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"Sleeping beauty" and her restless sleep: Charles Dotter and the birth of interventional radiology

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Abstract Charles Dotter has been described as the father of interventional radiology, a medical specialty born at the interface between radiology and cardiology. Before 1979, it was relatively difficult to find citations to a landmark paper that Dotter had first published in 1964—qualifying this study, from a scientometric perspective, as a sleeping beauty. Sleeping beauties are texts that suffer due to delayed recognition. The present paper explores the Dotter case study's bibliometric characteristics while analyzing the Van Raan criteria's usefulness for defining sleeping beauties in science. Citation network analysis using CitNetExplorer has proven helpful in identifying the "Prince" in this fairy tale. The duration of sleep is viewed here as a period of restlessness marked by science and social controversies that are often documented in publication databases using a wide range of bibliographic references. Hence the idea of introducing alongside this sleeping beauty construct the idea of "restless sleep". These observations should open new avenues in identifying sleeping beauties while nurturing scientific controversy studies revolving around the use of scientometric approaches.

Keywords Sleeping beauty · Co-referencing · Network · History of science · Sociology of science · Innovation

Introduction

Charles Dotter, father of interventional radiology

Charles Theodore Dotter (1920–1985) was a pioneering US vascular radiologist credited with the development of interventional radiology (IR) based on the invention of angioplasty and catheter-delivered stents. On January 16, 1964, Dotter percutaneously dilated a

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narrow and localized stenosis in the superficial femoral artery of an 82-year-old woman who was suffering from painful leg ischemia and gangrene but refused amputation. This led to his invention of percutaneous transluminal angioplasty (PTA), with Dotter and his trainee (Dr. Melvin P. Judkins) describing their technique in a landmark paper published in the medical journal "Circulation" (Dotter and Judkins 1964).

Today, Charles Dotter is described as the father of IR, a sub-specialty of radiology that uses minimally invasive image-guided procedures to diagnose and treat diseases in all body organs. The Oregon Health Sciences University, where Dotter spent his entire medical career, boasts the Dotter Interventional Institute. The Society of Interventional Radiology also hosts an annual "Dr. C.T. Dotter lecture" to honor his extraordinary contributions to IR (Rösch et al. 2003).

The initial relationship between surgeons and radiologists can only be described as adversarial, however. Dotter's technique was initially viewed as a paradigmatic revolution that invited radiologists to transgress medical specialty boundaries. In Dotter's own words, "The angiographic catheter can be more than a tool for passive means for diagnostic observations; used with imagination, it can become an important surgical instrument" (Payne 2001). The end result is that over the years, since Dotter first came up with his then innovation, it has had a major impact on a number of medical professions and translated into a new division of work in many care organizations.

A scientometric analysis of IR reveals that through 1979 very few studies contained references to Dotter's seminal article. This is particularly significant given that as far back as 1956, the Nobel Prize had already been awarded to Dr. Forssman for the use of cardiac catheterization as a diagnostic tool (Mehta and Khan 2002). The combined effect is that in scientometric terms at least, Dotter's main publication qualifies as a sleeping beauty.

Sleeping beauties in scientific literature

Delayed recognition has been a well-described phenomenon in scientometrics ever since the pioneering observations of Eugene Garfield (1980). Associated analyses since this time have referred to constructs such as premature discoveries, resisted discoveries, delayed recognition or sleeping beauties (Burrell 2005; Braun et al. 2010). Van Raan (2004) defined sleeping beauties as articles that go unnoticed ("sleep") for long periods of time before suddenly receiving a large number of citations in a "Prince" (i.e. another article). Four variables are said to be at work in such processes:

- the *depth of sleep,* with less than one citation/year qualifying as deep sleep and between one and two citations/year qualifying as medium deep sleep;
- the *length of the sleep,* often lasting between 5 and 10 years
- the *intensity of the awakening,* amounting for instance to 15 citations/year over a period of 4 years.

Some publications have experienced an erratic trajectory, characterized by an initial period where the paper enjoyed a relatively large number of citations were before subsequently quieting down (i.e. so-called "flashes in the pan"). Other studies have come to be equated with "spindles", referring to delayed recognition situations where sleeping beauties seem to be injured, falling into sleep before being awakened by Princes (Van Dalen and Henkens 2005). The sum total of the cases evoked in this corpus is generally referred as "all-element-sleeping beauties" (Li and Ye 2012; Li 2014).

