METHODS: Using the database of Journal Citation Reports the 40 highest impact factor radiology journals were chosen. From these journals the 100 most cited interventional radiology papers were chosen and analysed.

RESULTS: The top paper received 2497 citations and the 100$^{th}$ paper 200 citations. The average number of citations was 320. Dates of publication ranged from 1953-2005. Most papers originated in the United States ($n=67$) followed by Italy ($n=20$) and France ($n=10$). Harvard University ($n=18$) and Osped Civile ($n=11$) were the most prolific institutions. Ten journals produced all of the top 100 papers with "Radiology" and "AJR" making up the majority. SN Goldberg and T Livraghi were the most prolific authors. Nearly two thirds of the papers ($n=61$) were published after 1990.

CONCLUSION: This analysis identifies many of the landmark interventional radiology papers and provides a fascinating insight into the changing discourse within the field. It also identifies topics, authors and institutions which have impacted greatly on the specialty.

Key words: Interventional radiology; Citation classic; Radiology; Citation; Citation analysis; Classic papers

© The Author(s) 2015. Published by Baishideng Publishing Group Inc. All rights reserved.

Core tip: Interventional radiology is a young and rapidly evolving specialty. This study defined and analysed the 100 most cited interventional radiology papers identifying much of the landmark interventional radiology research and providing a fascinating insight into the changing discourse within the field. It also identified the topics, authors and institutions which have impacted greatly on the specialty.
INTRODUCTION
A citation is the intellectual acknowledgement of a published or unpublished source in order to substantiate fact. Whilst the intellectual acknowledgement that one paper gives to another is known as a reference, the acknowledgement that one paper receives from another is known as a citation[1]. The field of citation analysis uses the citation rate of a paper as a surrogate marker of a paper’s recognition and impact within its biomedical field, the more citations that a paper receives, the greater that paper’s impact and recognition[2]. The most cited papers within a specialty can be defined as that specialty’s classic papers, with the 100 most cited papers representing the “best of” of that specialty[3]. Recent studies have analysed the highly cited papers in other specialties and produced “best of” lists of the top 100 classic papers[4-6]. From these studies it is clearly evident that highly cited works in a particular field often represent the landmark papers, seminal advances and technical innovations of that specialty. However there are also limitations in using the citation rate of a paper alone to define that paper’s scientific quality and impact. Whether a paper is cited by another author can depend upon various factors and biases some of which can lead to citations which are not wholly appropriate[7]. Despite these limitations, citation analysis remains a well recognised method of objectively identifying classic papers within a specialty.

The purpose of this study is to identify and analyse the 100 most cited papers within the specialty of interventional radiology - the 100 citation classics. This will allow the topics, authors and institutions which have impacted greatly on this rapidly evolving specialty to be reviewed whilst also critically evaluating the strengths and weaknesses of citation analysis as a method of defining a paper’s quality and impact within its specialty.

MATERIALS AND METHODS
Using the database of Journal Citation Reports, 40 radiology journals were chosen for analysis from the subcategory of “Radiology, Nuclear Medicine and Medical Imaging” (Table 1). The subcategory of “Radiology, Nuclear Medicine and Medical Imaging” covers a broad range of journals and therefore excluded from our selection were those journals dealing purely with nuclear medicine, those dealing with basic imaging science and physics as well as radiotherapy journals.

These 40 journals were then analysed using the Science Citation Index of the Institute of Scientific Information and the 100 most cited interventional radiology papers were chosen. Each of the papers was categorised by body system involved, interventional procedure performed, country of origin, institution of origin, author of paper and year of publication.

Statistical analysis
No biostatistics were used in this study.

RESULTS
Table 2 lists the 100 most cited interventional radiology papers in descending order according to the number of citations received.

Table 3 below summarises some of the analysed characteristics of the 100 most cited papers in interventional radiology.

The top paper received 2497 citations whilst the 100th paper in the list was cited 200 times. Seven papers received 500 citations or more with the average number of citations being 320.

The oldest paper is Seldinger’s 1953 seminal work on the technique of percutaneous arteriography and this paper also occupies first place in this top 100 list. The most recent paper is published in 2005 by Goldberg et al[8]. This is one of Goldberg’s six 1st name papers in this list whilst he is also a named author on another nine papers. Nine persons were named authors on four or more papers.

