Journal Impact Factors, *h* Indices, and Citation Analyses in Toxicology

Steven B. Bird, MD

University of Massachusetts Medical School, Department of Emergency Medicine, Division of Medical Toxicology

INTRODUCTION

Academic departments, institutions, and funding sources are increasingly interested in quantifying the academic's productive output and quality of individual researchers. Since Gross and Gross first published a detailed analysis of a single journal's bibliography in 1927 [1], there has been a progressive increase in the scientific methods of journal citation quantification. The most commonly used databases are *Journal Citation Reports* (JCR) and the *Science Citation Index* (SCI) [2] produced by the Institute for Scientific Information (ISI). Originally introduced in 1961 as a means for retrieving bibliographic data, the SCI has undergone numerous changes, both in its content and methods, as well as how the information from the database is used.

The recent expansion of biomedical knowledge and increasingly sophisticated scientific techniques has led to a proliferation of biomedical journals. The *JCR* is an annual publication by the ISI, which reports the impact factor and other bibliometric data for thousands of journals—the *JCR* cited 6,164 journals in 2006, compared with just 4,625 in 1995 [3]. In a remarkably prescient article published over 70 years ago, Bradford (4) found that a small percentage of journals accounts for a large percentage of what is published and that an even smaller percentage of journals accounts for what is most often cited. That is, there are diminishing returns in trying to comprehensively cover the world's body of literature. Careful selection thus is an effective way to avoid "documentary chaos," a phrase coined by Samuel C. Bradford referring to the angst felt when trying to keep up to date with the information explosion.

The *JCR* provides quantitative tools for ranking, evaluating, categorizing, and comparing journals within and without scientific fields. The impact factor of a journal is a measure of the frequency with which the average article in a journal has been cited in a particular period. The impact factor is the ratio between citations and recent citable items published by a journal. Thus, the impact factor of a journal is calculated by dividing the number of current-year citations to the total items published in that journal during the previous 2 years. Whether erroneous or not, the impact factor is considered a surrogate for the importance or influence of a journal.

While the impact factor is one way to rank journals, it cannot easily be used to rank or objectively rate an individual. In 2005, J. E. Hirsch proposed the *h* index as a means of quantifying one's academic productivity [5]. While very simple in principle, the *h* index is slightly more difficult to define. An individual's *h* index is the number of manuscripts (N) that have each been cited N or more times. For example, if an author has 8 manuscripts that have each been cited 8 or more times, that individual's *h* index is 8. The *h* index thus rewards academicians for both the quantity and importance or relevance of their publications (where importance and relevance are proportional to citations).

A large contributor to an individual's *h* index is the duration of an individual's academic productivity. That is, a more senior author will have had more time to publish as well as more time for the subsequent citation of his or her work. In an effort to level the playing field with regard to the *h* index, it has been proposed to divide an individual's *h* index by the number of years out of residency, postdoctoral work, or the number of years a researcher has been publishing, thus yielding the so-called *m* index [5]. Similar *h*- and *m*-indices for individual journals can be calculated, and each journal's *h* index is now listed by the JCR. No published literature has addressed the *m* indices of journals, but these could be calculated by dividing the *h* index by the number of years of that journal's publication.

Three other core metrics of scientific journals are the immediacy index, cited half-life, and citing half-life. The immediacy

Keywords: Impact factor, h indices, citation analyses, toxicology
Note: There was no outside funding of any kind used for this study.
Corresponding author: Steven B. Bird, MD, University of Massachusetts Medical School, Department of Emergency Medicine, 55 Lake Avenue North, Worcester, MA 01655. *Email: BirdS@ummhc.org*

index is a measure of how quickly the "average" article in a given journal is cited. The immediacy index is calculated by simply dividing the number of citations to articles published in a given year by the number of articles published by that journal in the same year [2]. The immediacy index is best used in conjunction with other journal metrics. The immediacy index can assist in adjusting for journals with large versus small circulations because it represents a number based on a per-article basis. However, journals with frequent publication (e.g., weekly or biweekly) will still have a competitive advantage over less-frequently published journals because an article published early in a given year is more likely to be cited within the same year [2,6].

Cited and citing half-lives are easily confused, but they represent fundamentally different data. The cited half-life of a journal indicates the number of years that account for one-half of all citations to that journal. This number is a gauge of the age of articles from that journal that are cited in a given year. For example, if a journal has a cited half-life of 5.0 years in 2006, that means that one-half of all citations to that journal in 2006 were from 2001 to 2006. The citing half-life of a journal, however, represents the age of articles references *by* that journal in a given year. Specifically, the citing half-life indicates the number of years that account for 50% of the citations by articles in that journal. For example, if a journal's citing half-life in 2006 is 5.0 years, it means that one-half of the references in that journal's articles from 2006 are 5 years old. A short citing half-life often represents a rapidly changing or developing scientific field (2,6).

The aim of this study was to identify and analyze the most-frequently cited journals and articles in the field of medical toxicology, as well as to determine the trend of journal impact factors and *h* indices from 1999 to 2006. Finally, a discussion of these core measures of productivity and relevance are discussed.

METHODS

The JCR journal list was searched for category of "toxicology" for the years 1999 and 2006. Twenty-seven of the journals considered most applicable to the practice of medical toxicology were included for further analyses and are identified by an asterisk (*) in *Table 1*. The journal *Environmental Health Sciences*, which is not indexed under "toxicology" by the *JCR*, was included for comparison, yielding 28 journals. For all toxicology journals, the impact factors from 1999 and 2006 along with the *h* indices were recorded. Additionally, the most cited article from each of the *JCR*'s toxicology journal index since 1966 was determined from ISI Web of Science, as was the total number of articles that have been cited 100 or more times from each journal.