Note the recent (2015) introduction by Ke et al. of a parametric-free measure called "beauty coefficient". This quantifies the extent to which a paper comprises a sleeping beauty while also offering a simple method for identifying its awakening time.

Aim

The present work studies the bibliometric characteristics of the Dotter case study; questions the definition of sleeping beauties; explores the dissemination of Dotter's concept during its sleeping period; documents its awakening phase; and identifies the relevant Prince using citation network analysis.

Methods

A literature search on Dotter's scientific outputs was conducted using both the PubMed and Scopus databases. The ensuing corpus ($n = 219$ publications) was then exported to build an in-house database that uses Intellixir® software to parse data and disambiguate names. Intellixir® software was further used for descriptive statistics and network analysis. Citations of Dotter's publications were extracted from the Web of Science database through 31 December 2013 ($n = 7866$ citations). In order to identify the Prince paper, CitNetExplorer® software was used to draw a citations network pattern for the landmark paper over a given, during a certain period of time, (Van Eck and Waltman 2014). "Beauty coefficient "and awakening year were measured according to Ke et al. (2015). Complementary queries were run using "Dotter" or "Percutaneous" Translumnial Angioplasty" (PTA) as keywords in different search fields (title, abstract or keywords) for different types of documents (editorial, letter or note). The aim here was to explore literature of sleeping periods at a deeper level of analysis. Cocitation and RPYS "Reference Publication Year Spectroscopy" (RPYS) analysis were conducted to identify the historical roots of interventional radiology (Marx 2014; Marx et al. 2014).

Findings

Charles Dotter's scientific production

In January 1948 and while still in his residency, Charles Dotter published his first paper in what was then, a new field of medical research, to wit: angiocardiography. The article appeared in: the New England Journal of Medicine, a leading medical journal, and was co-authored by his mentor, Israel Steinberg (Dotter and Steinberg 1948). During the 33 years that he worked at Oregon Health and Science University (OHSU), Dotter produced a total of 219 publications. About one-quarter of this output was publishedd in top-quality journals. These tended to split between two main medical disciplines: radiology; and cardiology (Table 1).

Intellixir® software was used to draw co-publications graph exploring Dotter's many academic scientific collaborations. In total, Dotter co-published with 140 different authors (Gorry and Ragouet 2015). His main collaborators were his fellows, Josef Rösch, Frederick Keller and Melvin Judkins who stayed at OHSU (340, 215 and 68 co-publications respectively; Fig. 1; Table 2).

Table 1 Journal distribution of C.T. Dotter's scientific production

Source title	Publications number	Journal impact factor
Radiology	46	5561
Am. J. Roentgenol. Radium Ther. Nucl. Med.	27	na
Circulation	19	12,755
New England J. Medicine	8	52,589
Am. J. Roetgenol.	6	247

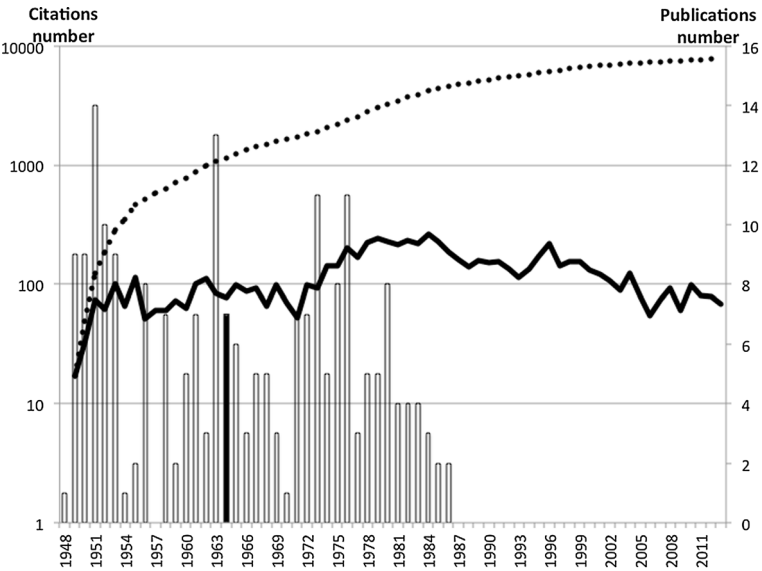

Fig. 1 Dotter's publications and citations. *White box* number of publications by Dotter/year; *black box* publication year of Dotter's landmark paper; *black line* number of citations for all publications by Dotter/year; *dotted line* cumulative citations for all publications by Dotter/year

