Comment

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The evolution of biomaterials research

Amir A. Zadpoor discusses how the field of biomaterials has changed since the turn of the century

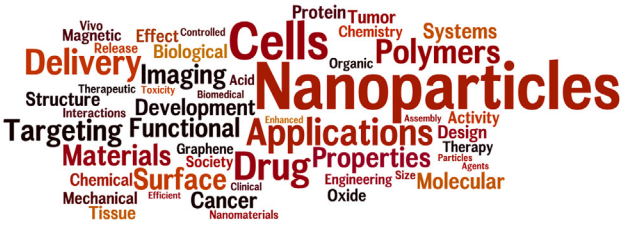
Biomaterials research has been on the rise over the last few decades, since the first dedicated journals appeared in the field. Parallel to this expansion, biomaterials research has experienced an evolution in terms of the topics that constitute the frontiers of research and those that have the greatest impact. There is of course some anecdotal evidence as to what topics are currently considered the hottest topics and how they compare to the common perception of the hottest research topics ten years ago. However, there has not been much quantitative analysis of the literature data to support the anecdotal evidence.

To address this, I used Scopus to search for publications that contained the keyword 'biomaterial' or similar keywords somewhere in their metadata. The search was performed two times: once for the papers published in the year 2000 and once for the papers published in the year 2012. The searches returned 7 and 40k results for the years 2000 and 2012, respectively. For every year, the results were sorted according to their number of citations and the top 1% of the search results (of each search) was exported for further text analysis. The title, abstract, and keywords of the exported search results were analyzed using a text analysis program to determine the most frequently recurring words. The resulting data was then used to create two word clouds: Figure 1 shows two clouds for the years 2000 (left) and 2012 (right) containing the keywords found in the abstract, titles, and keywords of the most highly cited (top 1%) biomaterials studies. In each cloud word cloud, the 50 most recurring words were plotted with font sizes in proportion to their frequencies of recurrence.

The 5–6-fold increase in the number of search results shows the huge expansion that biomaterials research has experienced since 2000. Moreover, the word clouds show interesting trends in the evolution of the hottest biomaterials research topics during the same period. The evolution of three important aspects of biomaterials research, namely: targeted diseases, therapeutic/diagnostic approaches, and biomaterials development, are noted here.

For targeted diseases, there is a clear shift from orthopedic diseases to other diseases particularly cancer. This shift is highlighted by the strong presence of the terms *bone*, *cartilage*, and *osteoblast* in the word cloud corresponding to the year 2000: these

Year 2000



Year 2012

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terms have disappeared from the 2012 word cloud, while *cancer* and *tumor* have appeared.

For therapeutic/diagnostic approaches, the hottest topics seem to have been tissue engineering and surface science in the year 2000: but currently drug delivery (including targeted cancer therapy), biomaterial-assisted diagnostic imaging, and theranostics (approaches aimed at combined diagnostic and therapy of diseases) [1] are generating the most interest.

The type of biomaterials that are having the greatest impact has also changed since the beginning of the 21st century. While polymers were highly prominent in the year 2000, nanoparticles have become by far the most recurring term in the top biomaterials research published in 2012. The terms *polymers*, *biodegradable*, *PEG*, and *hydrogels* signify the importance of polymeric materials in the most highly cited research of the year 2000; while in 2012 the terms *nanoparticles*, *nanomaterials*, *magnetic*, and *graphene* have entered into the lexicon of top publications.

These changes suggest certain trends in the evolution of biomaterials research topics. First, it seems that biomaterials research is becoming much more sophisticated and is increasingly going beyond the traditional boundaries of materials science. At the beginning of the 21st century, cutting edge biomaterials research was related to orthopedic diseases that are relatively less complex and often require the use of structural materials. Materials scientists have been playing important roles in the design and manufacturing of orthopedic implants and tissue engineering scaffolds for several decades. However, until more recently, they have not had much involvement in cancer therapy. The increased sophistication of biomaterials and the improved controllability in (co-)delivery of complex drugs has enabled biomaterial scientists to work with oncologists, pharmacologists, biologists, and imaging specialists to target increasingly more sophisticated diseases such as cancer. The important role of nanotechnology in this transition is undeniable. At the turn of the century, nanotechnology was far less developed and accessible compared to today. The availability of many different types of highly controllable nanomaterials has created an enormous opportunity for the application of very novel biomaterial approaches for the treatment of sophisticated diseases.

It is important to realize that the trends reported here pertain to the relative importance of research topics. There is anecdotal evidence supporting the belief that the more traditional areas of biomaterials research remain important and perfectly active, and have preserved their absolute impact. It is exciting to observe what turns biomaterials research will take in the coming years and how newly developed biomaterials will find their way to clinical settings and the patients that will benefit from them.

Further reading

[1] A.J. Cole, V.C. Yang, A.E. David, Cancer theranostics: the rise of targeted magnetic nanoparticles, Trends in Biotechnolgy 29 (July (7)) (2011) 323–332. , http://dx.doi.org/10.1016/j.tibtech.2011.03.001, Epub 2011 Apr 12.