The papers were published between 1953 and 2005. Two thirds of the papers (n = 61) were published after 1990 with just 5 originating before 1970.

The 100 papers originated from just seven countries. The vast majority of the papers (n = 67) originated in the United States followed by Italy (n = 20) and France (n = 10).

Eleven institutions produced more than two publications in the top 100. Harvard University (United States) tops the list with 18 publications followed by Osped Civile (Italy) with 11 publications. Several multicentre studies spanned more than one country or institution. For papers published from these studies all countries or institutions involved have been credited.

The most cited papers in interventional radiology were published in 10 specialist radiology journals with nearly two thirds published in Radiology (n = 62) and a fifth (n = 20) published in the American Journal of Roentgenology. No papers originated from the high impact factor general medical journals analysed.

The interventional technique of radiofrequency ablation is well represented when the papers are broken down by procedure, with 29 entries in the top 100. This is followed by angiography and embolization with 14 papers a piece and subsequently image guided biopsy with 11 papers. The hepatobiliary system is the most studied body system with 30 papers focusing upon it and this is followed by 20 papers focusing upon the vascular system. Although categorising these papers
by body system studied or interventional procedure performed gives a useful overall picture of the studies included in this list, it is obvious that the two categories are interlinked. Closer inspection reveals 10 papers in the top 20, and 26 papers in the top 100 focusing upon liver metastases. Most look specifically at ablation or embolization of these metastases and this goes some way to explaining why the hepatobiliary system and radiofrequency ablation are so highly represented.

**DISCUSSION**

This list of the 100 citation classic papers of interventional radiology provides a fascinating insight into the history and development of the specialty over the last 60 years. It identifies many of the topics, authors and institutions which have contributed most heavily to the field and includes many landmark papers.

Many authors featuring prominently here might be considered to be the forerunners in the development interventional radiology as a specialty. The impact of authors such as Seldinger, Judkins, Gianturco, vanSonnenburg and Mueller cannot be underestimated and techniques and equipment bear their names to this day.

Despite the prominence of these authors, it must be noted that inclusion in this list of the 100 citation classics of interventional radiology does not necessarily mean that the cited authors contributed to the development of a particular technique. Goodwin’s paper which is in 89th place in this top 100 list is a good example. This paper dealt with preliminary results of uterine artery embolization, but it was not him who introduced this technique, but Ravina et al.1995. It is also surprising that important developments such as the pioneering work of Serbinenko and Djindjian in the development of intracerebral embolization, Portsmann’s occlusion technique of the Ductus arteriosus, and Volodos work in the development of the first aortic endograft are not covered by this citation analysis. This is likely due to the fact that their papers were published outside of the specialist radiology journals and therefore are not captured by this study. This flaw is covered later in the discussion section.

It is interesting to see the changing topics covered by papers over the last 60 years which mirror the history of interventional radiology. The very early papers, representing the birth of the specialty, focus almost solely on cardiac and vascular interventional techniques. As time progresses the variety of interventions rises to include neurological and musculoskeletal procedures and there is also increasing focus on techniques dealing with malignant metastatic disease. This represents interventional radiology branching out into oncolgy where it now plays an important role within the multidisciplinary structure. Some other techniques, such as coronary angiography, began as the role of the interventional radiologist but have now been subsumed by other specialties and consequently recent papers concerning these techniques are now likely to be published outside of radiology journals.

Just under two thirds of the papers were published after 1990 which is surprising as it is natural to assume that older papers will accumulate more citations. However this is only true to a certain degree. It will generally take 1-2 years after publication for a paper to be cited. This is followed by an increase in citation rate up to a maximum point which is usually between 5 and 10 years after publication. After this maximum point the rate of citation gradually starts to decline[11]. This has two main implications; firstly older papers do not continue to accumulate citations in proportion to their age, this is why the top of this list is not solely made up...
by the oldest papers; secondly very recently published papers will not be included in this list as, despite their scientific originality and impact, they have not had time to accumulate sufficient citations. Whilst it is reassuring that older doesn’t necessarily mean more cited, the fact that recently published papers are inherently excluded from citation analysis demonstrates one of its major flaws. Another limitation of citation analysis is the process of “obliteration by incorporation”[10]. This describes the phenomenon where information from landmark papers becomes incorporated and absorbed into current knowledge and thus these papers are not explicitly cited. For this reason it has been noted that many true “classic papers” and seminal works in a particular field are not found in the most cited list itself but rather in the reference lists of the most cited papers. 