Table 2 C.T. Dotter main scientific collaborators

Author	Lab./Dpt.	Institution	Publi.
Rösch, Johannes	Center of Cardiac Surgery	Friedrich Alexander University, (DE)	340
Keller, Frederick	Dotter Interventional Inst.	Oregon Health and Sciences Medical Center, (USA)	215
Steinberg, Israel	Dpt. of Surgery, Medicine and Radiology	New Loma Linda University, (USA)	174
Judkins, Melvin	Coordinating Center for Collaborative studies in Coronary Artery Surgery	New York Hospital – Cornell University, (USA)	68
Bilbao, Marcia	Dpt. of Radiology	University of Oregon Medical School, (USA)	22

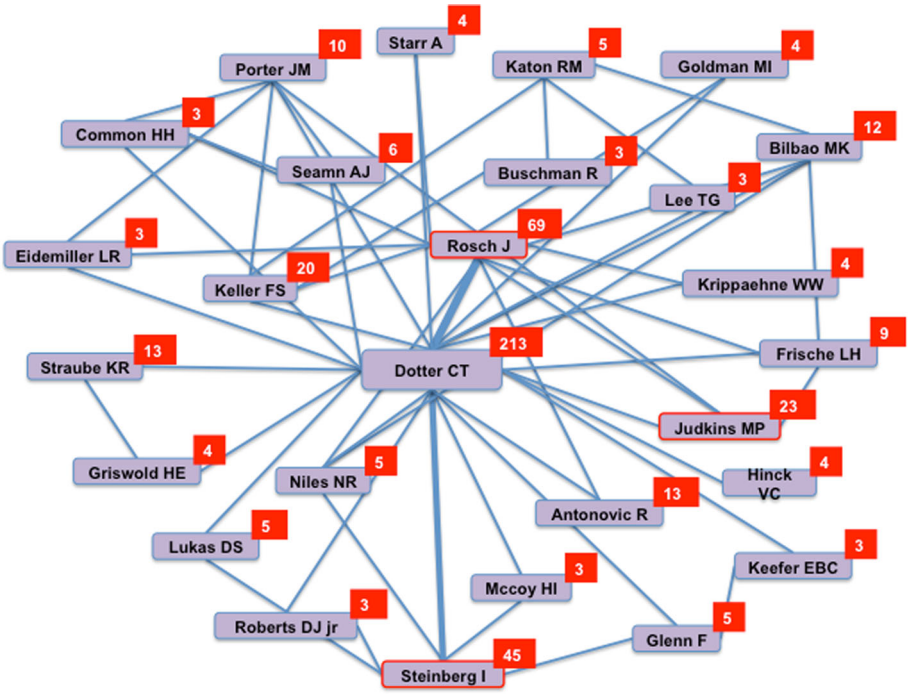

Fig. 2 C.T. Dotter co-publications network. Network filtered for a minimum of three publications by author plus a minimum of two co-publications with C.T. Dotter. *Red box* number of publication by author

Dotter published his last paper in 1981, 4 years before his death. By the end of his career, his scientific output had totaled more than 4500 citations—a number that reached 7866 by yearend 2013 (Fig. 2). Dotter was very successful in disseminating his findings and being recognized by his academic peers, with a number of yearly citations ranging from 52 to 251. It is noteworthy that even before Dotter's landmark paper was published in 1964, he was already recognized as a valuable and active researcher, with his 100 publications by that time already enjoying 1068 citations.