To investigate the correlation between a journal's *h* index and impact factor, the Spearman's correlation coefficient between a journal's 2006 impact factor and *h* index was determined. Lastly, to compare the performance of the toxicology journals to other medical and scientific journals, the 1999 and 2006 impact factors of 9 selected major journals that occasionally publish articles relevant to toxicology were determined.

RESULTS

In 1999 a total of 74 journals were listed in the "toxicology" category of *JCR*; in 2006 the number had increased to 76 (*Table 1*). There were 6 entirely new journals created in the toxicology category between 1999 and 2006, while 10 journals ceased publication. Two journals, *Teratology* and *Journal of Toxicology and Environmental Health*, were each split into 3 new journals. The journal *Mutagenesis* was added to the toxicology category between 1999 and 2006. The journals that either ceased publication or were dropped from the *JCR* between 1999 and 2006 are listed in *Table 2*. Seven of the original 74 journals (10%) changed titles during the 7 years covered. One journal, *SAR and QSAR in Environmental Research*, did not have an impact factor calculated by *JCR* in 1999. Because it is a new journal and just recently indexed by Medline, the *Journal of Medical Toxicology* is not yet listed in the *JCR*.

The 27 journals deemed most relevant to clinical toxicology had a mean impact factor of 1.54 in 1999. By 2006, the mean had increased to 2.01. Adding data from *Environmental Health Perspectives* to this category resulted in increases in the impact factors for 1999 and 2006 to 1.58 and 2.14, respectively. The entire *JCR* toxicology category had a mean impact factor of 1.69 and 2.24 in 1999 and 2006, respectively. If the journal *Annual Review of Pharmacology and Toxicology*, which publishes only review articles, is removed from the above calculation, then the impact factors of the toxicology category decreased to 1.39 in 1999 and 1.99 in 2006.

The most-frequently cited articles from each of the *JCR* toxicology category journals from 1965 until the end of 2007 are presented in *Table 3*. The total number of articles from each of the journals that has been cited 100 or more times and 1000 or more times are also provided in Table 3. A total of 12 articles from all of the journals have been cited more than 1000 times; 9 (75%) of these articles were published in *Annual Review of Pharmacology and Toxicology*. From the toxicology category, a total of 1768 articles have been cited more than 100 times; 298 (16.8%) of these were published in *Annual Review of Pharmacology and Toxicology*.

The 2006 *h* index of all *JCR* toxicology journals are presented in *Table 1*. Because the *h* index is a new measure and little has been published regarding its application to individual journals, the correlation between *h* index and the 2006 impact factor for all *JCR* toxicology journals was determined (*Figure 1*). The R^2 value of 0.6015 demonstrates that there is moderate to large correlation between a toxicology journal's 2006 impact factor and *h* index.

Table 4 shows the impact factors of 9 selected well-known journals that occasionally publish articles relevant to medical toxicology. For these 9 journals, there was an increase in impact factor from 1999 to 2006 in 7 of 9 (77%), with mean impact factors of 18.57 in 1999 and 24.94 in 2006. The overall *h* indices of these journals are impossible to calculate because they publish so many articles (the *JCR* can only analyze 10,000 articles at a time) and the *h* indices are so large. For example, the *h* index for *Nature* in the year 2006 alone was greater than 300.

Table 1: Bibliometric Data for JCR Toxicology Category Journals

Journal Name	Name changed from	1999 Impact factor	2006 Impact factor	*h* index	Immediacy index	Cited half-life	Citing half-life
Alcohol		1.433	2.020	61	0.087	7.7	8.6
Annals of Occupational Hygiene		1.577	1.919	45	0.808	6.6	7.4
Annual Review of Pharmacology		21.175	22.808	54	7.059	6.5	5.6
Aquatic Toxicology		1.619	2.964	69	0.55	6.1	7.6
Archives of Environmental Contamination and Toxicology		1.173	1.419	68	0.199	8.1	8.6
Archiv Fur Lebensmittelhygiene		0.355	0.131	20	0.156	>10.0	6.9
*Archives of Toxicology**		1.683	1.787	70	0.336	9.1	8.2
Bullletin of Environmental Contamination and Toxicology		0.617	0.505	63	0.056	9.9	9
*Basic Clinical Pharmacology Toxicology**	*Pharmacology and Toxicology*	1.263	1.788	14	0.277	2.2	7.4
Biomarkers		1.427	2.203	24	0.222	4.3	7
Birth Defects Research Part A		new	2.005	14	0.253	2.5	7.8
Birth Defects Research Part B		new	1.629	10	0.312	2.7	8.6
Cell Biology and Toxicology		1.300	1.400	35	0.233	6.7	8.1
*Chemical Research in Toxicology**		3.470	3.162	97	0.663	6.2	7.7
Chemical Speciation and Bioavailability		0.533	0.879	16	0	7	>10
*Chemico Biological Interactions**		1.887	1.800	93	0.489	7.2	7.9
*Clinical Toxicology**	*J Toxicology - Clinical Toxicology*	1.732	1.091	42	0.114	>10.0	>10.0
Comparative Biochemistry and Physiology C		0.655	1.991	35	0.529	8	8.4
Critical Reviews in Toxicology*		4.906	3.707	66	0.88	>10.0	9.9
Cutaneous and Ocular Toxicology	J Toxicology - Cutaneous and Ocular Toxicology	0.212	0.273	2	0.04	0	>10.0
DNA Repair		new	5.868	40	0.855	2.6	6.1
Drug and Chemical Toxicology*		0.458	1.239	27	0	6.7	>10.0
Drug Safety		2.557	3.673	60	0.689	5.6	5.9
Drugs		4.150	4.472	128	0.464	6.6	4.6
Ecotoxicology		1.377	1.400	31	0.167	5.3	8.8
Ecotoxicology and Environmental Safety		1.276	2.000	53	0.325	6.7	9.3
Environmental and Molecular Mutagenesis		1.990	2.653	55	0.274	7.2	8
Environmental Toxicology*		0.646	1.582	25	0.108	5.2	8.3
Environmental Toxicology and Chemistry*		2.462	2.202	90	0.404	6.6	7.9
Environmental Toxicology and Pharmacology*		0.707	1.119	26	0.179	4.1	8.4
Experimental and Toxicologic Pathology*		0.603	0.755	24	0.152	6.5	8.7
Fluoride		0.469	1.611	23	0.522	6.4	9.2
Food Additives and Contaminants		0.879	1.780	48	0.148	5.7	7.2
Food and Agricultural Immunology		0.794	0.667	18	0.214	6.8	8.9
Food and Chemical Toxicology		1.243	2.393	71	0.3	6.6	8.5
Human Experimental Toxicology*		1.063	1.122	33	0.081	7.4	8.4

