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Citation classics in critical care medicine

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Abstract *Objective:* The number of citations an article receives after its publication reflects its impact on the scientific community. Our purpose was to identify and examine the characteristics of the most frequently cited articles in the field of critical care medicine. *Design:* The 74 top-cited articles in critical care journals were identified by a computer search using the database of the Science Citation Index Expanded (SCI-EXPANDED, 1945 to present) and the Web of SCIENCE. The 45 top-cited critical care articles in all other biomedical journals were identified using the database SciSearch (1974 to present) with the key word "Critical Care". *Results:* The most cited articles received 3402 and 2860 citations, respectively. The citation classics in critical care journals were published between 1968 and 1999 in six high-impact journals, led by *Critical Care Medicine* (37 articles), followed by the *Journal of Trauma* (21), and *American Journal of Respiratory and Critical Care Medicine* (9). Seventy articles were original publications, two were reviews or guidelines, and two were editorials. The top 45 classic articles in non-critical care journals were published in 13 different journals, led by the *New England Journal of Medicine* (11 articles), followed by *JAMA* and *Lancet* (6 articles each). The United States of America contributed most of the classic articles. Pathophysiology of the lung, sepsis and scoring systems were the primary focus of classic publications. *Conclusions:* Our analysis gives a historical perspective on the scientific progress of critical care medicine and allows for recognition of important advances in this specialty.

Keywords Citation analysis · Critical care medicine · Publication · Scientometrics · Landmark article

Introduction

Governments, funding agencies and promotion committees often use citation data of the ISI, a company in Philadelphia formerly known as the Institute for Scientific Information and now owned by the Thomson Corporation of Toronto, to perform evaluations of individual scientists, research groups, departments, universities and even countries due to the lack of reliable measurements of research quality [1]. The argument is that important papers will be cited more frequently and therefore a popular method for measuring the impact of an article is to count its citations. The number of citations (i.e., how many times a given article is counted in the reference lists of subsequent articles) is then seen as a direct measure of the recognition that this publication has had in its scientific field.

Although citation statistics have been criticized on many accounts [2, 3, 4, 5], the analysis of citation rates may allow for the identification of advances in a specialty and may provide a historical perspective on its scientific progress. Therefore, various specialties have recently

summarized their so-called "citation classics" [6, 7, 8, 9]. In addition, various journals have published their own citation classics [10, 11, 12, 13, 14, 15]. However, a systematic analysis of top-cited articles in the field of critical care medicine is not yet available. The purpose of the present study was therefore to identify and examine the characteristics, such as ranking, year of publication, publishing journal, type of article, institution of origin, country, state, topic and authorship of the most frequently cited articles published in critical care journals. In addition, the most frequently cited articles related to critical care medicine published in other biomedical journals are also presented.

Materials and methods

All seventeen journals specializing in critical care medicine, according to the Journal Citation Report (JCR) 2002 under the subject category Critical Care Medicine, were analyzed (Table 1). The most frequently cited articles in critical care journals were identified using the database of the Science Citation Index Expanded (SCI-EXPANDED, 1945 to present). The Science Citation Index Expanded is a multidisciplinary database powered by the ISI and its Web of SCIENCE with searchable author abstracts covering the journal literature of the sciences; it indexes more than 5,700 major journals across 164 scientific disciplines. The Cited Reference Search option of the Web of SCIENCE returns a site-configured maximum number of results, which is limited to 500. To find more than the maximum number of results, the data can be searched in segments, as, for example, by searching one year or one journal for data at a time. For journals publishing articles with high citation rates, even this segmented search for one year of data yielded more than the maximum number of results. In these cases, each author's name, according to the author index of the respective journal and year, was "hand-searched" using the Web of SCIENCE interface.

To perform such a "hand-search" for other general medicine and biology journals such as the *New England Journal of Medicine*, *Nature*, *Science*, *Lancet*, *Cell*, *Chest*, *Journal of Clinical Investigation*, *Thorax*, *European Respiratory Journal*, *American Review of Respiratory Disease* etc. is almost impossible due to the large number of articles published in these journals. To retrieve highly cited articles related to the field of critical care medicine which were originally published in non-critical care journals, we performed a search using SciSearch with the broadest key word available, i.e., "Critical Care", since 1974 and combined it with the names of all other biomedical journals.

Data stored for each reference in the database include, among other categories, the title, author names, institutions, addresses, journal, abstract and key words. The most frequently cited articles in critical care journals and the most frequently cited articles related to critical care medicine in all other biomedical journals were read and reviewed online (PubMed) by both authors; when relevant information was not available online, the articles were obtained in a printed format by direct library access. After excluding articles from the study with no direct relevance to the field of critical care medicine, the 74 top-cited articles in critical care journals and the 45 top-cited articles related to the field of critical care medicine in all other biomedical journals were analyzed and the data tabulated according to their specific features.

