has resulted in a larger web version, known as the Web of Science: Science Citation Index Expanded.

The number of citations received by an article reflects the level of interest of the academic community in that particular topic. Therefore, a large number of citations indicate the significant impact of this article in the scientific community. The most frequently cited articles provide interesting insights into the process by which articles, subjects, and authors influence the field of research over time. By reviewing the most-cited articles, it can provide information on key areas of interest and avenues of research that have shown substantial growth in a specific field. Several researches have already analyzed the most frequently cited papers in several fields such as emergency medicine, general surgery, orthopedic surgery, plastic surgery, anesthesiaiology, obstetrics and gynecology, dermatology, critical-care medicine, and headache disorders.[5-13] However, no research has previously analyzed the 100 most-cited articles on HD.

This study presents the most cited articles related to HD and aims to broaden the understanding of HD through it.
2. Methods

We conducted an analysis of the citation-related HD. The study was performed as follows: First, we only searched for HD-related articles, except for peritoneal dialysis-related articles. We searched the Web of Science (https://apps.webofknowledge.com) by restricting the document type to reviews and journal articles. The publication period was from 1969 to 2019. Articles meeting these criteria were sorted by the number of citations they had received.

Second, according to citation frequency, we selected 100 articles on HD. We then reviewed the contents of each article and classified them by the number of citations, year of publication, publishing journal, published country, authorship, and topic categories. The topic categories were organized as pathophysiology, epidemiology, survival and mortality, mineral metabolism, and vascular calcification. The first author was used as the criterion when there was more than 1 author. Recommendations were excluded from the study. No statistical techniques were used in this study. The data are presented as frequencies only. Since this study is an analysis of data from online databases and the privacy of patients will not be disclosed, so patients’ informed consent and ethical approval are all not required.

3. Results

A total of 8941 HD-related articles were identified and analyzed. We chose the 100 most frequently cited papers and arranged them in descending order by the number of citations (Table 1). The most frequently cited paper was cited 1802 times, and the paper with the least number of citations was cited 322 times. Most of the papers (80 articles) received more than 360 citations. The 100 most-cited articles were published in 21 journals. Of the 21 journals, the one with the highest number of the most cited articles was *Kidney International* (26 articles), followed by *New England Journal of Medicine* (18 articles), *Journal of the American Society of Nephrology* (14 articles), and *American Journal of Kidney Disease* (13 articles). Over half of these articles were published in these 4 journals (58 articles) (Table 2).

These studies were published in 25 countries. The United States of America had the highest number of publications (65 articles), followed by France (20 articles), Japan (14 articles), Germany (10 articles), and Canada (8 articles) (Table 3).

The decades during which these articles were published are shown in Figure 1. Of all the articles, 55 were published in the past 2 decades. The earliest published article was published in 1966, while the most recently published article was published in 2013. More than 60 of the 100 most cited articles were provided by 17 institutions (Table 4). In articles with multiple authors, counting was based on the institution of the first author. The University of Michigan (14 articles) and the University of Michigan System (14 articles) were the institutions that published the highest number of articles, followed by the Assistance Publique Hopitaux Paris (12 articles) and the University of California system (12 articles).

### Table 1

The top 100 cited articles about Hemodialysis.