(*Continued*)

Table 1: (Continued)

Journal Name	Name changed from	1999 Impact factor	2006 Impact factor	*h* index	Immediacy index	Cited half-life	Citing half-life
Immunopharmacology and Immunotoxicology		0.740	0.654	29	0.107	7	8.6
Industrial Health		0.175	0.911	20	0.042	5.8	9.3
Inhalation Toxicology*		1.019	2.167	37	0.299	4.7	8.4
International Journal of Toxicology*		0.413	1.081	16	0.109	4	>10.0
Journal of Analytical Toxicology*		2.221	1.242	55	0.117	7.5	7.6
Journal of Applied Toxicology*		1.064	1.625	38	0.261	7.4	>10.0
Journal of Biochemical and Molecular Toxicology		new	1.418	21	0.237	4.5	9.6
Journal of Environmental Pathology and Toxicology		new	1.109	39	0.639	7	8.4
Journal of Environmental Science and Health Part C		0.538	2.154	16	0.333	–	7.2
Journal of Exposure Science and Environmental Epidemiology		0.853	2.492	7	0.596	5.7	6.7
Journal of Health Science		none	0.793	15	0.23	4	8.5
Journal of Toxicology and Environmental Health*		2.349	1.811	69	0.383	7.3	8.7
Journal of Toxicology–Clinical Toxicology*		1.732	1.988	41	–	7.3	–
Journal of Toxicology–Cutaneous and Ocular Toxicology		0.212	0.407	21	–	–	–
Journal of Toxicology–Toxin Reviews*		0.773	1.286	26	–	6.3	–
Marine Environmental Research		1.049	2.106	54	0.266	6.8	9
Molecular and Cellular Toxicology		new	0.317	3	0.049	–	7.3
Mutagenesis	new to Toxicology category	2.007	2.125	59	0.537	6.5	7.1
Mutation Research—Fundamental and Molecular Mechanisms of Mutagenesis	Mutation Research	2.107	4.111	76	0.514	5.1	7.2
Mutation Research—Genetic Toxicology and Environmental Mutagenesis	Mutation Research	2.107	2.122	44	0.169	5.6	8.8
Mutation Research—Reviews in Mutations Research	Mutation Research	2.107	7.579	53	1.05	5.1	7.8
Neurotoxicology and Teratology		1.822	2.143	64	0.242	8.1	8.8
Neurotoxicology*		1.282	2.718	64	0.471	7	8
Regulatory Toxicology and Pharmacology		1.530	1.836	44	0.3	6	8.3
Reproductive Toxicology		1.277	2.362	41	0.369	5.4	8.6
Reviews of Environmental Contamination and Toxicology	Residue Reviews	none	2.619	37	0.143	>10.0	8.7
SAR and QSAR in Environmental Research		none	1.630	20	0.054	4.7	6.9
Therapeutic Drug Monitoring		1.383	3.032	57	0.371	5.6	6.2
Toxicology and Applied Pharmacology*		2.723	4.722	59	0.522	7.9	7.2
Toxicology In Vitro		1.136	2.045	37	0.402	4.6	7.6
Toxicology and Industrial Health		1.545	0.673	40	0.051	8.5	9.2
Toxicology Letters*		0.773	2.784	68	0.526	5.5	7.4
Toxicology Mechanisms and Methods	Toxicology Methods	0.735	0.411	8	0.102	–	8.9
Toxicologic Pathology*		1.310	2.092	48	0.429	6.2	7.5
Toxicological Sciences*	Fundamental and Applied Toxicology	2.205	3.598	60	0.734	4.2	6.9

Table 1: (Continued)

Journal Name	Name changed from	1999 Impact factor	2006 Impact factor	*h* index	Immediacy index	Cited half-life	Citing half-life
Toxicology*		1.343	2.685	79	0.487	5.3	7.6
Toxicon*		1.248	2.509	76	0.255	7.1	9.2
Toxin Reviews*	J Toxicoogy – Toxin Reviews	none	0.474	3	0.037	–	>100
Veterinary and Human Toxicology		0.531	0.660	27	–	>10.0	–
Xenobiotica		1.335	1.613	73	0.357	8.5	5.8

** denotes current journal of interest to clinical toxicology*
– denotes data not applicable or available

Table 2: Journals that Ceased Publication or Were Dropped from *JCR* between 1999 and 2006

In Vitro and Molecular Toxicology	
In Vitro Toxicology	
Journal of Clean Technology Environmental Toxicology and Occupational Medicine	
Journal of Natural Toxins	
Journal of Pharmacological and Toxicological Methods	
Journal of Toxicology and Environmental Health—Part A	
Journal of Toxicology and Environmental Health—Part B, Critical Reviews	no longer in *JCR*
Japanese Journal of Toxicology and Environmental Health	no longer in *JCR*
Teratogenesis Carcinogenesis and Mutagenesis	
Teratology	
Toxic Substances Mechanisms	split into 3 journals
Veterinary and Human Toxicology	

DISCUSSION

There has been a marked proliferation of medical and scientific journals in the last 10 years. However, this proliferation is more significant among disciplines favoring emerging scientific technology than traditional medical specialties or subspecialties. In 1995, there were 72 journals indexed under "toxicology," while in 2005 that category was comprised of 76 journal titles (*Table 1*). This is in contrast to an increase of 32% in the number of journals indexed by the ISI Web of Science in the same time period.

