Bibliometrics and visualization analysis of artificial blood vessel research

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The growth and development of research productivity concerning artificial blood vessels in terms of publication output as reflected in Science Citation Index are analysed for the period of 1998–2013 using HistCite to know global publication share, rank, growth rate, citation impact, output of top journals and high-frequency words in this field. The citation chronological chart and main development path are demonstrated by HistCite and Pajek software to understand the basic situation and summarize the research status in the field of artificial blood vessels.

Keywords: Artificial blood vessels, bibliometrics, research output, visualization analysis.

ARTIFICIAL blood vessels are a kind of repairing and replacing diseased vascular prostheses which play an important role in the cardiovascular, reconstructive vascular surgery, tumour and trauma surgery, etc.

Artificial blood vessels are not harvested from natural organ or tissue, but from man-made materials. They can be divided into woven vessels (such as polyethylene terephthalate fibre (Dacron®)[1,2], polytetrafluoroethylene (PTFE), silk, etc.) and non-woven vessels (such as expanded PTFE blood vessels, polyurethanes and biodegradable polyester blood vessels, etc.)[3–6].

The materials used for artificial blood vessels should have reliable lasting strength and tolerance to different blood flows without deformation and fracture. Furthermore, they must not suffer interference in a complex biochemical environment, and must not cause serious inflammatory or foreign-body reactions. They must be non-carcinogenic *in vivo*, non-toxic, non-teratogenic and have no variation in reactions and not cause various types of allergic diseases. As the human body blood organ, the artificial blood vessels must have good blood and tissue compatibility, and should not cause any destruction of blood components *in vivo*. In addition, they must facilitate surgical sutures, no decoherence in the cut end, and be easy to sterilize and store[7].

Nowadays, artificial blood vessels have successfully been applied which as prosthetic grafts function satisfactorily only in large-diameter, high-flow vessels. However, in artificial small diameter blood vessels (< 6 mm) as prosthetic grafts for coronary arteries, they usually result in early thrombosis, plaque and intimal hyperplasia[8–10]. Problems such as thrombogenicity, poor vaso-activity and inappropriate mechanical properties still remain to be solved. Many approaches and strategies have been developed to solve these problems, such as surface biomimetic modification, special morphology, new biomaterials, tissue engineering to prepare the scaffold for artificial blood vessels[11–14].

Additionally, the following problems need to be addressed in artificial blood vessels.

(1) Tissue engineered grafts require an extended period of preparation, so they cannot be used in emergency situations. The prolonged duration of culture increases the risk of infection and raises the cost in terms of manpower, equipment and materials needed[15].
(2) In order to perfect organ body healing, the endothelial cell should be cultured or sown in advance *in vitro*, so that the artificial blood vessel wall is covered perfectly by endothelial cells before transplantation, thus shortening the time of endothelialization *in vivo* in artificial vessels.
(3) Enhancing the antibacterial ability to avoid bacterial infection to vascular substitutes.
(4) Research on new artificial blood vessel materials needs to be explored and strengthened.

Significant advancements in the properties of artificial blood vessels can be expected in the near future with the combination of new biomaterials, tissue engineering and gene therapy. Tissue-engineered blood vessels developed by stem cell technology are suggested to be a promising solution to the above problems[16,17].

Scientometrics is a tool by which the state of science and technology can be observed, through the overall production of scientific literature, at a given level of specialization. It provides an approach for assessment of scientific disciplines internationally[18,19]. Scientometrics

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indicators provide reliable evidence of scientific activity, and have been used in various research topics such as dental science[20], psychology[21,22], sociology[23], materials science[24], hydrogeology[25], antioxidants[26] and biochemistry, genetics and molecular biology[27].

HistCite is an analytical and visual tool which enables analysis of a subject and helps to identify the most significant work on a topic and trace its evolution[28].

The present article aims to map artificial blood vessels research as reflected in *Web of Science* (*WoS*), by examining the volume of work published in the countries, the journals that publish the research output and their ranking (as reflected by their impact factors) and the high-frequency words, citation situation and main development path using HistCite and Pajek software.