Whether Dotter's landmark paper qualifies as a sleeping beauty

Dotter's landmark paper from 1964 (Figs. 2, 3; black box) has averaged 19.31 citations per annum, amounting to 1275 citations at present. During its first 14 years, however, the paper was only 51 times (Fig. 3; full line). This suddenly rose to 29 citations in 1979, with the paper averaging 50 citations per annum since then. Prima facie, this exemplifies a sleeping beauty, albeit one that does not fit exactly into Van Raan's definition. With its 3.64 citations/year, the paper qualifies as a "light sleep"; it slept for 14 years instead of five to ten; and the number of citations it averaged over the 4 years following its awakening (57.75 per annum) was largely superior to the numbers specified by Van Raan (minimum of 15 citations/year for a 4-year period).

The "beauty coefficient" B for Dotter's landmark paper was determined as per the equation contained in Ke et al. (2015), with the paper's citations history being compared to a referenced line determined by its publication year, the maximum number of citations

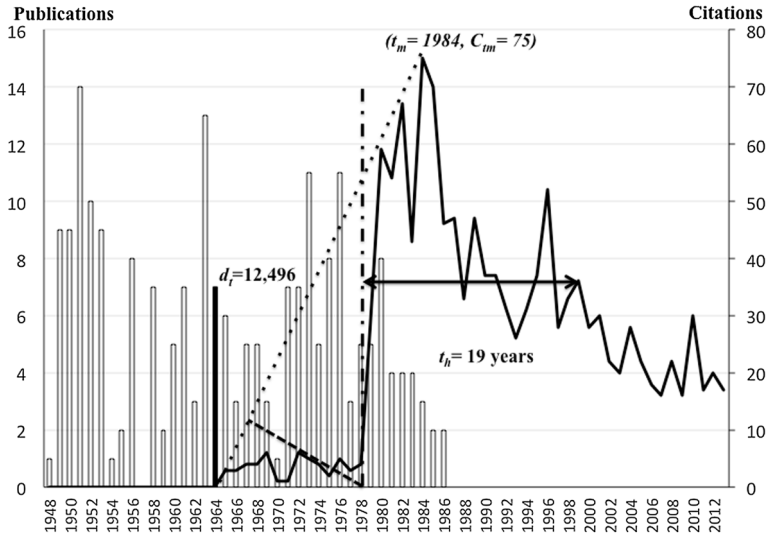

Fig. 3 Citations *curve* of Dotter's main paper. *White box* number of publication by Dotter/year; *black line* number of citations for Dotter's landmark paper/year; *black dotted line* reference line l_t; *dashed line* distance d_t maximizing the awakening time; *vertical line* awakening time; *black arrow* half-life citations time

received in 1 year ($C_{tm} = 75$), and the year when this maximum was achieved ($tm = 1984$): $B = 409.5$. The end result is that Dotter's landmark paper's beauty coefficient is in the range of B values calculated for the papers that Ke et al. ranked between 10 and 24 in their dataset (2015). The awakening time d_t—the distance between point [t, Ct] and reference line l_t—was calculated according to this definition. The paper's maximum $d_t = 12.496$ was reached in 1978 (Ke et al. 2015), following which it experienced a decreasing citations pattern, as witnessed by a number of yearly citations C_{tm} that hit a maximum in 1984 followed by a yearly count that decreased below $C_{tm}/2$ by the year 2013 ($C_{2013} = 17$). This gave the paper a half-life $t_h = 19$ years. Note, however, that the paper's yearly citation rate neither decreased exponentially nor as quickly as Ke et al. (2015) predicted for this category of sleeping beauties (Fig. 3).

Because Dotter's new technique was so controversial, it is worth a further exploration of literature using complementary queries tracing the scientific debate in question. During its delayed recognition period, the Dotter paper was frequently referred to ($n = 76$) in medical literature (Fig. 4: dotted line)—as was his technique (-percutaneous transluminal angioplasty, data not shown). This often involved-journal editorials or letters, attesting to the controversies that raged during the paper's sleeping period.