| Rank | Journal                                      | Title                                                                 | Number of citations |
|------|---------------------------------------------|-----------------------------------------------------------------------|---------------------|
| 1    | Journal of the American Society of Nephrology | Mineral metabolism, mortality, and morbidity in maintenance hemodialysis | 1802                |
| 2    | American Journal of Kidney Disease          | Association of serum phosphorus and calcium phosphate product with mortality risk in chronic hemodialysis patients: A national study | 1778                |
| 3    | New England Journal of Medicine             | Atorvastatin in patients with type 2 diabetes mellitus undergoing hemodialysis | 1710                |
| 4    | New England Journal of Medicine             | Accelerated atherosclerosis in prolonged maintenance hemodialysis     | 1642                |
| 5    | Circulation                                 | Impact of aortic stiffness on survival in end-stage renal disease      | 1632                |
| 6    | American Journal of Kidney Disease          | Death risk in hemodialysis-patients—the predictive value of commonly measured variables and an evaluation of death rate differences between facilities | 1572                |
| 7    | New England Journal of Medicine             | The effects of normal as compared with low hematocrit values in patients with cardiac disease who are receiving hemodialysis and epoetin | 1537                |
| 8    | New England Journal of Medicine             | Chronic hemodialysis using venipuncture and a surgically created arteriovenous fistula | 1322                |
| 9    | New England Journal of Medicine             | Effect of dialysis dose and membrane flux in maintenance hemodialysis. | 1234                |
| 10   | New England Journal of Medicine             | Rosuvastatin and cardiovascular events in patients undergoing hemodialysis | 1214                |
| 11   | Nephrology Dialysis Transplantation         | Arterial media calcification in end-stage renal disease: impact on all-cause and cardiovascular mortality | 1214                |
| 12   | New England Journal of Medicine             | Fibroblast growth factor 23 and mortality among patients undergoing hemodialysis | 1140                |
| 13   | Kidney International                        | Sevelamer attenuates the progression of coronary and aortic calcification in hemodialysis patients | 1106                |
| 14   | New England Journal of Medicine             | The urea reduction ratio and serum albumin concentration as predictors of mortality in patients undergoing hemodialysis | 1091                |
| 15   | Lancet                                      | Effect of human erythropoetin derived from recombinant-DNA on the anemia of patients maintained by chronic-hemodialysis | 1090                |
| 16   | Journal of Clinical Investigation           | Hemodialysis leukopenia—pulmonary vascular leukostasis resulting from complement activation by dialyzer | 1034                |
| 17   | Hypertension                                | Arterial calcifications, arterial stiffness, and cardiovascular risk in end-stage renal disease | 1029                |
| 18   | New England Journal of Medicine             | Complement and leukocyte-mediated pulmonary dysfunction in hemodialysis | 1014                |
| 19   | Journal of The American Society of Nephrology | Association of elevated serum P04, Ca × P04 product, and parathyroid hormone with cardiac mortality risk in chronic hemodialysis patients | 929                 |

(continued)
| Rank | Journal                                      | Title                                                                 | Number of citations |
|------|---------------------------------------------|----------------------------------------------------------------------|---------------------|
| 20   | Biochemical and Biophysical Research Communications | A new form of amyloid protein associated with chronic-hemodialysis was identified as beta-2-microglobulin  | 850                 |
| 21   | Journal of The American College of Cardiology | Cardiac calcification in adult hemodialysis patients—a link between end-stage renal disease and cardiovascular disease? | 835                 |
| 22   | New England Journal of Medicine              | Sympathetic overactivity in patients with chronic renal failure       | 820                 |
| 23   | Nephrology Dialysis Transplantation          | Arterial stiffening and vascular calcifications in end-stage renal disease | 792                 |
| 24   | Lancet                                       | Secondary prevention with antioxidants of cardiovascular disease in endstage renal disease (SPACE): randomised placebo-controlled trial | 784                 |
| 25   | Circulation                                 | Impact of aortic stiffness attenuation on survival of patients in end-stage renal failure | 763                 |
| 26   | New England Journal of Medicine              | Onxalacet for secondary hyperparathyroidism in patients receiving hemodialysis | 754                 |
| 27   | New England Journal of Medicine              | Survival of patients undergoing hemodialysis with paricalcitol or calcitriol therapy | 748                 |
| 28   | Kidney International                         | Survival predictability of time-varying indicators of bone disease in maintenance hemodialysis patients | 671                 |
| 29   | Journal of The American Society of Nephrology | Adiponectin, metabolic risk factors, and cardiovascular events among patients with end-stage renal disease | 652                 |
| 30   | Journal of The American Society of Nephrology | Activated injectable vitamin D and hemodialysis survival: a historical cohort study | 647                 |
| 31   | American Journal of Kidney Disease          | Electron beam computed tomography in the evaluation of cardiac calcifications in chronic dialysis patients | 647                 |
| 32   | New England Journal of Medicine              | In-center hemodialysis 6 times per week versus 3 times per week | 630                 |
| 33   | Kidney International                         | Survival as an index of adequacy of dialysis                        | 626                 |
| 34   | American Journal of Kidney Disease          | Mortality risk for dialysis patients with different levels of serum calcium, phosphorus, and PTH: The dialysis outcomes and practice patterns | 610                 |
| 35   | Transactions American Society For Artificial International Organs | Cannulation of blood vessels for prolonged hemodialysis | 609                 |
| 36   | Kidney International                         | Vascular access use in Europe and the United States: results from the DOPPS Study | 606                 |
| 37   | Kidney International                         | Effects of sevelamer and calcium on coronary artery calcification in patients new to hemodialysis | 599                 |
| 38   | Hypertension                                | Central pulse pressure and mortality in end-stage renal disease       | 594                 |
| 39   | Kidney International                         | Vitamin D levels and early mortality among incident hemodialysis patients | 592                 |
| 40   | Kidney International                         | Atherosclerotic cardiovascular disease risks in chronic hemodialysis patients | 585                 |
| 41   | Kidney International                         | Predictors and consequences of altered mineral metabolism: the Dialysis Outcomes and Practice Patterns Study | 556                 |
| 42   | Kidney International                         | Health-related quality of life as a predictor of mortality and hospitalization: the Dialysis Outcomes and Practice Patterns Study (DOPPS) | 522                 |
| 43   | Journal of The American Society of Nephrology | Association of comorbid conditions and mortality in hemodialysis patients in Europe, Japan, and the United States: the dialysis outcomes and practice patterns study (DOPPS) | 511                 |
| 44   | Kidney International                         | Type of vascular access and mortality in US hemodialysis patients | 508                 |
| 45   | New England Journal of Medicine              | Daily hemodialysis and the outcome of acute renal failure | 507                 |
| 46   | American Journal of Kidney Disease          | A malnutrition-inflammation score is correlated with morbidity and mortality in maintenance hemodialysis patients | 497                 |
| 47   | Kidney International                         | U curve association of blood pressure and mortality in hemodialysis patients | 488                 |
| 48   | Nephron                                     | Mortality risk-factors in patients treated by chronic-hemodialysis—report of the diaphand collaborative study | 488                 |
| 49   | Kidney International                         | Increasing arteriovenous fistulas in hemodialysis patients: problems and solutions | 484                 |
| 50   | American Journal of Kidney Disease          | Reevaluation of risks associated with hyperparathyroidism and hyperparathyroidism in dialysis patients: Recommendations for a change in management | 479                 |
| 51   | Hypertension                                | Carotid arterial stiffness as a predictor of cardiovascular and all-cause mortality in end-stage renal disease | 479                 |
| 52   | American Journal of Kidney Disease          | Canadian hemodialysis morbidity study | 473                 |
| 53   | JAMA- Journal of the American Medical Association | Effect of capodogrel on early failure of arteriovenous fistulas for hemodialysis—a randomized controlled trial | 465                 |
| 54   | Journal of The American Society of Nephrology | Hematocrit level and associated mortality in hemodialysis patients | 458                 |
| 55   | Kidney International                         | The dose of hemodialysis and patient mortality | 450                 |
| 56   | New England Journal of Medicine              | Infection with hepatitis GB virus C in patients on maintenance hemodialysis | 446                 |
| 57   | Annals of Surgery                           | Vascular access for hemodialysis—patency rates and results of revision | 443                 |
| 58   | American Journal of Kidney Disease          | Interleukin-6 predicts hyperalbuminemia, hypocholesterolemia, and mortality in hemodialysis patients | 437                 |
| 59   | BMJ-British Medical Journal                 | Association between recombinant human erythropoietin and quality of life and exercise capacity of patients receiving haemodialysis | 434                 |