Table 1 List of screened critical care journals

American Journal of Respiratory and Critical Care Medicine
Anaesthesia and Intensive Care
Anasthesiologie, Intensivmedizin, Notfallmedizin, Schmerztherapie
Anasthesiologie and Intensivmedizin
Burns
Critical Care
Critical Care Clinics
Critical Care Medicine
Injury—International Journal of the Care of the Injured
Intensive Care Medicine
Journal of Critical Care
Journal of Intensive Care Medicine
Journal of Neurotrauma
Journal of Trauma-Injury Infection and Critical Care
Resuscitation
Seminars in Respiratory and Critical Care Medicine
Shock

Results

Citation classics in critical care journals

Four hundred and eighteen articles were retrieved that were published in critical care journals and that were cited 100 times or more. Using the Web of SCIENCE update of July 27, 2003, we selected the top 74 most frequently cited articles with a direct relation to the field of critical care medicine from this list for further analysis and ranked them according to the number of citations they received (Table 2). The most cited article received 3402 citations and the four least cited articles received 170 citations. The mean number of citations per article was 341. The majority (55 articles) received more than 200 citations. The top 74 citation classics were published between 1968 and 1999. The decade from 1990 to 1999 produced the most citation classics with 38 articles followed by the decade from 1980 to 1989 with 30 articles. The most classic papers published within a given year were 7 articles each in 1989 and 1994. Sixty percent of the classic articles were published after 1989. The top-cited articles were all published in six high-impact critical care journals, led by *Critical Care Medicine* (37 articles) and followed by the *Journal of Trauma* (21 articles), *American Journal of Respiratory and Critical Care Medicine* (9 articles), *Intensive Care Medicine* (4 articles), *Journal of Neurotrauma* (2 articles) and *Shock* (1 article). Of the 74 articles, 70 articles were original publications (45 human studies, 9 animal studies and 16 laboratory investigations), 2 were review or guideline articles and 2 were editorials. While 36 clinical human studies and 9 physiological-experimental studies received a mean citation rate of 246 and 244 citations, respectively, per article, the 12 studies related to critical care scoring systems achieved 845 citations per article.

The 74 top-cited articles originated from 12 countries, with the United States (US) contributing 51 (69%)

Table 2 Top seventy-four citation classics in critical care journals ranked in order of citations received