Overall, toxicology journals as a group have low impact factors compared to other scientific disciplines. This is likely attributed to several facts. First, the shear numbers of practitioners of medical or clinical toxicology is small, leading to relatively fewer researchers publishing in peer-reviewed journals than other disciplines. Second, while the clinical field of toxicology is small, the subject matter of toxicology is enormous, overlapping with many other scientific and medical specialties. This leads to toxicology manuscripts being published in many other journals that are not classified as "toxicology" by the JCR. Third, the perceived narrow focus of toxicology journals may lead researchers with some connection to toxicology to publish their results in journals that they perceive will have an audience larger than that of toxicology journals. This exact scenario was demonstrated in the emergency medicine literature by Callaham et al. [7]. They found that publications by emergency medicine researchers were cited about 3 times as often when published by non-emergency medicine journals with larger audiences. Fourth, it could be that journals with low impact factors are destined to have low impact factors indefinitely, as researchers seek to publish their results in journals with high impact factors [8].

To quantify both the published productivity and the apparent impact of an individual scientist (as measured by how often that scientist's manuscripts are referenced) as a single metric, J. E. Hirsch in 2005 devised the *h* index [5]. Sometimes referred to as the Hirsch index or Hirsch number, the *h* index is simply the number of papers by a scientist that have a citation number $\geq h$. An *h* index of 20 *means*, for example, that a scientist has published 20 papers that each had at least 20 citations. In a similar manner, the *h* index can also be applied to groups of individuals, institutions, and journals. Hirsch's *h* index was intended to improve upon other measures of productivity, such as the total number of citations or publications, in order to distinguish influential researchers from those who publish many manuscripts that lack influence in their scientific field (again, citations taken as a marker of influence). Because citation conventions differ greatly among different scientific disciplines, the *h* index should only be used for comparing scientists working in the same field.

As is evident from the calculation of the *h* index, a scientist's *h* index can never decrease, and an increase is expected as new (frequently cited) papers are published, as "sleeping beauties" are discovered and cited, and as the scientist's papers attract citations [9,10]. The idea of ranking scientists within a given field by a single number and the advantages that the *h* index has over other

Table 3: Most Frequently Cited Papers and the Number of Papers Cited 100 or More Times from All *JCR* Toxicology Journals

Journal and Author	# times cited	Most Cited Article
Alcohol		
O'Brien CP et al.	101	Naltrexone in the treatment of alcoholism: A clinical review. 13:35–39, 1996.
Ann Occup Hyg		
Kenny LC et al.	96	A collaborative European study of personal inhalable aerosol sampler performance. 41:135–153, 1997.
Ann Rev Pharmacol Toxicol		
Watkins JC and Evans RH	2131	Excitatory amino-acid transmitters. 21:165–204, 1981.
9 articles cited >1000 times		
298 articles cited ≥100 time		
Aquat Toxicol		
Jobling S and Sumpter JP	557	Detergent components in sewage effluent are weakly estrogenic to fish—an in-vitro study using rainbow-trout (Oncorhynchus mykiss) hepatocytes. 27:361–372, 1993.
24 articles cited >100 times		
Arch Environ Contam Toxicol		
Kubiak TJ et al.	235	Microcontaminants and reproductive impairment of the Forster's tern on Green Bay, Lake Michigan. 18:706–727,1989.
22 articles cited >100 times		
Arch Lebensmittelhyg		
Arnold D et al.	41	Radioimmunological determination of chloramphenicol residues in muscles, milk and eggs. 35:131–136 1984.
Arch Toxicol		
Johnson MK	330	Improved assay of neurotoxic esterase for screening organophosphates for delayed neurotoxicity potential. 37:113–115, 1977.
29 articles cited >100 times		
Basic Clin Pharmacol Toxicol		
Safe S et al.	214	2,3,7,8-Tetrachlorodibenzo-para-dioxin (TCDD) and related-compounds as antiestrogens—characterization and mechanisms of action. 69: 400–409, 1991.
12 articles cited >100		
Biomarkers		
d'Errico A et al.	136	Genetic metabolic polymorphisms and the risk of cancer: A review of the literature. 1:149–173, 1996.
Birth Defects Res Part A		
Rasmussen SA et al.	40	Guidelines for case classification for the national birth defects prevention study. 67:193–201, 2003.
Birth Defects Res Part B		
Cappon GD et al.	20	Relationship between cyclooxygenase 1 and 2 selective inhibitors and fetal development when administered to rats and rabbits during the sensitive periods for heart development and midline closure. 68:47–56, 2003.
Bull Environ Contam Toxicol		
Payne JF and Penrose WR	179	Induction of aryl-hydrocarbon (benzo[A]pyrene) hydroxylase in fish by petroleum. 14:112–116, 1975.
18 articles cited >100 times		
Cell Biol Toxicol		
Bondessoon I et al.	128	MEIC—a new international multicenter project to evaluate the relevance to human toxicity of in vitro cytotoxicity tests. 5:331–347, 1989.
2 articles cited >100 times		

Table 3: (*Continued*)