Andreas Gruntzig, the "Prince"

In line with the fairy tale, a sleeping beauty must be awoken by a Prince. In this present context, the Prince paper is likely to be found among the first highly cited citing articles. Hence the use of CitNetExplorer software to identify this Prince by visualizing the pattern of citations over the period of time in question (Van Eck and Waltman 2014). The first to refer to Dotter's previous work was a German cardiologist working in Switzerland, Andreas Grüntzig (also spelled Gruntzig or Gruentzig), the inventor of coronary balloon

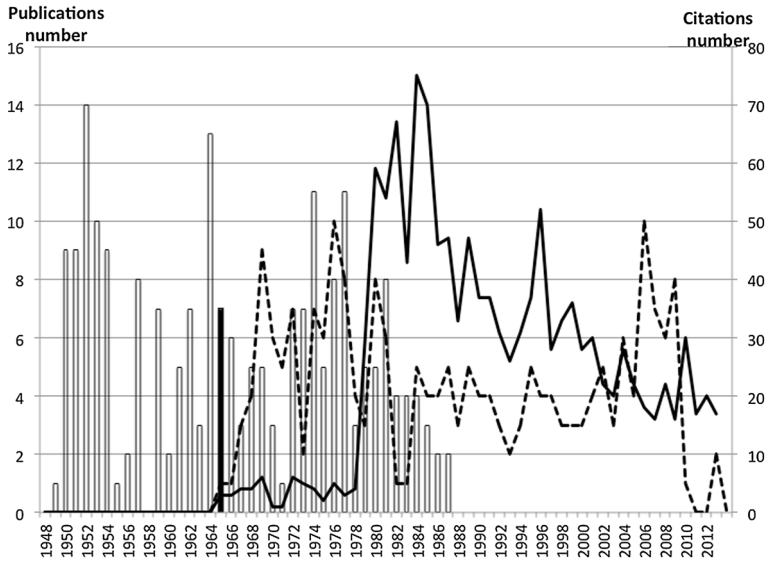

Fig. 4 Citations of Dotter's main paper and appearance of Dotter's name in literature. *White box* number of publication by Dotter/year; *black box* publication year of Dotter's landmark paper; *black line* number of citations for Dotter's landmark paper/year; *dotted line* number of documents, other than articles, citing Dotter in title/abstract/keyword fields

angioplasty (Fig. 5). This initial citation was in a German language paper published in 1974, in the Deutsche Medizinische Wochenschrift, (Grüntzig and Hopff 1974). The citation had very little resonance, however, that is, until his work was published in the well-established New England Journal of Medicine (Grüntzig et al. 1979). Note that his paper received the highest number of citations out of the 29 documents published in the awakening year, becoming the highest ever cited paper citing Dotter's main paper (Table 3).

Following this breakthrough, Grüntzig's paper—with its citation of Dotter's pioneering work—quickly came to be cited in medical literature with a peak coinciding with the awakening of citations referring to Dotter's landmark paper itself (Fig. 6). The temporal co-linearity between Dotter's main paper citation curve and Gruntzig's paper curve was very strong (c.f. Fig. 6: red line and green line; $r^2 = 0.689$).

Gruntzig's work was essential in Dotter's delayed recognition work, with 3 publications ranking 1st, 5th and 9th among the top 10 publications citing Dotter's main paper—amounting to a total 1971 citations (Table 3). Gruntzig's annual publications citing Dotter's main paper peaked in 1984 (Fig. 6: blue line).

Gruntzig died young, with new key opinion leaders replacing him in the following years. A variety of authors wrote the remaining publications citing Dotter's main paper (Table 3) in the time span between the awakening year and 1984, which saw the maximum number of citations. All of these publications presented a normal pattern, peaking at their maximum between 2 and 6 years post-publication, followed by a rapid decline in yearly citations (data not shown).

It is important to note that none of the main collaborators identified via network analysis (Fig. 2) were influential in the delayed recognition of Dotter's main paper.