Methodology and source data

All publications on artificial blood vessels were searched with topic of 'blood vessel prosthe*' or 'artificial blood vessel*' or 'vascular graft*' or 'vascular prosthes*' or 'artificial vessel*' from 1998 to 2013 in *Science Citation Index–Expanded* (*SCIE*). Then the data on 3643 papers from four document types such as article, proceedings paper, review and meeting abstract were collected.

The data were exported and processed using HistCite to obtain the output of worldwide contributions in the field of artificial blood vessels. The publication year, contribution by countries and journals as well as high-frequency words, highly cited papers, chronological chart and the main development path have been demonstrated and the development status of artificial blood vessels is summarized.

Results and discussion

Year-wise distribution of research output

The number of records obtained from the *SCIE* database for each publication year is given in Figure 1. In 1998, 168 papers on artificial vessels research were published. The growth rate of publication in the following 5 years was slow, but since 2004 the output of papers has been growing steadily.

Global publication share and ranking

Table 1 shows the publication share of the top 10 most productive countries in artificial blood vessels research during 1998–2013. The 16 years from 1998 to 2013 have been divided into three stages: stage 1 from 1998 to 2003; stage 2 from 2004 to 2008; stage 3 from 2009 to 2013. USA tops the list with 1096 papers (30.1%), and paper growth rate from stage 1 to stage 3 is 36.3%. Germany ranks the second, with 9.8% share for 357 papers and growth rate is 57.4%, followed by Japan, China and France, whose publication shares are 9.0%, 5.9% and 5.6% respectively. China tops the list for paper growth rate from stage 1 to stage 3, indicating that the field has developed very fast during the past 16 years.

Citation-based indicators are valuable and reveal measures of the impact of the scientific work[29]. Citation analysis is more formal, open, scholarly founded and supplemented in the evaluation of research topic. HistCite also calculates the total local citation score (TLCS) and the total global citation score (TGCS)[30]. TLCS is the number of times a paper is cited by other papers in the local collection, which means in this study the citation scored by the collection of 3643 papers in the topic of artificial blood vessels. TGCS is the number of times a paper is included in the collection cited in *WoS*.

By comparing citation score per paper among the top 10 countries, it is observed that UK and USA top the list with TLCS per paper of 5.87 and 4.77 and TGCS per paper of 22.96 and 24.55 respectively. This indicates that papers from these countries are cited more by the peer authors in the area of artificial blood vessels and other researchers in *WoS* (Table 2).

Journal-wise distribution of research output

The total number of journals in the collection is 777. The 10 most productive journals published 988 papers in the area of artificial blood vessels, which contributed to 27.12% of the total output of papers during 1998–2013 (Table 3). *Biomaterials* published the higher number of papers (210) in artificial blood vessels during 1998–2013, sharing 5.8% of the total output. The IF-5 of this journal is 8.415 and ranks Q1/Q1 in the corresponding categories of engineering, biomedical/materials science, biomaterials. This is followed by the *Journal of Vascular Surgery* and *European Journal of Vascular and Endovascular Surgery*, which published 3.7% and 3.1% of the total papers output with IF-5 of 3.315 and 2.936 respectively,

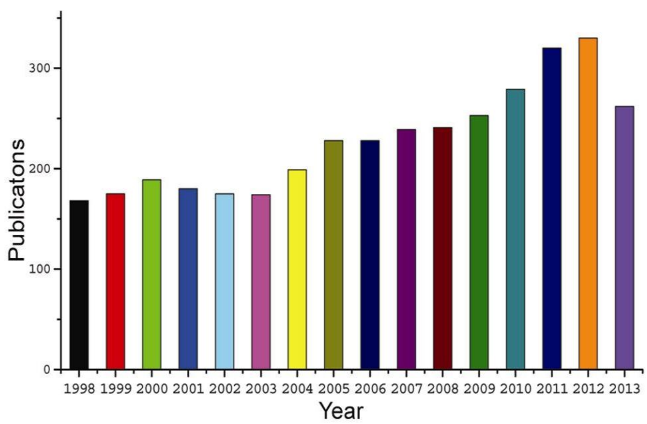

Figure 1. Year-wise publications of artificial blood vessels research output, 1998–2013.