Journal and Author	# times cited	Most Cited Article
Chem Res Toxicol		
Guengerich FP et al.	910	Role of human cytochrome P-450–2E1 in the oxidation of many low-molecular-weight cancer suspects. 4:168–179, 1991.
91 articles cited >100 times		
Chem Spec Bioavailab		
Rieuwerts JS et al.	48	Factors influencing metal bioavailability in soils: preliminary investigations for the development of a critical loads approach for metals. 10:61–75, 1998.
Chem Biol Interact		
O'Brien PJ	437	Molecular mechanisms of quinone cytotoxicity. 80:1–41, 1991.
72 artlces cited >100 times		
Clin Toxicol		
Wilber CG	162	Toxicology of selenium—a review. 17: 171–230, 1980.
8 articles cited >100 times		
Comp Biochem Physiol C		
Hahn ME	160	The aryl hydrocarbon receptor: A comparative perspective. 121:23–53, 1998.
2 articles cited >100 times		
Crit Rev Toxicol		
Safe S	1268	Polychlorinated-biphenyls (PCBS), dibenzo-para-dioxins (PCDDS), dibenzofurans (PCDF) and related compounds—environmental and mechanistic considerations which support the development of toxic equivalency factors (TEFS). 21:51–88, 1990.
41 articles cited >100 times		
Cutan Ocul Toxicol		
Farage M et al.	3	Cutaneous and sensory effects of two sanitary pads with distinct surface materials: A randomized prospective trial. 24:227–241, 2005.
DNA Repair		
Fernandez-Capetillo O et al.	118	H2AX: the histone guardian of the genome. 3:959–967, 2004.
3 articles cited >100 times		
Drug Chem Toxicol		
Miller RR et al.	79	Chronic toxicity and oncogenicity bioassay of inhaled ethyl acrylate in Fischer 344 rats and B6C3F1 mice. 8:1–42, 1985.
Drug Safety		
Vial T and Descotes J	166	Clinical toxicity of the interferons. 10:115–150, 1994.
9 articles cited >100 times		
Drugs		
Ward A and Clissold SP	487	Pentoxifylline—a review of its pharmacodynamic and pharmacokinetic properties, and its therapeutic efficacy. 34:50–97, 1987.
212 articles cited >100 times		
Ecotoxicol Environ Safety		
Vanstraalen NM and Denneman CAJ	189	Ecotoxicological evaluation of soil quality criteria. 18:241–251, 1989.
8 articles cited >100 times		

(*Continued*)

Table 3: (Continued)

Journal and Author	# times cited	Most Cited Article
Ecotoxicology		
MacDonald DD et al.	114	Development and evaluation of sediment quality guidelines for Florida coastal waters. 5:253–278, 1996.
2 articles cited >100 times		
Environ Mol Mutagen		
Tice RR et al.	649	Single cell gel/comet assay: Guidelines for in vitro and in vivo genetic toxicology testing. 35:206–221, 2000.
17 articles cited >100 times		
Environ Health Perspect		
Colborn T et al.	1260	Developmental effects of endocrine-disrupting chemicals in wildlife and humans. 101: 378–384, 1993.
193 articles cited >100 times		
Environ Toxicol		
Falconer IR	74	An overview of problems caused by toxic blue-green algae (cyanobacteria) in drinking and recreational water. 14:5–12, 1999.
Environ Toxicol Chem		
Jobling S et al.	634	Inhibition of testicular growth in rainbow trout (*Oncorhynchus mykiss*) exposed to estrogenic alkylphenolic chemicals. 15: 194–202, 1996.
73 articles cited >100 times		
Environ Toxicol Pharmacol		
van der Oost R et al.	208	Fish bioaccumulation and biomarkers in environmental risk assessment: a review. 13:57–149, 2003.
1 article cited >100 times		
Exp Toxicol Path		
Dargel R	119	Lipid-peroxidation—a common pathogenetic mechanism. 44:169–181, 1992.
1 article cited >100 times		
Fluoride		
Li JX and Cao SR	50	Recent studies on endemic fluorosis in China. 27:125–128, 1994.
Food Addit Contam		
Price KR and Fenwick GR	305	Naturally-occurring estrogens in foods—a review. 2:73–106, 1985.
5 articles cited >100 times		
Food Agric Immunol		
Nakajima M et al.	45	Survey of aflatoxin B-1 and ochratoxin A in commercial green coffee beans by high-performance liquid chromatography linked with immunoaffinity chromatography. 9:77–83, 1997.
Food Chem Toxicol		
Formica JV and Regelson W	411	Review of the biology of quercetin and related bioflavonoids 33:1061–1080, 1995.
31 articles cited >100 times		
Human Exp Toxicol		
Ashby J et al.	151	Mechanistically-based human hazard assessment of peroxisome proliferator-induced hepatocarcino-genesis. 13:S1–117, 1994.
2 articles cited >100 times		
Immunopharm Immunotox		
Marzio R et al.	77	CD69 and regulation of the immune function. 21:565–582, 1999.

Table 3: (Continued)

Journal and Author	# times cited	Most Cited Article
Ind Health		
Kawakami N and Haratani T	54	Epidemiology of job stress and health in Japan: Review of current evidence and future direction. 37:174–186, 1999.
Inhal Toxicol		
Pope CA and Dockery DW	311	Review of epidemiological evidence of health-effects of particulate air pollution. 7:1–18, 1995.
5 articles cited >100 times		
Int J Toxicol		
Calabrese EJ and Baldwin LA	80	The dose determines the stimulation (and poison): Development of a chemical hormesis database. 16:545–559, 1997.
J Anal Toxicol		
Patrianokos C et al.	198	Chemical studies on tobacco smoke: Analysis of aromatic-amines in cigarette smoke. 3:150–154, 1979.
8 articles cited >100 times		
J Appl Toxicol		
Heinrich U et al.	144	Chronic effects on the respiratory tract of hamsters, mice and rats after long-term inhalation of high concentrations of filtered and unfiltered diesel-engine emissions. 6:383–395, 1986.
4 articles cited >100 times		
J Biochem Mol Toxicol		
Maritim AC et al.	117	Diabetes, oxidative stress, and antioxidants: A review. 17:24–38, 2003.
J Environ Pathol Toxicol		
Calleman C et al.	177	Monitoring and risk assessment by means of alkyl groups in hemoglobin in persons occupationally exposed to ethylene oxide. 2:427–442, 1978.
5 articles cited >100 times		
J Environ Sci Health C		
Chan PC and Huff J	46	Arsenic carcinogenesis in animals and in humans: Mechanistic, experimental, and epidemiological evidence. 15:83–122, 1997.
J Expo Sci Environ Epidemiol		
Ahsan H et al.	20	Health Effects of Arsenic Longitudinal Study (HEALS): Description of a multidisciplinary epidemiologic investigation. 16:191–205, 2006.
J Health Sci		
Nishihara T et al.	155	Estrogenic activities of 517 chemicals by yeast two-hybrid assay. 46:282–298, 2000.
J Toxicol Environ Health		
Dreher KL et al.	264	Soluble transition metals mediate residual oil fly ash induced acute lung injury. 50:285–305,1997.
30 articles cited >100 times		
J Toxicol/Clin Toxicol		
Barceloux DG	77	Selenium. 37:145–172, 1999.
J Toxicol Toxin Rev		
Gordon D et al.	129	Functional anatomy of scorpion toxins affecting sodium channels. 17:131–159, 1998.
2 articles cited >100 times		
Mar Environ Res		
Alzieu C	162	Environmental problems caused by TBT in France—assessment, regulations, prospects. 32:7–17, 1991.
10 articles cited > 100 times		