(continued)
| Rank | Journal                                      | Title                                                                 | Number of citations |
|------|---------------------------------------------|----------------------------------------------------------------------|---------------------|
| 60   | New England Journal of Medicine             | Hepatitis-B vaccine in patients receiving hemodialysis—immunogenicity and efficacy | 426                 |
| 61   | Kidney International                        | Cardiac and arterial interactions in end-stage renal disease         | 420                 |
| 62   | Journal of The American Society of Nephrology | Arterial calcifications and bone histomorphometry in end-stage renal disease | 408                 |
| 63   | Circulation                                 | Predictive value of cardiac troponin I and T for subsequent death in end-stage renal disease | 403                 |
| 64   | Journal of The American Society of Nephrology | EPBACDIAL: a multicenter prospective study of risk factors for bacteremia in chronic hemodialysis patients | 399                 |
| 65   | Kidney International                        | Aortic pulse wave velocity index and mortality in end-stage renal disease | 392                 |
| 66   | Circulation                                 | Plasma norepinephrine predicts survival and incident cardiovascular events in patients with end-stage renal disease | 391                 |
| 67   | Kidney International                        | Immuneologic function and survival in hemodialysis patients          | 388                 |
| 68   | American Journal of Kidney Disease         | Hemodialysis patient-assessed functional health status predicts continued survival, hospitalization, and dialysis-attendance compliance | 387                 |
| 69   | Kidney International                        | Multiple measurements of depression predict mortality in a longitudinal study of chronic hemodialysis outpatients | 383                 |
| 70   | Annals of Internal Medicine                 | Catheter-related bacteremia and outcome of attempted catheter salvage in patients undergoing hemodialysis | 382                 |
| 71   | Journal of Clinical Investigation           | Beta(2)-microglobulin modified with advanced glycation end-products is a major component of hemodialysis-associated amyloidosis | 381                 |
| 72   | Journal of Vascular Surgery                 | A strategy for increasing use of autogenous hemodialysis access procedures: impact of preoperative noninvasive evaluation | 380                 |
| 73   | Clinical Journal of The American Society Of Nephrology | Hemodialysis-induced cardiac injury: determinants and associated outcomes | 374                 |
| 74   | Kidney International                        | Effects of sevelamer and calcium-based phosphate binders on mortality in hemodialysis patients | 371                 |
| 75   | Transactions American Society For Artificial International Organ | Syndrome of dyspraxia and multifocal seizures associated with chronic hemodialysis | 371                 |
| 76   | New England Journal of Medicine             | Staphylococcus-aureus nasal carriage and infection in patients on hemodialysis—efficacy of antibiotic | 370                 |
| 77   | Nephrology Dialysis Transplantation         | Vascular access use and outcomes: an international perspective from the dialysis outcomes and practice patterns study | 369                 |
| 78   | Kidney International                        | Hemodialysis-associated hypotension as an independent risk factor for 2-yr mortality in hemodialysis patients | 369                 |
| 79   | JAMA- Journal of the American Medical Association | The quality of life of hemodialysis recipients treated with recombinant human erythropoietin | 369                 |
| 80   | Kidney International                        | Depression as a predictor of mortality and hospitalization among hemodialysis patients in the United States and Europe | 366                 |
| 81   | Neurology                                   | Cognitive impairment in hemodialysis patients is common | 362                 |
| 82   | Journal of The American Society of Nephrology | Diabetes mellitus, aortic stiffness, and cardiovascular mortality in end-stage renal disease | 359                 |
| 83   | American Journal of Kidney Disease         | Anemia management and outcomes from 12 countries in the Dialysis Outcomes and Practice Patterns Study (DOPPS) | 357                 |
| 84   | Kidney International                        | Influence of uremia and hemodialysis on circulating interleukin-1 and tumor necrosis factor-alpha | 357                 |
| 85   | Kidney International                        | Prevention of hemodialysis fistula thrombosis—early detection of venous stenosis | 353                 |
| 86   | American Journal of Kidney Disease         | Simple nutritional indicators as independent predictors of mortality in hemodialysis patients | 349                 |
| 87   | American Journal of Kidney Disease         | Predialysis blood pressure and mortality risk in a national sample of maintenance hemodialysis patients | 346                 |
| 88   | Journal of Clinical Pathology               | Acquired cystic disease of kidneys – hazard of long-term intermittent maintenance hemodialysis | 344                 |
| 89   | Journal of The American Society of Nephrology | Alterations of left ventricular hypertrophy in and survival of patients receiving hemodialysis: follow-up of an interventional study | 343                 |
| 90   | Kidney International                        | Vascular access and increased risk of death among hemodialysis patients | 340                 |
| 91   | Kidney International                        | Influence of excess weight on mortality and hospital stay in 1346 hemodialysis patients | 339                 |
| 92   | New England Journal of Medicine             | Use of a Staphylococcus aureus conjugate vaccine in patients receiving hemodialysis | 338                 |
| 93   | Kidney International                        | Cardiac diseases in maintenance hemodialysis patients: results of the HEMO Study | 332                 |
| 94   | Kidney International                        | Anaphylatoxin formation during hemodialysis—effects of different dialyzer membranes | 331                 |
| 95   | Journal of The American Society of Nephrology | Effects of body size and body composition on survival in hemodialysis patients | 330                 |
Table 1
(continued).