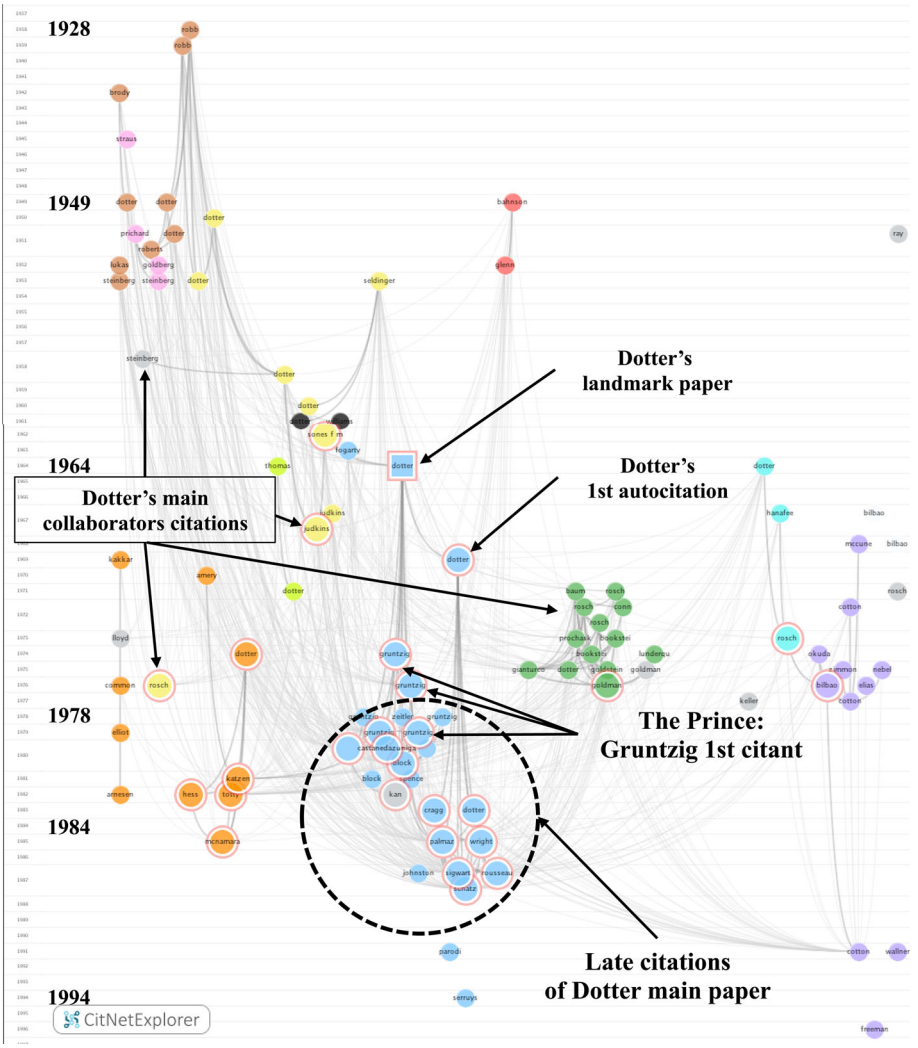

Fig. 5 Citation network of C.T. Dotter landmark paper over particular period of time

Finally, Dotter's self-citation in another paper in 1969 (i.e. during his first seminal work's sleeping period) was not sufficient to generate citations of his publication from the year before. This did not occur until the 1980s (Fig. 5).

Significance in the percutaneous trans luminal angioplasty medical research area

The sudden awakening of Dotter's main paper can be attributed to the sudden discovery of his pioneering work by a whole medical community of cardiologists. Measuring the dissemination of Dotter and Gruntzig writings involved searching for publications using percutaneous transluminal angioplasty as keywords and compiling the rate of yearly

Table 3 Top publications citing Dotter's main paper

Rank	Author	Source	Year	Times cited
1	Gruntzig AR et al.	New England J. of Med.	1979	1105
2	Schwartz SM et al.	Circulation Research	1995	769
3	Schwartz SM et al.	Circulation	1991	540
4	Serruys PW et al.	New England J. of Med.	1991	504
5	Gruntzig AR et al.	Deutsche Med. Wochenschrift	1974	481
6	Dotter CT	Investigative Radiolology	1969	425
7	Kan et al.	New England J. of Med.	1982	416
8	Sos TA et al.	New England J. of Med.	1983	393
9	Kent KM, … Gruntzig AR et al.	Am. J. of Cardiology	1982	380
10	Castanedazuniga WR et al.	Radiology	1980	371