Rank	Citation	Times cited
1.	Knaus WA, Draper EA, Wagner DP et al. (1985) APACHE II: a severity of disease classification system. Crit Care Med 13:818–829	3402
2.	Baker SP, O'Neill B, Haddon W et al. (1974) The injury severity score: a method for describing patients with multiple injuries and evaluating emergency care. J Trauma 14:187–196	1978
3.	Bernard GR, Artigas A, Brigham KL et al. (1994) The American-European Consensus Conference on ARDS. Definitions, mechanisms, relevant outcomes and clinical trial coordination. Am J Respir Crit Care Med 149:818–824	889
4.	Knaus WA, Zimmerman JE, Wagner DP et al. (1981) APACHE—acute physiology and chronic health evaluation: a physiologically based classification system. Crit Care Med 9:591–597	607
5.	Le Gall JR, Loirat P, Alperovitch A et al. (1984) A simplified acute physiology score for ICU patients. Crit Care Med 12:975–977	581
6.	Bone R (1992) American College of Chest Physicians and Society of Critical Care Medicine Consensus Conference—Definitions for sepsis and organ failure and guidelines for the use of innovative therapies in sepsis. Crit Care Med 20:864–874	517
7.	Boyd CR, Tolson MA, Copes WS (1987) Evaluating trauma care: the TRISS method. Trauma Score and the Injury Severity Score. J Trauma 27:370–378	486
8.	Bone RC, Fisher CJ, Clemmer TP et al. (1989) Sepsis syndrome: a valid clinical entity. Crit Care Med 17:389–393	461
9.	Gustilo RB, Mendoza RM, Williams DN (1984) Problems in the management of type III (severe) open fractures: a new classification of type III open fractures. J Trauma 24:742–746	439
10.	Baker SP, O'Neill B (1976) The injury severity score: an update. J Trauma 16:882–885	438
11.	Champion HR, Sacco WJ, Carnazzo AJ et al. (1981) Trauma score. Crit Care Med 9:672–676	434
12.	Cullen DJ, Civetta JM, Briggs BA et al. (1974) Therapeutic intervention scoring system: a method for quantitative comparison of patient care. Crit Care Med 2:57–60	426
13.	Keene AR, Cullen DJ (1983) Therapeutic Intervention Scoring System: update 1983. Crit Care Med 11:1–3	377
14.	Champion HR, Sacco WJ, Copes WS et al. (1989) A revision of the Trauma Score. J Trauma 29:623–629	364
15.	Pollack MM, Ruttimann UE, Getson PR (1988) Pediatric risk of mortality (PRISM) score. Crit Care Med 16:1110–1116	360
16.	Moore FA, Moore EE, Jones TN et al. (1989) TEN versus TPN following major abdominal trauma—reduced septic morbidity. J Trauma 29:916–922	355
	Chesnut RM, Marshall LF, Klauber MR et al. (1993) The role of secondary brain injury in determining outcome from severe head injury. J Trauma 34:216–222	355
18.	Hickling KG, Henderson SJ, Jackson R (1990) Low mortality associated with low volume pressure limited ventilation with permissive hypercapnia in severe adult respiratory distress syndrome. Intensive Care Med 16:372–377	338
19.	Stoutenbeek CP, van Saene HK, Miranda DR et al. (1984) The effect of selective decontamination of the digestive tract on colonisation and infection rate in multiple trauma patients. Intensive Care Med 10:185–192	336
20.	Kooy NW, Royall JA, Ye YZ et al. (1995) Evidence for in vivo peroxynitrite production in human acute lung injury. Am J Respir Crit Care Med 151:1250–1254	323
21.	Marshall JC, Cook DJ, Christou NV et al. (1995) Multiple organ dysfunction score: a reliable descriptor of a complex clinical outcome. Crit Care Med 23:1638–1652	319
22.	Damas P, Reuter A, Gysen P et al. (1989) Tumor necrosis factor and interleukin-1 serum levels during severe sepsis in humans. Crit Care Med 17:975–978	316
23.	Fisher CJ, Opal SM, Dhainaut JF et al. (1993) Influence of an anti-tumor necrosis factor monoclonal antibody on cytokine levels in patients with sepsis. Crit Care Med 21:318–327	287
24.	Dreyfuss D, Saumon G (1998) Ventilator-induced lung injury: lessons from experimental studies. Am J Respir Crit Care Med 157:294–323	277
25.	Faist E, Baue AE, Dittmer H et al. (1983) Multiple organ failure in polytrauma patients. J Trauma 23:775–787	276
	Doglio GR, Pusajo JF, Egurrola MA et al. (1991) Gastric mucosal pH as a prognostic index of mortality in critically ill patients. Crit Care Med 19:1037–1040	276
27.	Baker JW, Deitch EA, Li M et al. (1988) Hemorrhagic shock induces bacterial translocation from the gut. J Trauma 28:896–906	269
28.	Muscedere JG, Mullen JB, Gan K et al. (1994) Tidal ventilation at low airway pressures can augment lung injury. Am J Respir Crit Care Med 149:1327–1334	267
29.	Fiddian-Green RG, Baker S (1987) Predictive value of the stomach wall pH for complications after cardiac operations: comparison with other monitoring. Crit Care Med 15:153–156	266
	Champion HR, Copes WS, Sacco WJ et al. (1990) The Major Trauma Outcome Study: establishing national norms for trauma care. J Trauma 30:1356–1365.	266
31.	Siesjo BK (1988) Mechanisms of ischemic brain damage. Crit Care Med 16:954–963	264
32.	Vincent J, Moreno R, Takala J et al. (1996) The SOFA (sepsis-related organ failure assessment) score to describe organ dysfunction/failure. Intensive Care Med 22:707–710	254
33.	Rich NM, Baugh JH, Hughes CW (1970) Acute arterial injuries in Vietnam: 1,000 cases. J Trauma 10:359–369	253
34.	Walker HL, Mason AD (1968) A standard animal burn. J Trauma 8:1049–1051	247
35.	Takala J, Keinanen O, Vaisanen P et al. (1989) Measurement of gas exchange in intensive care: laboratory and clinical validation of a new device. Crit Care Med 17:1041–1047	235
36.	Szabo C (1996) The pathophysiological role of peroxynitrite in shock, inflammation and ischemia-reperfusion injury. Shock 6:79–88	234

Table 2 (continued)