(*Continued*)

Table 3: (Continued)

Journal and Author	# times cited	Most Cited Article
Mol Cell Toxicol		
Park KS et al.	4	Eco-toxicogenomics research with fish. 1:17–25, 2005.
Mutagenesis		
Neill JP et al.	169	Refinement of a lymphocyte-T cloning assay to quantify the in vivo thioguanine-resistant mutant in humans. 2:87–94, 1987.
14 articles cited >100 times		
Mutat Res—Fund Mol M		
Fenech M	260	The in vitro micronucleus technique. 455:81–95, 2000.
38 articles cited >100 times		
Mutat Res—Gen Tox En		
Phillips DH	133	Polycyclic aromatic hydrocarbons in the diet. 443:139–147, 1999.
3 articles cited >100 times		
Mutat Res—Rev Mutat		
Kasai H	362	Analysis of a form of oxidative DNA damage, 8-hydroxy-2'-deoxyguanosine, as a marker of cellular oxidative stress during carcinogenesis. 387:147–163, 1997.
12 articles cited >100 times		
Neurotoxicology		
Bayer SA et al.	321	Timetables of neurogenesis in the human brain based on experimentally determined patterns in the rat. 14:83–144, 1993.
16 articles cited > 100 times		
Neurotoxicol Teratol		
Grandjean P et al.	383	Cognitive deficit in 7-year-old children with prenatal exposure to methylmercury. 19:417–428, 1997.
23 articles cited >100 times		
Regul Toxicol Pharmacol		
Barnes DG and Dourson M	241	Reference dose (RFD)—description and use in health risk assessments. 8: 471–486, 1988.
9 articles cited >100 times		
Reprod Toxicol		
Jansen HT et al.	169	Estrogenic and antiestrogenic actions of PCBs in the female rat—in vitro and in vivo studies. 7: 237–248, 1993.
4 articles cited >100 times		
SAR QSAR Environ Res		
Greene N et al.	49	Knowledge-based expert systems for toxicity and metabolism prediction: DEREK, StAR and METEOR. 10: 299–314, 1999.
Ther Drug Monit		
Erling M et al.	201	Fluvoxamine inhibition and carbamazepine induction of the metabolism of clozapine—evidence from a therapeutic drug-monitoring service. 16: 368–374, 1994.
15 articles cited >100 times		
Toxicol Appl Pharmacol		
Kociba RJ et al.	735	Results of a 2-year chronic toxicity and oncogenicity study of 2,3,7,8-tetrachlorodibenzo-para-dioxin in rats. 46: 279–303, 1978.
243 articles cited >100 times		

Table 3: (Continued)

Journal and Author	# times cited	Most Cited Article
Toxicol In Vitro		
Borenfreund E et al.	198	Comparisons of 2 in vitro cytotoxicity assays—the neutral red (NR) and tetrazolium MTT tests. 2:1–6, 1988.
3 articles cited >100 times		
Toxicol Ind Health		
Vom Saal FS et al.	275	A physiologically based approach to the study of bisphenol A and other estrogenic chemicals on the size of reproductive organs, daily sperm production, and behavior. 14: 239–260, 1998.
6 articles cited >100 times		
Toxicol Lett		
Borenfreund E and Puerner JA	659	Toxicity determined in vitro by morphological alterations and neutral red absorption. 24:119–124, 1985.
24 articles cited >100 times		
Toxicol Mech Methods		
Gupta RC	27	Brain regional heterogeneity and toxicological mechanisms of organophosphates and carbamates. 14:103–143, 2004.
Toxicol Pathol		
Trump BF et al.	126	The pathways of cell death: Oncosis, apoptosis, and necrosis. 25:82–88, 1997.
4 articles cited >100 times		
Toxicol Sci		
Jaeschke H et al.	214	Forum—Mechanisms of hepatotoxicity. 65:166–176, 2002.
23 articles cited >100 times		
Toxicol		
Price RG	398	Urinary enzymes, nephrotoxicity and renal disease. 23:99–134, 1982.
43 articles cited >100 times		
Toxicon		
Kini RM and Evans HJ	250	A model to explain the pharmacological effects of snake venom phospholipases-A2. 27:613–635, 1989.
32 articles cited >100 times		
Toxin Rev		
Gordon D et al.	129	Functional anatomy of scorpion toxins affecting sodium channels. 17:131–159, 1998.
3 articles cited >100 times		
Vet Human Toxicol		
Bruning-Fann CS and Kaneene JB	90	The effects of nitrate, nitrite, and n-nitroso compounds on human health—a review. 35:521–538, 1993.
Xenobiotica		
Oesch F	745	Mammalian expoxide hydrases—inducible enzymes catalyzing inactivation of carcinogenic and cytooxic metabolites derived from aromatic and olefinic compounds. 3:305–340, 1973.
35 articles cited >100 times		

citation-based indices (for example, ranking by total number of papers, total number of citations, or the number of citations per paper) quickly attracted the attention of major scientific journals, including *Science* and *Nature* [11,12]. The *h* index is seen to have the advantage that it gives a robust estimate of the broad impact of a scientist's cumulative research contributions [5,9]. This means that the *h* index is insensitive to a set of infrequently or non-cited papers or to one or several highly cited papers: A scientist with very few highly cited papers or, alternatively, many lowly cited papers will have a low *h* index. A further advantage for the *h* index is that the necessary data for calculation is easy to access in the Thomson Scientific Web of Science. The *h* index can