This list is dominated by the United States with 67 papers in the top 100. This correlates with similar studies in other fields such as dermatology[11] (United States = 75%), general surgery[12] (United States = 78%) and orthopaedics[5] (United States = 77%). It reflects the huge influence of the United States on medical research and the massive scientific output of the country. It has also been noted that there is a tendency for American authors to preferentially cite other papers from the United States and this is likely to increase their dominance[7-13]. In fact interventional radiology appears to be less dominated by the United States than other specialties with significant contributions from the European power houses of Italy (n = 20) and France (n = 10).

All papers were published in only 10 journals. With 60 publications in the top 100 Radiology is by far the most prolific publisher followed by the American Journal of Roentgenology (AJR) with 20 publications. Most papers are published in general radiology journals with only a handful (n = 6) published in the two specific interventional journals in the list – Cardiovascular and Interventional Radiology and the Journal of Vascular and Interventional Radiology. However this is likely to reflect relatively recent emergence of specialised interventional radiology journals (1977 and 1990 respectively) when compared to the traditional pre eminent radiology journals such as Radiology and the AJR.

One flaw of this study is that, due to technological limitations of the database of Journal Citation Reports, the search for papers was limited to specialist radiology journals. This meant that papers published in non-radiology journals would not be included in this “top 100 list”. This is particularly relevant when considering older papers which would have been more likely to have been published in non specialist radiology journals.

Citation bias towards authors of the same nationality has already been discussed. Other limitations of this study can be linked to the inherent weakness of using citation rate alone in measuring a paper’s strength. Instead of using a citation to give credit to those who have significantly influenced their work, some authors use citations to support their own results or to persuade the reader towards a particular conclusion, a process known as incomplete citing[14]. Many other biases are recognised which might influence the citation of papers. These include self or in house citation bias, bias towards citing review articles over original research and English language bias.

It is clear from discussion of the flaws and limitations of this study, as well as the biases inherent in the field of citation analysis, that the number of citations that a paper receives should not be used alone as a measure of its scientific quality[1,15]. However it is also clear that the citation rate of a paper is one of many useful tools in measuring the recognition that a paper has received and therefore the impact that a paper has had on its specialty[16]. Whilst this list of citation classics in interventional radiology should not be considered the definitive “top 100” of this specialty, it does reveal many landmark papers and identifies many of the topics, authors and institutions which have dominated the specialty over the last sixty years.

This is the first study to use citation analysis in an attempt to identify the research papers which have had the greatest impact on the specialty of interventional radiology. Although citation analysis does have limitations, many of the seminal papers of interventional radiology and pioneers of the field are included in this list of “100 citation classics”.

**COMMENTS**

**Background**

The value of a scientific paper may be defined by its impact on the biomedical...
field in which it is published. Papers which impact greatly on their field may achieve the status of a “classic paper”. This may be defined using the concept of a citation classic - the number of times a paper is cited reflects its impact and relevance. The aim of this study was to define the top 100 citation classics of the rapidly evolving specialty of interventional radiology and in the process identify the topics, authors and institutions that have impacted greatly on this rapidly evolving specialty.

**Research frontiers**

Interventional radiology is a young and rapidly evolving specialty. For the last 40 years interventional radiologists have been at the vanguard of innovation with the development of numerous minimally invasive procedures which have revolutionised patient management in multiple areas. The specialty has rapidly grown and evolved from its origins with Seldinger’s refinement of arterial cannulisation and Dodder’s development of angioplasty and the catheter delivered stents. Embolization of arterial haemorrhage in trauma, catheter directed thrombolysis and coiling of aneurysms are now the gold standard treatments in their respective areas. Recent advances in the specialty include drug eluting balloons and stents in peripheral vascular disease, microwave tumor ablation for liver, kidney and lung tumors and transarterial catheter directed chemotherapy or radionuclide therapy in primary liver tumors and metastases. This study has used citation analysis to define many of the seminal papers within interventional radiology.