Rank	Citation	Times cited
37.	Moore FA, Moore EE, Poggetti R et al. (1991) Gut bacterial translocation via the portal vein: a clinical perspective with major torso trauma. J Trauma 31:629–636	231
38.	Debets JM, Kampmeijer R, van der Linden MP et al. (1989) Plasma tumor necrosis factor and mortality in critically ill septic patients. Crit Care Med 17:489–494	230
39.	Kramer N, Meyer TJ, Meharg J et al. (1995) Randomized, prospective trial of noninvasive positive pressure ventilation in acute respiratory failure. Am J Respir Crit Care Med 151:1799–1806	227
	Fuhrman BP, Paczan PR, DeFrancisis M (1991) Perfluorocarbon-associated gas exchange. Crit Care Med 19:712–722	227
41.	Moore EE, Jones TN (1986) Benefits of immediate jejunostomy feeding after major abdominal trauma—a prospective, randomized study. J Trauma 26:874–881	225
42.	Bower RH, Cerra FB, Bershadsky B et al. (1995) Early enteral administration of a formula (Impact) supplemented with arginine, nucleotides and fish oil in intensive care unit patients: results of a multicenter, prospective, randomized clinical trial. Crit Care Med 23:436–449	223
43.	Moore EE, Shackford SR, Pachter HL et al. (1989) Organ injury scaling: spleen, liver and kidney. J Trauma 29:1664–1666	221
44.	Klain M, Smith RB (1977) High frequency percutaneous transtracheal jet ventilation. Crit Care Med 5:280–287	220
45.	Amato MB, Barbas CS, Medeiros DM et al. (1995) Beneficial effects of the "open lung approach" with low distending pressures in acute respiratory distress syndrome. A prospective randomized study on mechanical ventilation. Am J Respir Crit Care Med 152:1835–1846	217
46.	Deitch EA, Maejima K, Berg R (1985) Effect of oral antibiotics and bacterial overgrowth on the translocation of the GI tract microflora in burned rats. J Trauma 25:385–392	216
47.	Shibutani K, Komatsu T, Kubal K et al. (1983) Critical level of oxygen delivery in anesthetized man. Crit Care Med 11:640–643	214
	Bone RC (1996) Toward a theory regarding the pathogenesis of the systemic inflammatory response syndrome: what we do and do not know about cytokine regulation. Crit Care Med 24:163–172	214
49.	Morris AH, Wallace CJ, Menlove RL et al. (1994) Randomized clinical trial of pressure-controlled inverse ratio ventilation and extracorporeal CO_2 removal for adult respiratory distress syndrome. Am J Respir Crit Care Med 149:295–305	213
50.	Zeni F, Freeman B, Natanson C (1997) Anti-inflammatory therapies to treat sepsis and septic shock: a reassessment. Crit Care Med 25:1095–1100	212
51.	Hickling KG, Walsh J, Henderson S et al. (1994) Low mortality rate in adult respiratory distress syndrome using low-volume, pressure-limited ventilation with permissive hypercapnia: a prospective study. Crit Care Med 22:1568–1578	209
52.	Greenspan L, McLellan BA, Greig H (1985) Abbreviated Injury Scale and Injury Severity Score: a scoring chart. J Trauma 25:60–64	206
53.	Dellinger RP, Zimmerman JL, Taylor RW et al. (1998) Effects of inhaled nitric oxide in patients with acute respiratory distress syndrome: results of a randomized phase II trial. Crit Care Med 26:15–23	204
54.	Fisher CJ, Slotman GJ, Opal SM et al. (1994) Initial evaluation of human recombinant interleukin-1 receptor antagonist in the treatment of sepsis syndrome: a randomized, open-label, placebo-controlled multicenter trial. Crit Care Med 22:12–21	203
55.	Clifton GL, Allen S, Barrodale P et al. (1993) A phase II study of moderate hypothermia in severe brain injury. J Neurotrauma 10:263–271	201
56.	Streat SJ, Beddoe AH, Hill GL (1987) Aggressive nutritional support does not prevent protein loss despite fat gain in septic intensive care patients. J Trauma 27:262–266	193
	Bone RC (1996) Sir Isaac Newton, sepsis, SIRS and CARS. Crit Care Med 24:1125–1128	193
58.	Rackow EC, Falk JL, Fein IA et al. (1983) Fluid resuscitation in circulatory shock: a comparison of the cardiorespiratory effects of albumin, hetastarch and saline solutions in patients with hypovolemic and septic shock. Crit Care Med 11:839–850	191
59.	Bernstein DP (1986) A new stroke volume equation for thoracic electrical bioimpedance: theory and rationale. Crit Care Med 14:904–909	187
60.	Stuber F, Petersen M, Bokelmann F et al. (1996) A genomic polymorphism within the tumor necrosis factor locus influences plasma tumor necrosis factor-alpha concentrations and outcome of patients with severe sepsis. Crit Care Med 24:381–384	184
61.	Parker JC, Hernandez LA, Peevy KJ (1993) Mechanisms of ventilator-induced lung injury. Crit Care Med 21:131–143	183
62.	Mattson MP, Scheff SW (1994) Endogenous neuroprotection factors and traumatic brain injury: mechanisms of action and implications for therapy. J Neurotrauma 11:3–33	181
63.	Silkoff PE, McClean PA, Slutsky AS et al. (1997) Marked flow-dependence of exhaled nitric oxide using a new technique to exclude nasal nitric oxide. Am J Respir Crit Care Med 155:260–267	178
64.	Hoch RC, Rodriguez R, Manning T et al. (1993) Effects of accidental trauma on cytokine and endotoxin production. Crit Care Med 21:839–845	176
	Mizock BA, Falk JL (1992) Lactic acidosis in critical illness. Crit Care Med 20:80–93	176
66.	Brochard L, Rauss A, Benito S et al. (1994) Comparison of three methods of gradual withdrawal from ventilatory support during weaning from mechanical ventilation. Am J Respir Crit Care Med 150:896–903	175
	Lachmann B (1992) Open up the lung and keep the lung open. Intensive Care Med 18:319–321	175
68.	Copes WS, Champion HR, Sacco WJ et al. (1988) The Injury Severity Score revisited. J Trauma 28:69–77.	174
69.	Rosner MJ, Daughton S (1990) Cerebral perfusion pressure management in head injury. J Trauma 30:933–940	172