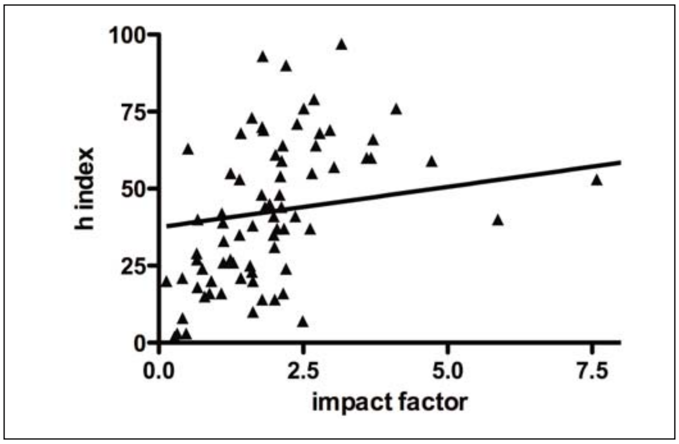

Figure 1: Relationship of h *index to impact factor for JCRR Toxicology journals.*

Table 4: 1999 and 2006 Impact Factors for Selected Highly Cited Journals

Journal	1999 Impact Factor	2006 Impact Factor
Nature	29.49	26.68
New England Journal of Medicine	28.86	51.30
Nature Medicine	26.58	28.59
Science	24.59	30.03
Journal of Experimental Medicine	15.65	14.48
JAMA	11.43	23.18
Proceedings of the National Academy of Sciences	10.26	9.64
Lancet	10.20	25.80
Annals of Internal Medicine	10.10	14.78
Mean	18.57	24.94

be viewed by first searching the ISI Web of Knowledge database by author, then using the "Create Citation Report" option. Both graphical and numerical representations of that author's cumulative citations, numbers of citations per year, as well as the *h* index are then provided.

Even though the *h* index was rapidly adopted by academia [13] and the *JCR*, it remains an incomplete marker of academic success for several reasons. Perhaps most important, the *h* index is biased against junior investigators [14]. This is because more senior authors have both a longer time span of publications as well as a greater number of publications compared to junior authors—thus Hirsch devised the *m* index [5]. An *m* index of ≥ 1 is considered a successful research career, whereas an *m* index of ≥ 3 represents a truly extraordinary researcher uncommon at even the highest academic centers. The *m* index has attracted limited attention so far, but with the advent of more methods to level the academic-promotion playing field, it is likely that the *m* index and additional metrics will be promulgated.

Because an author's *h* index can never decline, it is also biased in favor of more senior researchers, as their apparent scientific impact in a field of study will continue even beyond their academically productive time. Moreover, the *h* index currently considers primary authorship, senior authorship, and coauthorship to be equal. Therefore, an individual with frequent coauthorship on highly cited papers, but with few on no primary author papers, will have a high *h* index while their scientific contributions may be quite modest. Ironically, an individual's *h* index can also be elevated by frequent citations to work that has been refuted, questioned, or found to be entirely wrong.

The *h* index can also be applied to journals, and is viewed as a metric of a journal's influence. In fact, the *JCR* now provides *h* index information on all of its indexed journals. In order to increase the impact factor and *h* index, journals can adopt editorial policies that improve the likelihood of citations to its articles. One method to do this is to publish a large percentage of review articles, which are sources of frequent citation. It has been stated that up to 90% of published scientific articles are never cited [15] and that more than one-half of research articles remain uncited after 3 years [16]. However, nearly all review articles receive at least 1 citation. This has led some authors to question the applicability of calculating an impact factor for review articles [13]. Another editorial policy to increase citations to a journal is the application of editorial pressure to authors: that is, some editors request authors to cite work published in that journal, whether by other authors or by self-citation [13]. Regardless of the method applied, editorial practices aimed solely to increase a journal's subsequent citations and reputation cannot be condoned.

However, a journal's reputation may not tell the complete story about its impact on the scientific and scholarly communities. In fact, Christenson and Sigelman found the opposite to be true [17]. They found a nonlinear relationship between a journal's reputation and its impact, especially at the extremes of the "prestige" scale. They concluded that citation data "permit scholars to evaluate the importance of journals based not on opinion but on the frequency of citations" and that "frequency of citation implies scholarly acceptance . . . ." As further evidence of the importance of a journal's reputation, Callaham et al. found that the impact factor of the journal was more important than any other variable in determining the subsequent citation frequency of an article [18].

As discussed briefly, a journal's total circulation number can also affect its impact factor and *h* index. That is, the more individuals and institutions subscribe to a given journal, the larger its readership and potential audience. This fact places smaller journals at a competitive disadvantage relative to larger journals or journals that publish more issues per year. In an attempt to control for a journal's circulation, Barendse investigated what was termed the strike rate index (SRI) [19]. The SRI is based on the log relationship of the *h* index and the size of the journal. Barendse found that there is a linear log-log relationship between the *h* index and the size of the journal [19]. That is, the larger the journal, the more likely it is to have a high *h* index. When he looked at journals from 4 scientific disciplines, he found a similar distribution of the SRI, perhaps allowing journals across diverse fields to be compared to each other.