**Innovations and breakthroughs**

This is the first study which has used citation analysis in an attempt to define the most innovative and significant papers in interventional radiology and those which have had the most significant impact on this field. Although citation analysis does have limitations, many of the seminal papers of interventional radiology are included in this list of “100 citation classics”.

**Applications**

This study has used citation analysis to identify the 100 classic papers of interventional radiology. These papers included many of the seminal works in this field by many of the pioneers of the specialty providing a fascinating discourse on the evolution and development of interventional radiology.

**Terminology**

IR: Interventional radiology.

**Peer-review**

Nice paper with good analyses.

**REFERENCES**

1. Marx WSH, Wanitschek M. Citation analysis using online databases: feasibilities and shortcomings. *Scientometrics* 2001; **52**: 59-82 [DOI: 10.1023/A: 1012798911792]
2. Seglen PO. Citation frequency and journal impact: valid indicators of scientific quality? *J Intern Med* 1991; **229**: 109-111 [PMID: 199734]
3. Hall GM. BJA citation classics 1945-1992. *Br J Anaesth* 1998; **80**: 4-6 [PMID: 9505768]
4. Heldwein FL, Rhoden EL, Morgentaler A. Classics of urology: a half century history of the most frequently cited articles (1955-2009). *Urology* 2010; **75**: 1261-1268 [PMID: 19962736]
5. Kelly JC, Glynn RW, O’Brian DE, Felle P, McCabe JP. The 100 classic papers of orthopaedic surgery: a bibliometric analysis. *J Bone Joint Surg Br* 2010; **92**: 1338-1343 [PMID: 20884968]
6. Li Z, Wu FX, Yang LQ, Sun YM, Lu ZJ, Yu WF. Citation classics in main pain research journals. *J Anesth* 2012; **26**: 85-93 [PMID: 22008797]
7. Seglen PO. Citation rates and journal impact factors are not suitable for evaluation of research. *Acta Orthop Scand* 1998; **69**: 224-229 [PMID: 9703939]
8. Goldberg SN, Grassi CJ, Cardella JF, Charboneau JW, Dodd GD, Dupuy DE, Gervais D, Gillams AR, Kane RA, Lee FT, Livraghi T, McGahan J, Phillips DA, Rhim H, Silverman SG. Image-guided tumor ablation: standardization of terminology and reporting criteria. *J Vasc Interv Radiol* 2005; **16**: 765-778 [PMID: 15947040]
9. Ravina JH, Merland JJ, Ciraru-Vigneron N, Bouret JM, Herbetuea D, Houdart E, Aymard A. [Arterial embolization: standardization of terminology and reporting criteria]. *Presse Med* 1995; **24**: 1754 [PMID: 8545421]
10. Picknett T, Davis K. The 100 most-cited articles from JMB. *J Mol Biol* 1999; **293**: 171-176 [PMID: 10529345]
11. Dubin D, Häfner AW, Arndt KA. Citation classics in clinical dermatologic journals. Citation analysis, biomedical journals, and landmark articles, 1945-1990. *Arch Dermatol* 1993; **129**: 1121-1129 [PMID: 8363395]
12. Paladugu R, Schein M, Gardezi S, Wise L. One hundred citation classics in general surgical journals. *World J Surg* 2002; **26**: 1099-1105 [PMID: 12209239]
13. Paris G, De Leo G, Menozzi P, Gatto M. Region-based citation bias in science. *Nature* 1998; **396**: 210 [PMID: 10744503]
14. Cole S. Citations and the evaluation of individual scientists. *Trends Biochem Sci* 1989; **14**: 9-13 [DOI: 10.1016/0968-0004(89)90078-9]
15. Braun T. The reliability of total citation rankings. *J Chem Inf Comput Sci* 2003; **43**: 45-46 [PMID: 12546536]
16. Dumont JE. The bias of citations. *Trends Biochem Sci* 1989; **14**: 327-328 [PMID: 2799004]

P- Reviewer: Lakhdir F, Pinto A, Sener RN  S- Editor: Ji FF L- Editor: A  E- Editor: Jiao XK