Table 1. Publication output, share and growth rate of top 10 countries in artificial blood vessels research, 1998–2013

Country	Stage 1 (1998–2003)	Stage 2 (2004–2008)	Stage 3 (2009–2013)	Growth rate from stages 1 to 3 (%)	Total papers	Share (%)
USA	321	336	439	36.3	1,096	30.1
Germany	94	115	148	57.4	357	9.8
Japan	118	96	114	–3.4	328	9.0
China	4	49	163	3975	216	5.9
France	70	63	70	0	203	5.6
UK	69	77	54	–21.7	200	5.5
Italy	71	47	69	–2.8	187	5.1
The Netherlands	54	48	49	–9.3	151	4.1
Canada	38	28	61	60.5	127	3.5
Switzerland	20	33	50	150	103	2.8

Table 2. Citation score of top 10 countries in artificial blood vessels research, 1998–2013

Country	Total papers	TLCS	TLCS/p	TGCS	TGCS/p
USA	1,096	5,231	4.77	26,907	24.55
Germany	357	903	2.53	5,200	14.57
Japan	328	941	2.87	3,512	10.71
China	216	291	1.35	1,695	7.85
France	203	602	2.97	2,423	11.94
UK	200	1,174	5.87	4,592	22.96
Italy	187	358	1.91	2,037	10.89
The Netherlands	151	637	4.22	3,182	21.07
Canada	127	365	2.87	2,473	19.47
Switzerland	103	392	3.81	1,395	13.54

TLCS, Total local citation score; TLCS/p, Total local citation score per paper; TGCS, Total global citation score; TGCS/p, Total global citation score per paper.

and ranked Q2/Q1 in the corresponding categories of peripheral vascular disease/surgery. The *Journal of Biomedical Materials Research, Part A*, which published 2.9% of the total papers, is also remarkable for its high IF-5 of 3.105, ranking Q1/Q2 in engineering, biomedical/materials science, biomaterials categories. From Table 3 the quality of global papers in artificial blood vessels research is noticeable.

Word-wise distribution of research output

Keyword is natural word to express literature theme concept. By analysing changes in keywords, one can grasp the dynamic process, characteristics and rules of the development of the discipline.

'Vascular', 'graft', 'tissue', 'cells' and 'endothelial' are highest frequency words in the top 50 high-frequency words list of the three stages from 1998 to 2013, which show that cell endothelialization is the research focus in artificial blood vessels. Scientists intend to induce rapid endothelialization on artificial blood vessels to form a stable layer of endothelial[31]. Rapid endothelialization *in situ* can improve the hemocompatibility of the artificial blood vessels and avoid thrombosis[32,33]. In stage 1 PTFE, Dacron and polyester were the commonly used materials which appeared in the list from 1998 to 2003, while in stages 2 and 3 (from 2004 to 2013) polyurethane was the preferred material and scaffold technology appeared in artificial blood vessels research. Since 2009, 'electrospun' has been the newly involved word in the list in stage 3 and ranked 14th among the top 50 words, revealing that electrospinning technology has been recently introduced in producing artificial blood vessels. This technology enables synthetic polymers and natural polymers to form nanofibrous tubular grafts with various diameters and lengths. The electrospun artificial blood vessels are able to promote cell proliferation, and are becoming a promising substitute for tissue engineering vascular grafts[34].

Citation visualization analysis and main development path

HistCite is used to generate the visualized citation chronological chart for papers on artificial blood vessels. A total of 3643 papers were input into HistCite and the top 30 papers with LCS citation were selected to make citation chronological chart (Figure 2). In Figure 2, there are 30 nodes, 63 links; minimum LCS is 46, maximum LCS is 257.