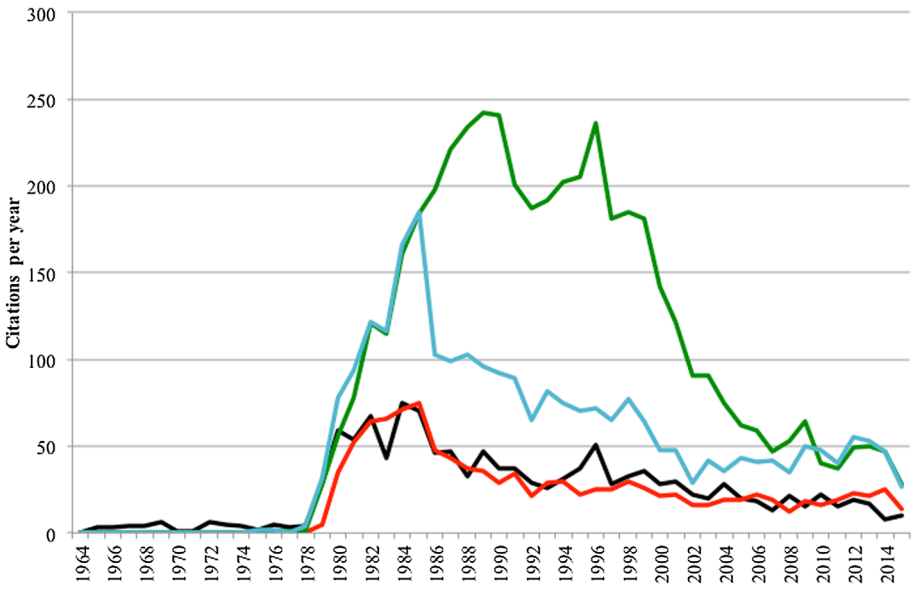

Fig. 6 Citations history of Dotter's main paper, Grüntzig's papers and PTA publications. *Black line* number of citations for Dotter's landmark paper/year; *red line* number of citations for the "Prince" (i.e. Grüntzig's NEJM paper); *blue line* number of citations for the group of Grüntzig's most cited publications of Grüntzig; *green line* number of citations for publications on percutaneous transluminal angioplasty (PTA)

publications. It is worth nothing that Gruntzig's citations curves matched the annual rate of PTA publications (Fig. 6).

Changes in the contextual importance of Dotter's 1964 paper can be further witnessed in the frequency of keywords appearing in the titles of citing papers before and after 1979 (Fig. 7a, b), with the concept of "angioplasty" becoming the main difference at this point.

Lastly (and in line with the so-called RPYS "Reference Publication Year Spectroscopy" method; Marx 2014; Marx et al. 2014), analysis was conducted of the

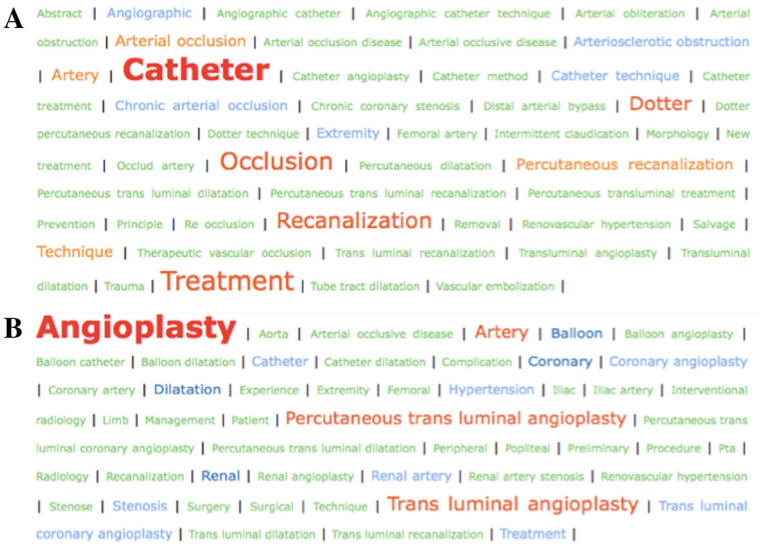

Fig. 7 Cloud of keywords appearing in main papers citing Dotter. Most frequent keywords appearing in title of publications citing Dotter's main paper, respectively before (**a**), and after (**b**) awakening year = 1978

publication years of the papers cited by PTA research papers. Figure 8 shows the reference number distribution across the different publication year. The peak was 1979 (Fig. 8), i.e. the same time as the awakening of Dotter's main paper.