Table 2 (continued)

Rank	Citation	Times cited
	Cohen J, Carlet J (1996) INTERSEPT: an international, multicenter, placebo-controlled trial of monoclonal antibody to human tumor necrosis factor-alpha in patients with sepsis. Crit Care Med 24:1431–1440	172
71.	Faist E, Mewes A, Baker CC et al. (1987) Prostaglandin E2 (PGE2)-dependent suppression of interleukin alpha (IL-2) production in patients with major trauma. J Trauma 27:837–848	170
	Fink MP (1991) Gastrointestinal mucosal injury in experimental models of shock, trauma and sepsis. Crit Care Med 19:627–641	170
	Tremper KK, Shoemaker WC (1981) Transcutaneous oxygen monitoring of critically ill adults, with and without low flow shock. Crit Care Med 9:706–709	170
	Richards MJ, Edwards JR, Culver DH et al. (1999) Nosocomial infections in medical intensive care units in the United States. Crit Care Med 27:887–892	170

articles, followed by five countries (Germany, Canada, Netherlands, France, New Zealand) with three articles each (Table 3). Only 15 articles originated from non-English speaking countries (Table 3). Within the US, Ohio, California and Washington, DC, lead the list of citation classics with six articles each. Eight states contributed three or more classic articles (Table 3). Of the total 74 articles, 21 originated from multi-institutional collaboration, of which 10 were from multinational collaborations and 53 from individual institutions. Sixty different institutions produced the 74 top-cited articles. Ten institutions produced more than one citation classic article (Table 4). The Department of Surgery of the Washington Hospital Center, Washington, DC, and the Department of Surgery of the Denver General Hospital, Denver, Colorado, share the lead in this list with four classic articles each.

Table 3 Country and state of origin and number of articles identified as citation classics in critical care journals

Country	No. of citation classics
United States of America (US)	51
Ohio	6
California	6
Washington, DC	6
Massachusetts	4
Colorado	3
Illinois	3
Maryland	3
Alabama	3
Germany	3
Canada	3
Netherlands	3
France	3
New Zealand	3
United Kingdom (UK)	2
Belgium	2
Argentina	1
Sweden	1
Brazil	1
Finland	1

The first author was affiliated with an academic department in all classic articles. The number of authors of the top-cited articles ranged from one to 50. Nine articles were authored by a single author and nine articles by two authors. Forty-eight persons authored two or more of the top-cited articles. Table 5 presents a list of "frequent authors" with three or more classic articles. This list is led by Roger C. Bone, who authored or co-authored six classic papers; he is also the only person who is first author of four such articles. Among the first authors is only one woman; Susan P. Baker's papers on the injury severity score were cited 1978 and 438 times (Table 2, ranks 2 and 10). Three classic papers were not authored by individual authors but by a consortium or committee of authors such as the American-European

Table 4 Institution of origin of first author and number of articles identified as citation classics in critical care journals

Rank	Department	Institution	No. of citation classics
1	Surgery	Washington Hospital Center, Washington, DC	4
	Surgery	Denver General Hospital, Denver, Colorado	4
3	Intensive Care	Christchurch Hospital, Christchurch, New Zealand	2
	Anesthesiology	Hopital Henri Mador, Creteil, France	2
	Surgery	Klinikum Grosshader, Munich, Germany	2
	Surgery	Louisiana State University Medical Center, Shreveport, Louisiana	2
	Forensic Pathology	Johns Hopkins University School of Hygiene and Public Health, Baltimore, Maryland	2
	Anesthesiology	University of Pittsburgh, Pittsburgh, Pennsylvania	2
	Surgery	University of Massachusetts, Worcester, Massachusetts	2
	Anesthesiology	George Washington University, Medical Center, Washington, DC	2

Table 5 List of authors who contributed more than two citation classics in critical care journals

Author	No. of citation classics	Position on author list
Bone, RC	6	First author - 4, fifth - 1, thirty-fifth - 1
Champion, HR	5	First author - 3, second - 1, sixth - 1
Copes, WS	5	First author - 1, second - 1, third - 1, fourth - 1, last - 1
Fisher, CJ	4	First author - 2, second - 1, fifteenth - 1
Moore, EE	4	First author - 2, second - 2
Knaus, WA	4	First author - 2, sixth - 1, thirty-second - 1
Sacco, WJ	4	Second author - 2, third - 2
Dellinger, RP	3	First author - 1, fourth - 1, thirty-fifth - 1

Consensus Committee on ARDS (Table 2, rank 3), American College of Chest Physicians and Society of Critical Care (rank 6) and the American Association for the Surgery of Trauma (rank 43). In addition, many papers present the results of multicenter studies organized by research groups such as the Sepsis Study Group (ranks 8, 23 and 54), ARDS Study Group (rank 53) or the International Sepsis Trial Study Group (rank 69b).