Table 3. Research output and impact factor of top 10 most productive journals contributing to artificial blood vessels, 1998–2013

Journal	Total papers	Share (%)	IF-5*	Quartile in category**
Biomaterials	210	5.8	8.415	Q1/Q1 (engineering, biomedical/materials science, biomaterials)
Journal of Vascular Surgery	134	3.7	3.315	Q2/Q1 (peripheral vascular disease/surgery)
European Journal of Vascular and Endovascular Surgery	113	3.1	2.936	Q2/Q1 (peripheral vascular disease/surgery)
Journal of Biomedical Materials Research, Part A	106	2.9	3.105	Q1/Q2 (engineering, biomedical/materials science, biomaterials)
Journal of Cardiovascular Surgery	94	2.6	1.296	Q3/Q3/Q2 (cardiac and cardiovascular systems/ peripheral vascular disease/surgery)
Texas Heart Institute Journal	94	2.6	0.747	Q4 (cardiac and cardiovascular systems)
International Journal of Artificial Organs	67	1.8	1.540	Q2/Q3 (engineering, biomedical/transplantation)
Journal of Biomedical Materials Research Part B – Applied Biomaterials	58	1.6	2.305	Q2/Q3 (engineering, biomedical/materials science, biomaterials)
Annals of Thoracic Surgery	56	1.5	3.664	Q2/Q1/Q1 (cardiac and cardiovascular systems/ respiratory system/surgery)
Tissue Engineering Part A	56	1.5	–	–
Total	3,643	100		

*Data from JCR 5-year journal impact factor from 2006 to 2010. **Data from JCR journal ranking of quartile in different categories.

Table 4. Top 50 keywords frequency order of artificial blood vessels research output in three stages, 1998–2013

Stage 1 (1998–2003)		Stage 2 (2004–2008)		Stage 3 (2009–2013)	
1 Vascular	26 Human	1 Vascular	26 Endovascular	1 Vascular	26 Polyurethane
2 Graft	27 Model	2 Graft	27 Surface	2 Grafts	27 Collagen
3 Grafts	28 Endovascular	3 Grafts	28 Vessel	3 Tissue	28 Treatment
4 Endothelial	29 Dacron	4 Tissue	29 Novel	4 Graft	29 Surface
5 Aortic	30 Aorta	5 Cells	30 Surgery	5 Cell	30 Mechanical
6 Cell	31 Diameter	6 Endothelial	31 New	6 Cells	31 Prostheses
7 Cells	32 Engineering	7 Aortic	32 Prosthetic	7 Endothelial	32 Muscle
8 Tissue	33 Synthetic	8 Small	33 Transplantation	8 Engineering	33 Vein
9 Arterial	34 New	9 Engineering	34 Development	9 Small	34 Vitro
10 Treatment	35 Aneurysms	10 Cell	35 Evaluation	10 Aortic	35 Properties
11 Infection	36 Using	11 Blood	36 Use	11 Engineered	36 Use
12 Prostheses	37 Collagen	12 Engineered	37 Repair	12 Blood	37 Arterial
13 Blood	38 Use	13 Diameter	38 Poly	13 Diameter	38 Heparin
14 Flow	39 Vivo	14 Prosthesis	39 Scaffold	14 Electrospun	39 Prosthesis
15 Vitro	40 Muscle	15 Infection	40 Vein	15 Scaffolds	40 Transplantation
16 Small	41 Polyester	16 Using	41 Synthetic	16 Using	41 Bypass
17 Bypass	42 Surface	17 Human	42 Muscle	17 Model	42 Novel
18 Prosthetic	43 Adhesion	18 Aneurysm	43 Patients	18 Poly	43 Results
19 Repair	44 Case	19 Model	44 Polyurethane	19 Human	44 Surgery
20 Abdominal	45 Engineered	20 Vitro	45 Applications	20 Based	45 Term
21 Artery	46 Expanded	21 Artery	46 Collagen	21 Scaffold	46 Tubular
22 Evaluation	47 Experimental	22 Treatment	47 EPTFE	22 Artery	47 Vessel
23 Aneurysm	48 Report	23 Vivo	48 Results	23 Infection	48 Smooth
24 Polytetrafluoroethylene	49 Surgical	24 Bypass	49 Scaffolds	24 Vivo	49 Development
25 Prosthesis	50 Coated	25 Prostheses	50 Biodegradable	25 Stem	50 Reconstruction

The size of the box in Figure 2 represents the cited number of papers and the arrows point to the papers which are cited. Figure 2 also shows that research work in artificial blood vessels developed rapidly and actively from 1999 to 2006 and there were several highly cited papers which cited each other during this period. Citation chronological chart reflects the annual change trend, evolution and inheritance relation of research papers in artificial blood vessels.