| Rank | Journal                                    | Title                                                                 | Number of citations |
|------|--------------------------------------------|----------------------------------------------------------------------|---------------------|
| 96   | Journal of Clinical Investigation          | Involvement of beta(2)-microglobulin modified with advanced glycation end-products in the pathogenesis of hemodialysis-associated amyloidosis—induction of human monocye chemotaxis and macrophage secretion of tumour-necrosis-factor-alpha and interleukin-1 | 329                 |
| 97   | American Journal of Kidney Disease        | Reduction in recombinant-human erythropoietin doses by the use of chronic intravenous iron supplementation | 327                 |
| 98   | Journal of The American Society of Nephrology | High-efficiency postdilution Online hemodialfiltration reduces all-cause mortality in hemodialysis patients | 325                 |
| 99   | Journal of The American Society of Nephrology | Mineral metabolism and arterial functions in end-stage renal disease: potential role of 25-hydroxyvitamin D deficiency | 324                 |
| 100  | Journal of The American Society of Nephrology | Association among SF36 quality of life measures and nutrition, hospitalization, and mortality in hemodialysis | 322                 |

DNA = deoxyribonucleic acid, DOPPS = the Dialysis Outcomes and Practice Patterns Study, HEMO = hemodialysis, PTH = parathyroid hormone.