Pathophysiology of the lung (18 articles) is the main topic covered by these highly cited articles. Considerable attention was also given to topics such as sepsis (13 articles), trauma (13 articles) and scoring systems (12 articles). Other topics include weaning procedures, antibiotic therapy and monitoring.

Citation classics related to critical care medicine published in other biomedical journals

The most cited critical care article published in a non-critical care journal received 2860 citations with a mean number of 810 citations per article for the 45 most cited articles (Table 6). To compare, the mean number of citations of the top 45 articles published in critical care journals was 440. Thirteen different non-critical care journals published the 45 classic critical care articles; the *New England Journal of Medicine* leads this list with 11 such articles, followed by *JAMA* and *Lancet* (6 articles each), and *American Review of Respiratory Disease* and *Annals of Internal Medicine* (5 articles each). The US also leads the list of citation classics in non-critical care journals with 40/45 (89%) articles, followed by the UK with three articles. Six articles were the result of a multinational cooperation. The topics covered are also similar to the classic articles published in critical care journals; the main topics were lung physiology and injury (12 articles), followed by sepsis (10 articles), cardiac disease (6 articles) and critical care scoring systems (5 articles). From the list of "frequent authors" in critical care journals (Table 5), five authors also contributed to classic critical care articles in other biomedical journals (W.A. Knaus, R.C. Bone, C.J. Fisher, R.P. Dellinger, W.S. Copes). Roger C. Bone and William A. Knaus both were first authors of three such articles.

Discussion

The lists of the top-cited critical care articles (Tables 2 and 6) identify authors and topics that reflect advances in critical care medicine and provide an insight into the history and development of this specialty. The number of citations received was significantly higher for the 45 top-cited articles published in non-critical care journals compared with the 45 top-cited articles published in the specialty journals (810 versus 440 citations per article). It is known that the true impact and fame of an article often cannot be accurately assessed for at least two decades [7, 10, 13, 14, 15]. The sum of the citations of an article is logically dependent on its publication year, since citations accumulate over time. Scientific papers usually are not cited until 1 or 2 years after their publication and generally reach a maximum after 3–10 years, at which time they continue to be cited but at a lower rate [16]. The decline of the citation rate is described as the half-life of a publication and is defined as the time when the citation rate has dropped to half of the maximum. This normal life span of a publication shows that evaluating the rank and significance of recent publications is, at best, limited; thus, articles that are not listed here will eventually deserve classic status.

Another limitation of the present method of calculating the impact of publications is the so-called "obliteration by incorporation," i.e., original seminal work is absorbed in current knowledge and it is no longer explicitly cited; the absolute number of citations an article has accumulated, therefore, cannot be used as a sole measurement of its "importance". On the other hand, articles describing critical care scoring systems achieve high citation rates in the present study (mean citation rate of 845 citations per such article in the specialty journals and 918 in all other biomedical journals) and are, with approximately 14%, also over-represented in the lists of top-cited articles (12/74 such articles in the specialty journals and 5/45 in all other biomedical journals). This is probably related to the circumstance that the reasons for citing specific articles may not be entirely appropriate; authors do not necessarily reference the work that have influenced them most significantly in their own work and it seems that citing is not simply giving credit where credit is due but, instead, is a complex social and psychological response with many

Table 6 Top forty-five citation classics in non-critical care journals ranked in order of citations received