Interestingly, though paper no. 54, 46 and 101 were published in 1998, paper no. 236 (which was published in 1999) received the highest number of citations, LCS of 257 and GCS of 907 (Figure 2). Paper no. 236 was published in *Science*, in which the authors Niklason *et al.* developed a tissue engineering approach 'to produce arbitrary lengths of vascular graft material from smooth muscle and endothelial cells that were derived from a biopsy of vascular tissue. Bovine vessels cultured under pulsatile

Table 5. Top 10 high LCS papers on artificial blood vessels, 1998–2013

Paper no.	Author/title/journal	LCS	LCSx	GCS
236	Niklason, L. E. *et al.*, Functional arteries grown *in vitro*. *Science*, 1999, **284**(5413), 489–493.	257	236	907
671	Kaushal, S., *et al.*, Functional small-diameter neovessels created using endothelial progenitor cells expanded *ex vivo*. *Nature Med.*, 2001, **7**(9), 1035–1040.	134	125	457
1532	Isenberg, B. C. *et al.*, Small-diameter artificial arteries engineered *in vitro*. *Circ. Res.*, 2006, **98**(1), 25–35.	93	89	210
1389	Kannan, R. Y. *et al.*, Current status of prosthetic bypass grafts: a review. *J. Biomed. Mater. Res. Part B – Appl. Biomater.*, 2005, **74B**(1), 570–581.	86	75	155
918	Xue, L. and Greisler, H. P., Biomaterials in the development and future of vascular grafts. *J. Vasc. Surg.*, 2003, **37**(2), 472–480.	84	83	176
321	Deutsch, M. *et al.*, Clinical autologous *in vitro* endothelialization of infrainguinal ePTFE grafts in 100 patients: a 9-year experience. *Surgery*, 1999, **126**(5), 847–855.	83	79	160
555	Salacinski, H. J. *et al.*, The mechanical behaviour of vascular grafts: a review. *J. Biomater. Appl.*, 2001, **15**(3), 241–278.	80	66	138
602	Meinhart, J. G. *et al.*, Clinical autologous *in vitro* endothelialization of 153 infrainguinal ePTFE grafts. *Ann. Thorac. Surg.*, 2001,**71**(5), S327–S331.	75	72	132
641	Hoerstrup, S. P. *et al.*, Tissue engineering of small caliber vascular grafts. *Eur. J. Cardio-Thorac. Surg.*, 2001, **20**(1), 164–169.	72	68	148
318	Huynh, T. *et al.*, Remodeling of an acellular collagen graft into a physiologically responsive neovessel. *Nature Biotechnol.*, 1999, **17**(11), 1083–1086.	70	70	171

LCS, Local citation score; LCSx, Local citation score, excluding self-citations; GCS, Global citation score.

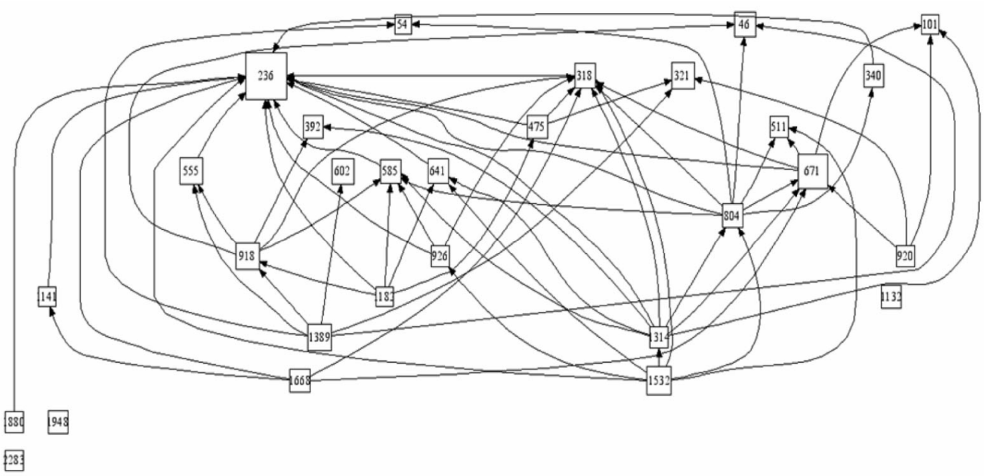

Figure 2. Citation chronological chart for papers of artificial blood vessels.

conditions had rupture strengths greater than 2000 millimeters of mercury, suture retention strengths of up to 90 grams, and collagen contents of up to 50 per cent. Cultured vessels also showed contractile responses to pharmacological agents and contained smooth muscle cells that displayed markers of differentiation such as calponin and myosin heavy chains. Tissue-engineered arteries were implanted in miniature swine, with patency documented up to 24 days by digital angiography'[35].