The top authors who have published more than 4 articles on HD are listed in Table 5. FK Port was the author who published the most number of articles (13 articles).

4. Discussion

In this article, we searched and reviewed the 100 most-cited articles on HD. These articles provided advanced insights on scientific perspectives and progress in the field of HD.

The most-cited article was published by the *Journal of the American Society of Nephrology* in 2004 and was written by the Block.[14] To identify associations between mineral metabolism disorders (hypercalcemia, hyperphosphatemia, and secondary hyperparathyroidism), mortality, and morbidity in HD patients, a nationally representative database of >40,000 HD patients was analyzed. This study showed strong associations between higher concentrations of serum calcium and phosphorus and higher mortality. They also found associations between hyperphosphatemia and hyperparathyroidism and cardiovascular, fracture, and all-cause hospitalization. These results support the hypothesis that mineral metabolism disorders are associated with the risk of cardiovascular disease in ESRD patients.

The second most cited article was published by the *American Journal of Kidney Disease*, entitled “Association of serum phosphorus and Ca × PO4 product with mortality risk in chronic HD patients: A national study.”[15] The goal of this study was to estimate the level to which serum phosphorus is maintained in 2 large national, random samples of patients who have been receiving HD for at least 1 year. Ca × PO4 product levels above 72mg²/dL² were observed in 20% of the patients and were associated with a higher relative risk of death compared with those with a Ca × PO4 product between 42 and 52mg²/dL². These results support that intensive control of hyperphosphatemia can increase the survival rate of patients.

The most frequent topic discussed in these articles was cardiovascular mortality in hemodialysis patients (22 articles). The most cited article about cardiovascular mortality in HD patients was authored by Lindner in 1974 and published by the *New England Journal of Medicine*.[16] This study reviewed mortality and morbidity due to cardiovascular complications in long-term HD patients in Seattle. The results showed that the incidence of arteriosclerotic complications was several times higher in this group than in the normal and hypertensive groups of comparable age, and was similar to the rate of cardiovascular complications found in patients with type 2 hyperlipoproteinemia. These outcomes indicate that increased atherosclerosis is a major risk for patients on long-term maintenance HD. The second most frequently discussed topic was chronic kidney disease-mineral and bone disorder in HD patients (15 articles). The articles about this topic provided information about laboratory changes in mineral metabolism during HD and mortality risks in chronic HD patients.

We also found some interesting trends among the subjects of the articles owing to the fact that they kept on changing from decade to decade. First, pathophysiology was the most frequently covered subject. The main key words related to this topic are: uremia, electrolyte, mineral metabolism. This was similar to the results of analyses performed in other fields.[4,5,7,12] Other
subjects often covered in articles were treatment and basic research. Second, an increasing number of articles were published as time passed from the 1990s to the 2010s. From 2000 to 2009, 53 of the 100 most-cited articles were published. Papers related to Chronic Kidney Disease-Mineral and Bone Disorder were more common before the 2000s, whereas papers on more diverse topics were published after the 2000s. Articles on the most common topic, cardiovascular mortality in HD patients, were published mainly after the 2000s. The main key words related to this topic are: atherosclerosis, vascular calcification. This trend is thought to be because of the higher concern regarding long-term complications, mortality, and morbidity in patients receiving maintenance HD.

Sixty-five articles were published in the United States, while 20 articles were published in France. In other areas where similar studies were conducted, the highest number of papers was published in the United States. Kidney International published the highest number of the most cited articles (26 articles), followed by the New England Journal of Medicine (18 articles). American institutions have made significant contributions to the advancement of HD research. This is because the American scientific community can conduct research with enormous financial resources. Moreover, American writers prefer to publish their research in easily accessible American journals and usually cite papers written in English.

We found that none of the 100 most cited papers originated in Africa. This may be due to the difficulties in accessing information, conducting and publishing research, and the language barrier experienced by researchers in Africa.

Our study has some inherent limitations. This research was conducted because of the controversy regarding the value of citations. The number of citations does not reflect whether the study was referenced in a positive or negative way. The papers cited most frequently may not necessarily be the most important and meaningful one. Certain types of articles, such as meta-analyses, systematic reviews, and guidelines tend to be cited more than others. In addition, older papers tend to be cited more frequently. However, evaluating the number of citations is a better way to assess the advantages of a paper. Analysis about citation rate is able to prove the advancement in a particular field of expert knowledge and give a retrospective aspect of scientific development.

5. Conclusions

This is the first study in the field of nephrology to provide a list of the 100 most-cited articles on HD. This study provides major academic interest and research trends related to HD.

Author contributions

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