Rank	Citation	Times cited
1.	Teasdale G, Jennett B (1974) Assessment of coma and impaired consciousness. A practical scale. Lancet 304:81–84	2860
2.	Jennett B, Bond M (1975) Assessment of outcome after severe brain damage. Lancet 305:480–484	2193
3.	Tracey KJ, Fong Y, Hesse DG et al. (1987) Anti-cachectin/TNF monoclonal antibodies prevent septic shock during lethal bacteraemia. Nature 330:662–664	1796
4.	Garner JS, Jarvis WR, Emori TG et al. (1988) CDC definitions for nosocomial infections, 1988. Am J Infect Control 16:128–140	1424
5.	Swan HJ, Ganz W, Forrester J et al. (1970) Catheterization of the heart in man with use of a flow-directed balloon-tipped catheter. N Engl J Med 283:447–451	1189
6.	Ashbaugh DG, Bigelow DB, Petty TL et al. (1967) Acute respiratory distress in adults. Lancet 290:319–323	1137
7.	Bone RC, Balk RA, Cerra FB et al. (1992) Definitions for sepsis and organ failure and guidelines for the use of innovative therapies in sepsis. Chest 101:1644–1655	1043
8.	Ziegler EJ, Fisher CJ, Sprung CL et al. (1991) Treatment of gram-negative bacteremia and septic shock with HA-1A human monoclonal antibody against endotoxin. A randomized, double-blind, placebo-controlled trial. N Engl J Med 324:429–436	996
9.	Rossaint R, Falke KJ, Lopez F et al. (1993) Inhaled nitric oxide for the adult respiratory distress syndrome. N Engl J Med 328:399–405	990
10.	Knaus WA, Wagner DP, Draper EA et al. (1991) The APACHE III prognostic system. Risk prediction of hospital mortality for critically ill hospitalized adults. Chest 100:1619–1636	971
11.	Murray JF, Matthay MA, Luce JM et al. (1988) An expanded definition of the adult respiratory distress syndrome. Am Rev Respir Dis 138:720–723	952
12.	Clark LC (1956) Monitor and control of blood and tissue oxygen tension. Trans Am Soc Artif Intern Organs 2:41–57	938
13.	Waage A, Halstensen A, Espevik T (1987) Association between tumour necrosis factor in serum and fatal outcome in patients with meningococcal disease. Lancet 329:355–357	932
14.	Kouwenhoven WB, Jude JR, Knickerbocker GG (1960) Closed-chest cardiac massage. JAMA 173:1064–1067	921
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17.	Le Gall JR, Lemeshow S, Saulnier F (1993) A new Simplified Acute Physiology Score (SAPS II) based on a European/North American multicenter study. JAMA 270:2957–2963	758
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22.	Deitch EA (1992) Multiple organ failure. Pathophysiology and potential future therapy. Ann Surg 216:117–134	640
23.	Shoemaker WC, Appel PL, Kram HB et al. (1988) Prospective trial of supranormal values of survivors as therapeutic goals in high-risk surgical patients. Chest 94:1176–1186	636
24.	Tate RM, Repine JE (1983) Neutrophils and the adult respiratory distress syndrome. Am Rev Respir Dis 128:552–559	632
25.	Knaus WA, Draper EA, Wagner DP et al. (1986) An evaluation of outcome from intensive care in major medical centers. Ann Intern Med 104:410–418	620
26.	Vincent JL, Bihari DJ, Suter PM et al. (1995) The prevalence of nosocomial infection in intensive care units in Europe. JAMA 274:639–644	591
27.	Brower RG, Matthay MA (2000) Ventilation with lower tidal volumes as compared with traditional tidal volumes for acute lung injury and the acute respiratory distress syndrome. N Engl J Med 342:1301–1308	588
	Montgomery AB, Stager MA, Carrico CJ et al. (1985) Causes of mortality in patients with the adult respiratory distress syndrome. Am Rev Respir Dis 132:485–489	588
29.	Knaus WA, Draper EA, Wagner DP et al. (1985) Prognosis in acute organ-system failure. Ann Surg 202:685–693	568
30.	Parrillo JE (1993) Pathogenetic mechanisms of septic shock. N Engl J Med 328:1471–1477	557
31.	Connors AF, Speroff T, Dawson NV et al. (1996) The effectiveness of right heart catheterization in the initial care of critically ill patients. JAMA 276:889–897	550
32.	Bernard GR, Vincent JL, Laterre PF et al. (2001) Efficacy and safety of recombinant human activated protein C for severe sepsis. N Engl J Med 344:699–709	538
33.	Carrico CJ, Meakins JL, Marshall JC et al. (1986) Multiple-organ-failure syndrome. Arch Surg 121:196–208	516
34.	Fry DE, Pearlstein L, Fulton RL et al. (1980) Multiple system organ failure. The role of uncontrolled infection. Arch Surg 115:136–140	511
	Weiland JE, Davis WB, Holter JF et al. (1986) Lung neutrophils in the adult respiratory distress syndrome. Clinical and pathophysiologic significance. Am Rev Respir Dis 133:218–225	511
36.	Bedell SE, Delbanco TL, Cook EF et al. (1983) Survival after cardiopulmonary resuscitation in the hospital. N Engl J Med 309:569–576	501
37.	Greenman RL, Schein RM, Martin MA et al. (1991) A controlled clinical trial of E5 murine monoclonal IgM antibody to endotoxin in the treatment of gram-negative sepsis. JAMA 266:1097–1102	494

Table 6 (continued)