Table 5 lists the top 10 high LCS papers on artificial blood vessels from HistCite. These are the important papers in the development of artificial blood vessels in recent years.

The data on LCS top 30 papers were transformed into .net file and input into Pajek to make the main development path map (Figure 3). The nodes represent paper record number, author and year. The direction of the arrow points to the paper which is cited. The path covers 9 years from 1998 to 2006 and 8 papers were involved starting with paper no. 101 (Evidence for circulating bone marrow-derived endothelial cells, 1998), paper no. 236 (Functional arteries grown *in vitro*, 1999), paper no. 318 (Remodeling of an acellular collagen graft into a physiologically responsive neovessel, 1999) and paper no. 511 (Acellular vascular tissues: natural biomaterials for tissue repair and tissue engineering, 2000), which are the

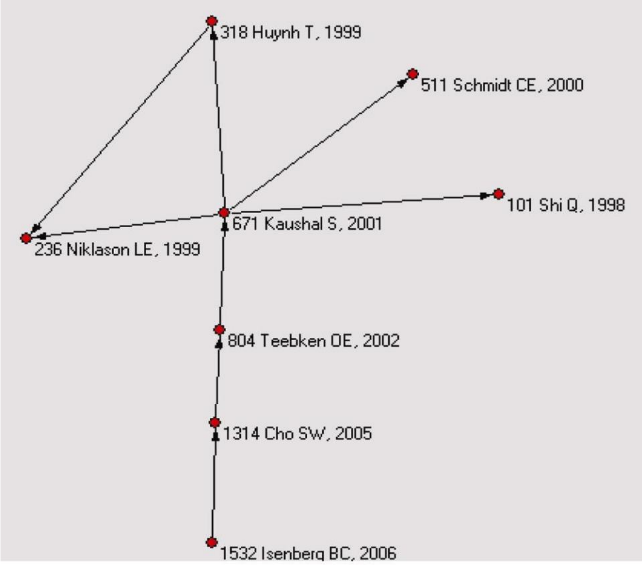

Figure 3. Main development path map for the development of artificial blood vessels.

elementary papers in artificial blood vessels. Paper no. 671 integrated the above four papers and developed functional small-diameter neovessels using endothelial progenitor cells. Later, paper no. 804 reviewed 'Tissue engineering of small diameter vascular grafts' in 2002 based on paper no. 671, and then paper no. 1314 developed 'Small-diameter blood vessels engineered with bone marrow-derived cells' in 2005 and paper no. 1532 reviewed 'Small-diameter artificial arteries engineered *in vitro*' in 2006. The literature in the main path does not include the most cited papers in this field, but puts forward the important theory and innovation concept and represents the main research direction of artificial blood vessels in recent years.

Conclusion

The HistCite-based analysis of artificial blood vessels research has shown how the field has developed in the past 16 years.

The research on artificial blood vessels developed relatively slowly from 1998 to 2003, but since 2004 the output of papers is growing steadily. USA tops the list with 30.1% papers and Germany ranks second (9.8%). China tops the paper growth rate by 3975% from stage 1 to stage 3. Citation score per paper indicates that papers from UK and USA were more cited by peer authors in the area of artificial blood vessels as well as other researchers in *WoS*. The most productive journals publishing artificial blood vessels papers are *Biomaterials* (IF-5 8.415), *Journal of Vascular Surgery* (IF-5 3.315), *European Journal of Vascular and Endovascular Surgery* (IF-5 2.936) and *Journal of Biomedical Materials Research, Part A* (IF-5 3.105), all ranking Q1/Q2 in the corresponding categories.