Discussion

Despite the fact that Charles Dotter is recognized today as the father of interventional radiology, his landmark paper suffered from delayed recognition. Nevertheless, it still does not fulfill Van Raan's sleeping beauty publication criteria, whose accuracy has been widely discussed in literature with the introduction of definitions for all-element-sleeping beauties. Nor is Dotter's landmark paper characterized by an initial "flash in the pan" period before it fell asleep, meaning that it cannot be assimilated with such categorizations either (Li and Ye 2012; Li 2014). One suggestion has been to re-calculate citations in whatever way facilitates the paper being classified as a sleeping beauty. However, the new criteria this involves may not be applicable to interdisciplinary productions such as Dotter's innovation, which—it should be remembered—was born at the interface between cardiology and radiology fields. Hence the idea of introducing a modified category for sleeping beauty publications that do not fit Van Raan's criteria but display roughly the same characteristics of delayed recognition. The likelihood here is that mathematical model identifying sleeping beauties' bibliometric characteristics should start to account for the endogenous relationship between awakening intensity and the depth/length of the sleep. Ke et al. recently introduced a parametric-free method that calculates this beauty coefficient and correctly identifies Dotter's sleeping beauty paper. It remains that the level of beauty distinguishing different publications in different disciplines needs to be documented, as does the citation pattern at different points in the literature cycle. The present case study should contribute to this effort.

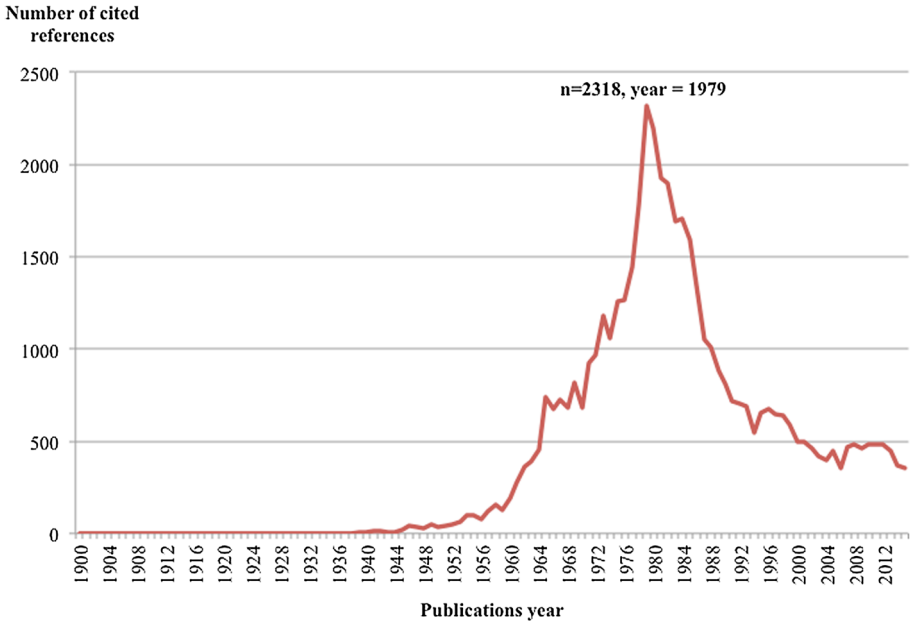

Fig. 8 Annual distribution of cited references in publications of research on PTA

It should also be noted that the sleeping period for Dotter's landmark paper was traversed by a scientific controversy whose traces can be witnessed in publications databases' differentiation between various bibliographic references to citations in the text, and by analysis of the documents' nature, especially where they involve editorials, letters or reviews that were critical of the original article.

Since Roger Everett's pioneering theory about the diffusion of innovation (Everett 1962) and Robert K. Merton's work on the sociology of science (Merton 1973), it is widely accepted that knowledge diffusion tends to be embedded in social organizations such as academic communities, with scientific discoveries potentially suffering as a result from science controversy and public debate. Hence the suggested introduction of the new construct of "restless sleep", involving sleeping beauty papers that integrate the social dimension of knowledge diffusion. Analysis and discussion of the present case study should open new avenues in identifying sleeping beauties in literature, while nurturing studies of resistance to science or controversy by providing the sociology of science with a new scientometric approach.

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