Rank	Citation	Times cited
38.	Fowler AA, Hamman RF, Good JT et al. (1983) Adult respiratory distress syndrome: risk with common predispositions. Ann Intern Med 98:593–597	489
39.	Ganz W, Donoso R, Marcus HS et al. (1971) A new technique for measurement of cardiac output by thermodilution in man. Am J Cardiol 27:392–396	479
40.	Bell RC, Coalson JJ, Smith JD et al. (1983) Multiple organ system failure and infection in adult respiratory distress syndrome. Ann Intern Med 99:293–298	473
41.	Knaus WA, Connors AF, Desbiens N et al. (1995) A controlled trial to improve care for seriously ill hospitalized patients. The study to understand prognoses and preferences for outcomes and risks of treatments. JAMA 274:1591–1598	471
	Craven DE, Kunches LM, Kilinsky V et al. (1986) Risk factors for pneumonia and fatality in patients receiving continuous mechanical ventilation. Am Rev Respir Dis 133:792–796	471
43.	Alverdy JC, Aoys E, Moss GS (1988) Total parenteral nutrition promotes bacterial translocation from the gut. Surgery 104:185–190	462
44.	Kinsella JP, Neish SR, Shaffer E et al. (1992) Low-dose inhalation nitric oxide in persistent pulmonary hypertension of the newborn. Lancet 340:819–820	459
45.	Gutierrez G, Palizas F, Doglio G et al. (1992) Gastric intramucosal pH as a therapeutic index of tissue oxygenation in critically ill patients. Lancet 339:195–199	453

different motives [17]. This may lead to the finding that some scientists are over-cited by, for example, a substantial number of ceremonial citations [18].

We have been able to make several observations concerning the authors, and their institutions, of the articles included in our study. The vast majority (69% and 89%, respectively) of citation classics in critical care and other biomedical journals originated in the US. This figure is comparable with the origin of citation classics in general surgical journals (78% US) [6], in clinical dermatologic journals (75% US) [7] and in otolaryngology-head and neck surgery journals (84% US) [8]. In the Citation Classics of JAMA, 95% of all articles originated in the US [10], thus confirming the overwhelming influence that the US has on medical research due to its large population and the financial resources available to the scientific community. One must keep in mind that biomedical research productivity world-wide is largely dependent on each country's per capita gross national product and the expenditure allotted for research and development [19]. Financial support, however, is not the only reason why this US dominance is so strong, as there is also a tendency for US authors to cite local papers and for European authors to publish in American journals [6, 8].

Another observation is rather surprising. In many cross-discipline studies of top-cited articles, methodological publications and review articles predominate [7, 10]. We, therefore, did not expect to find that original research articles accounted for 95% of all citation classics in the specialty journals, although only one of the top-ten articles was a clinical prospective study (Table 2, rank 8); the other top-ten cited articles were either reviews or consensus papers or those describing the development and validation of various scoring systems. Finally, a large gender gap exists in our results. Only one woman is represented among the first authors of top-cited articles in critical care journals; this finding is similar to the results of an earlier study which also identified only six women as first authors of citation classics in dermatologic journals [7]. However, this under-representation of women is rather surprising because critical care medicine is a modern and relatively young specialty of medicine, as reflected by the fact that 60% of the classic articles were published after 1989 in critical care journals.

Although we have tried to eliminate potential flaws in our citation analysis, some limitations were inevitable and are linked to the inherent problems of citation analysis as previously described [2, 3, 17, 18, 20]. It has also to be noted that ISI's databases and information products were primarily developed for bibliographic use and not for bibliometric analysis. Other problems include biased citing, such as self-citation, citing high-impact journals and review articles, and national or language preferences [21]. In addition, it has been documented that citation statistics at the level of individuals, research groups, journal and countries are strongly affected by sloppy referencing, editorial characteristics, referencing conventions, language problems, author-identification problems, unfamiliarity with foreign author names and ISI data-capturing conventions. Strongly affected entities are consortium papers, journals with dual volume-numbering systems or combined volumes, and journals published in different versions or languages applying different article-numbering systems [5]. The search for classic critical care articles in general biomedical journals was dependent on the key word "Critical Care"; other search terms would yield different data. In addition, key words are often incorrectly or incompletely entered in databases.

Keeping the above limitations in mind and using a high level of suspicion and sophistication, directly counting citations to papers of various researchers, as performed in our study, remains the most obvious measure of the general interest in their work [1]. The founder of ISI,

Eugene Garfield, stated that we tend to remember those works that receive the greatest public recognition [10]. The lists of classic papers in Tables 2 and 6, therefore, represent an index related to how often a specific article has been used. These classic articles have influenced many people and should help to bring to our attention important advances in critical care medicine. Citation analysis as a bibliometric indicator does not reflect scientific quality; however, the number of citations an article receives over the years tells us something about the impact on the scientific community of that article [2, 5].

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