'Vascular', 'graft', 'tissue', 'cells' and 'endothelial' are the high-frequency words. Polytetrafluoroethylene, Dacron and polyester were the commonly used materials in the early stage, but from 2004 to 2013 polyurethane has been the preferred material and scaffold technology appeared in artificial blood vessels. 'Electrospun' has been the newly involved word since 2009, revealing that electrospinning technology has been recently introduced in producing artificial blood vessels.

HistCite can be used to generate the visualized citation chronological chart for papers on artificial blood vessels. The main path graph obtained using Pajek can determine the most important papers in the stream of citations, which can reveal the development in the area of artificial blood vessels in recent years, i.e. from growing arteries *in vitro* and applying natural biomaterials as acellular vascular tissues to developing small-diameter neovessels and artificial arteries by tissue engineering with cells.

1. Takagi, H., Goto, S., Matsui, M., Manabe, H. and Umemoto, T., A contemporary meta-analysis of Dacron versus polytetrafluoroethylene grafts for femoropopliteal bypass grafting. *J. Vasc. Surg.*, 2010, **52**(1), 232–236.
2. Jeanmonod, P. *et al.*, Silver acetate coating promotes early vascularization of Dacron vascular grafts without inducing host tissue inflammation. *J. Vasc. Surg.*, 2013, **58**(6), 1637–1643.
3. Nerem, R. M. and Seliktar, D., Vascular tissue engineering. *Annu. Rev. Biomed. Eng.*, 2001, **3**, 225–243.
4. Uttayarat, P. *et al.*, Micropatterning of three-dimensional electrospun polyurethane vascular grafts. *Acta Biomater.*, 2010, **6**(11), 4229–4237.
5. Bergmeister, H. *et al.*, Electrospun small-diameter polyurethane vascular grafts: ingrowth and differentiation of vascular-specific host cells. *Artif. Organs*, 2012, **36**(1), 54–61.
6. Chung, E., Ricles, L. M., Stowers, R. S., Nam, S. Y., Emelianov, S. Y. and Suggs, L. J., Multifunctional nanoscale strategies for enhancing and monitoring blood vessel regeneration. *Nano Today*, 2012, **7**(6), 514–531.
7. http://www.baike.com/wiki/
8. Lovett, M., Cannizzaro, C., Daheron, L., Messmer, B., Vunjak-Novakovic, G. and Kaplan, D. L., Silk fibroin microtubes for blood vessel engineering. *Biomaterials*, 2007, **28**, 5271–5279.
9. Smith, M. J., McClure, M. J., Sell, S. A., Barnes, C. P., Walpoth, B. H., Simpson, D. G. and Bowlin, G. L., Suture-reinforced electrospun polydioxanone-elastin small-diameter tubes for use in vascular tissue engineering: a feasibility study. *Acta Biomater.*, 2008, **4**, 58–66.
10. Kidoaki, S., Kwon, Il, K. and Matsuda, T., Mesoscopic spatial designs of nano- and microfiber meshes for tissue-engineering matrix and scaffold based on newly devised multilayering and mixing electrospinning techniques. *Biomaterials*, 2005, **26**, 37–46.
11. Wang, H., Feng, Y., Zhao, H., Fang, Z., Khan, M. and Guo, J., A potential nonthrombogenic Small-diameter vascular scaffold with polyurethane/poly(ethylene glycol) hybrid materials by electrospinning technique. *J. Nanosci. Nanotechnol.*, 2013, **13**, 1578–1582.
12. Feng, Y., Zhao, H., Behl, M., Lendlein, A., Guo, J. and Yang, D., Grafting of poly(ethylene glycol) monoacrylates on polycarbonateurethane by UV initiated polymerization for improving hemocompatibility. *J. Mater. Sci. Mater. Med.*, 2013, **24**, 61–70.