There are also some fundamental limitations to the *JCR*. For instance, the assignment of a journal to one or more categories may not reflect fully that journal's entire audience. As an example, *Environmental Health Perspectives*—a well-regarded journal that frequently publishes articles of interest to toxicologists—is listed in the *JCR* categories of "environmental sciences" and "public, environmental, and occupational health" while it is absent from "toxicology." Thus, the accuracy or appropriateness of journal categories is dependent on the appropriate indexing of journals. As with any indexing, there is also a delay in the categorization of a journal. For instance, the *Journal of Medical Toxicology* is not yet indexed by the *JCR*. The *JCR* is also heavily biased towards journals published in the United States, Canada, and United Kingdom. This introduces bias against researchers not from these countries and excludes highly cited works published in many foreign journals [20]. Another important limitation to the *JCR* is that both impact factors and *h* indices of commentaries, editorials, perspectives, news articles, and other nonoriginal research are also calculated and included for each journal. These types of short, time-sensitive articles (a staple of journals that publish weekly editions) are often highly cited and contribute to a journal's citation analysis [21].

Considering that 10% of toxicology journals changed names from 1999 to 2006, a brief discussion of how the *Journal Citation Reports* handles these changes (and how the changes affect the impact factor) is warranted. This is best demonstrated by an example. Assume that in 2007 "*Journal A*" publishes its last issue, and that in 2008 the first issue is newly titled "*Journal B*." When the 2007 *JCR* is published (in June of 2008), only *Journal A* will be listed—because there were neither articles nor citations to *Journal B* in the year before its release. The listing for *Journal A* will have all of the *JCR* metrics.

When the 2008 *JCR* is published (in June of 2009), *Journal A* will have a listing based upon citation in 2008 to content published in 2006 and 2007. *Journal B* will have a deceptively low impact factor based on citations in 2008 to articles published in 2008. For the 2009 *JCR* (published in June of 2010), *Journal A* will have data listed based on citations in 2009 to articles published only in 2007. *Journal B* will have data based on citations in 2009 to articles published in 2008 only. Thus, the impact factor of *Journal A* in 2009 would be deceptively high, since it is based on a section of the citation time-course that is higher (that is, the greatest number of citations occur in the second year after publication). The impact factor of *Journal B*, on the other hand, would be somewhat lower than expected, since it is based on citations only to very recent articles. To gauge the performance of the journal across the time of the title transition, one simply adds the 2 individual impact factors. Finally, in data for the year 2010—published in June of 2011—only *Journal B* will be listed.

CONCLUSION

Overall, toxicology journals have low impact factors compared to other scientific journals. As academic promotion boards increasingly use semiquantitative methods of determining academic productivity (such as the impact factor and *h* index of the journals in which a person has published), it could be expected that the toxicology journals in which many people in the fields of medical and clinical toxicology publish will see decreased submissions, as authors attempt to get their work published in journals with higher impact factors.

The authors have no potential financial conflicts of interest to report.

REFERENCES

1. Gross PLK, Gross EM. College libraries and chemical education. *Science* 1927;66:385.

2. Information IfS. 2006 Science Citation Index. *Journal Citation Reports*. Philadelphia: Institute for Scientific Information; 2006.

3. Andersen J, Belmont J, Cho CT. Journal impact factor in the era of expanding literature. *J Microbiol Immunol Infect* 2006;39:436–43.

4. Bradford SC. Sources of Information on Specific Subjects. *Engineering: An Illustrated Weekly Journal* 1934;137:85–86.

5. Hirsch JE. An index to quantify an individual's scientific research output. Proc *Natl Acad Sci U S A* 2005;102: 16569–16572.

6. Sims JL, McGhee CNJ. Citation analysis and journal impact factors in ophthalmology and vision science journals. *Clin Experiment Ophthalmol* 2003;31:14–22.

7. Callaham M, Weber E, Wears R. Citation characteristics of research published in Emergency Medicine versus other scientific journals. *Ann Emerg Med* 2001;38:513–517.

8. Ioannidis JP. Concentration of the most-cited papers in the scientific literature: analysis of journal ecosystems. *PLoS ONE* 2006;1:e5.

9. Cronin B, Meho L. Using the h-index to rank influential information scientists. *Journal of the American Society for Information Science and Technology* 2006;27:1275–1278.

10. van Raan AF. Sleeping Beauties in Science. *Scientometrics* 2004;59:467–472.

11. Bhattacharjee Y. Data Point. Impact Factor. *Science* 2005;309:1181.

12. Ball P. Index aims for fair ranking of scientists. *Nature* 2005;436:900.

13. Monastersky R. The Number That's Devouring Science. *The Chronicle of Higher Education* 2005 October 14.

14. Kelly CD, Jennions MD. H-index: age and sex make it unreliable. *Nature* 2007;449:403.

15. Meho L. The rise and rise of citation analysis. *Physics World* 2007;29:32–36.

16. Redner S. Citation Statistics from 110 Years of Physical Review. *Phys Today* 2005;58:49–54.

17. Christenson JA, Sigelman L. Accrediting knowledge: Journal stature and citation impact in social science. *Soc Sci Q* 1985;66:964–975.

18. Callaham M, Wears RL, Weber E. Journal prestige, publication bias, and other characteristics associated with citation of published studies in peer-reviewed journals. *JAMA* 2002;287: 2847–2850.

19. Barendse W. The strike rate index: a new index for journal quality based on journal size and the h-index of citations. *Biomed Digit Libr* 2007;4:3.

20. Rey-Rocha J, Martin-Sempere MJ, Martinez-Frias J, Lopez-Vera F. Some misuses of Journal Impact Factor in research evaluation. *Cortex* 2001;37:595–597.

21. Garfield E. The history and meaning of the journal impact factor. *JAMA* 2006;295:90–93.