13. Yuan, W. *et al.*, Hemocompatible surface of electrospun nanofibrous scaffolds by ATRP modification. *Mater. Sci. Eng. C*, 2013, **33**(7), 3644–3651.
14. Gao, B. *et al.*, Grafting of phosphorylcholine functional groups on polycarbonate urethane surface for resisting platelet adhesion. *Mater. Sci. Eng. C*, 2013, **33**(5), 2871–2878.
15. Kakisis, J. D., Liapis, C. D. and Breuer, C., Artificial blood vessel: the Holy Grail of peripheral vascular surgery. *J. Vasc. Surg*., 2005, **41**(2), 349–354.
16. Krawiec, J. T. and Vorp, D. A., Adult stem cell-based tissue engineered blood vessels: a review. *Biomaterials*, 2012, **33**, 3388–3400.
17. Swartz, D. D. and Andreadis, S. T., Animal models for vascular tissue-engineering. *Curr. Opin. Biotechnol.*, 2013, **24**(5), 916–925.
18. Pouris, A. and Pouris, A., Scientometrics of a pandemic: HIV/AIDS research in South Africa and the world. *Scientometrics*, 2011, **86**(2), 541–552.
19. Pouris, A., Is fundamentalism a threat to science? Evidence from scientometrics. *Scientometrics,* 2007, **71**(2), 329–338.
20. Kaur, H. and Gupta, B. M., Mapping of dental science research in India: a scientometric analysis of India's research output, 1999–2008. *Scientometrics*, 2010, **85**, 361–376.
21. Barrios, M., Villarroya, A. and Borrego, A., Scientific production in psychology: a gender analysis. *Scientometrics*, 2013, **95**(1), 15–23.
22. Guilera, G., Barrios, M. and Gomez-Benito, J., Meta-analysis in psychology: a bibliometric study. *Scientometrics*, 2013, **94**(3), 943–954.
23. Cronin, B., Snyder, H. and Atkins, H., Comparative citation rankings of authors in monographic and journal literature: a study of sociology. *J. Document*., 1997, **53**, 263–273.
24. Garfield, E. and Pudovkina, A. I., From materials science to nanoceramics: citation analysis identifies the key journals and players. *J. Ceram. Process. Res.*, 2003, **4**, 155–167.
25. Schwartz, F. and Fang, Y. C., Citation data analysis on hydrogeology. *J. Am. Soc. Inf. Sci. Technol*., 2007, **58**, 518–525.
26. Ahmed, K. K. and Gupta, B. M., India's contribution on antioxidants: a bibliometric analysis, 2001–10. *Scientometrics*, 2013, **94**, 741–754.
27. Bala, A. and Gupta, B. M., Mapping of Indian neuroscience research: a scientometric analysis of research output during 1999–2008. *Neurol. India*, 2010, **58**(1), 35–41.
28. Garfield, E., Paris, S. and Stock, W., HistCite^{TM}: a software tool for informetric analysis of citation linkage. *Informetrics*, 2006, **57**(8), 391–400.
29. Garfield, E. and Welljams-Dorof, A., Citation data: their use as quantitative indicators for science and technology evaluation and policy-making. *Curr. Contents*, 1992, **49**, 5–13.
30. Thulasi, K. and Arunachalam, S., Mapping of cholera research in Indian using HistCite. *Ann. Lib. Inf. Stud.*, 2010, **57**, 310–326.
31. Wang, H. *et al.*, Fabrication of PU/PEGMA crosslinked hybrid scaffolds by *in situ* UV photopolymerization favoring human endothelial cells growth for vascular tissue engineering. *J. Mater. Sci.: Mater. Med*., 2012, **23**(6), 1499–1510.
32. Melchiorri, A. J., Hibino, N. and Fisher, J. P., Strategies and techniques to enhance the *in situ* endothelialization of small-diameter biodegradable polymeric vascular grafts. *Tissue Eng. Part B–Rev*., 2013, **19**(4), 292–307.
33. Li, S., Sengupta, D. and Chien, S., Vascular tissue engineering: from *in vitro* to *in situ*. *WIREs. Syst. Biol. Med*., 2014, **6**, 61–76.
34. Wang, H. *et al.*, Hemocompatible PU/gelatin–heparin nanofibrous scaffolds as potential artificial blood vessels by bi-layer electrospinning technique. *Front. Chem. Sci. Eng.*, 2011, **5**(3), 392–400.
35. Niklason, L. E., Functional arteries grown *in vitro*. *Science*, 1999, **284**, 489.

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