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Biomedical Engineering: An Exploratory Analysis of the Field

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Abstract

Technological advances have a significant impact in medical sciences. biomedical engineering, which is a multi-faceted field that includes engineering, biology, chemistry, computer science, and several areas of the medical sciences among others, is the topic of this study. With a humble beginning over a century ago and formally created in the early years of the 1960s, biomedical engineering has become a strong, highly competitive and productive field. Its literature has worldwide coverage with an accelerated increase after 2000.

In this study, the authors explore two issues: First, what constitute the subject domain of Biomedical Engineering and second with the use of the Web of Science present important bibliographic parameters of the literature.

Biomedical Engineering: An Exploratory Analysis of the Field

Introduction

Biomedical engineering as a subject domain has a long presence in scientific literature, searches done in three databases (Compendex, Web of Science and BIOSIS) give an idea of its origin in the recognized terminology. The results show that in the late nineteen-fifties it was initially referred to as the engineering of biomedical instrumentation (Hervey, J.P., 1959 and Klopsteg, P.E., 1959) and a few years later as biomedical engineering (Gowen, R.J. and Schock, G.J.D., 1963 and Le Croissette, D., 1963). Indeed, a formal development of the field of biomedical engineering occurred post Second World War when academic programs such as the one at Case-Western University in Bioengineering created in 1962. Today, biomedical engineering is a major engineering field; its research, design and development both in universities and the industrial sector is well recognized worldwide. In the United States, there is a strong research interest as demonstrated by the National Science Foundation research grant programs in Biosensing; Engineering of Biomedical Systems; and Disability and Rehabilitation Systems; the programs at the Institute of Biomedical Imaging and Bioengineering of the National Institute of Health , as well as by private institutions and professional societies such as the Whitaker Foundation, and the American Heart Association. As an economic sector, it has significant importance, for example, Ziganto, R. (2019) in *Production Machining* predicts that the medical equipment industry in the United States by the year 2030 will have 800 million dollars in revenues; the design and development of medical devices is only one of the major components of biomedical engineering.

Within the literature of library and information science, very few articles have been published in the last twenty years on biomedical engineering: Francová, P., and Krueger, S. (2016) present a strong argument about the importance of better access to grey literature and research data; and Spaan, J., and Coronel, R. (2012) in their role as editor of the journal *Medical and Biological Engineering and Computing*, MBEC, present a historical perspective of this publication's production since its beginning in

1963 under the title *Medical, Electronic and Biological Engineering*. Arntzen-Bechina, A. A., and Leguy, C. A. D. (2007) study the flow of technical information among medical practitioners, engineers, researchers, and technical designers in the development of new processes and products; and Linte, C. A. (2008) provides meaningful guidelines about successful technical writing in professional publication with emphasis articles for the *IEEE Engineering in Medicine & Biology Magazine*.

Stallings, J. et al. (2013) in a study published in the *Proceedings of the National Academy of Sciences of the United States of America* examine bibliometric data from the publications of nearly two-hundred biomedical engineering academics with the purpose of determining their impact in collaboration and productivity. Further, Boudry, C., and Chartron, G. (2017) discussed the use of digital object identifiers (DOIs) in PubMed for the analysis of geographical distribution of research productivity.

In the initial years of the field, two articles about the literature were published, the work by Thuss, J. (1972) makes a strong argument for the need for proper coverage in bibliographic sources of the literature of this new area and that its access was essential for research and teaching. A few years earlier, Lawson, C. L., and Hodes, L. (1970) in the *Communications of the ACM* presents the development of a computer-based system to analyze biomedical images.

There is a large body of studies of biomedical engineering within the realms of bioinformatics, although bioinformatics is not the focus of this paper. In this study we present an exploratory analysis of the subject, both a historical and present perspective of the field as we also present some bibliometric parameters that give insights into the research productivity of this important area. The presentation is descriptive and educational; it is particularly intended for new science librarians without a strong science background and for library science students considering entering in science/engineering librarianship.

Methodology

A traditional method of literature analysis is used in order to find a definition and the major components of biomedical engineering. Fifteen key articles published as book chapters or in academic journals were identified and critically analyzed; these publications were obtained from searches done in scientific databases such as Web of Science.

Second, A bibliometric analysis was done with the purpose of determining bibliographic parameters such as leading publications, authors' productivity, and principal research institutions. In order to obtain suitable and credible data, a search was done in Web of Science. For this search, a selection of twenty-nine keywords representing recognized elements of the subject, such as biomedical imaging and biomedical instrumentation, were selected. To assist in the selection of these keywords, several reference resources such as the *Encyclopedia of Biomaterials and Biomedical Engineering* were scrutinized. The purpose was to perform a database search using significant keywords that were able to capture a good number of articles about biomedical engineering. Several of the data analytic tools provided by Web of Science were also used.

The quest for a definition: What is Biomedical Engineering?

There are multiple titles and descriptions for biomedical engineering. One possible summarization from its many definitions is that biomedical engineering is the research, theory and application of engineering for the improvement of human health (Bronzino 2012, Richard- Kortum 2010, Saltzman 2009, Stark et al. 1968, White and Plonsey 1982). Biomedical engineering is a vast multi-disciplinary field that is relatively young as its own individually recognized discipline but has roots going back to the early history of medicine. Saltzman (2009) described the early beginnings of bioengineering as an "iterative process of discovery and invention". As people developed tools to makes tasks easier to perform, they had more leisure time. Some used the extra time and tools when possible to learn more about the function of the human body. This lead to the development of more tools for the care and repair of that body which aided in further study of the human body and the cycle would repeat itself. Both Saltzman (2009) and Bronzino (2012) equate the development of new tools and technology for the continued studied of the human body and the advancement of medicine with the early development of biomedical engineering.

An example of biomedical engineering given by Saltzman (2009) is the development of contact lenses, starting with Roger Bacon’s writing about the use of convex lens to treat farsightedness in 1249, to the FDAs approval of contact lenses for corrective refractive therapy in 2002. Bronzino (2012) highlights the development of instruments and tools to advance the analysis, diagnosis, and treatment health related issues over time. Notable examples being William Einthoven's creation of the first electrocardiograph machine 1903, W.K. Roentgen's development of X-rays in 1930, and Drinker's respirator in 1927,Bi which made the performance of the first heart-lung bypass procedure in 1939 possible. In the 1960s, the position of clinical engineers, an early forerunner of the biomedical engineer, was created by many hospitals concerned with patient safety around all the electrically charged equipment. Among their duties was the maintenance and repair of all the instrumentation used for diagnosis and treatment of patients (Bronzino 2012).

Richards-Kortum (2010) divides the diverse field of biomedical engineering into seven sub disciplines: biomechanics, biomedical imaging, biomedical instrumentation and biomedical sensor, biomaterials and drug delivery, biosystems engineering and physiology, molecular and cellular engineering, tissue engineering and regenerative medicine.

Biomechanics

Biomechanics is basically a mechanical study of a living system. This covers a wide range of topics. From the basic mechanics of movement of the human body to the mechanical function of cells in the body itself. The most well known biomechanical topic that has seen the most advances recently is that of prosthetics. In a 1968 (Stark et al.) report on the status of research in biomedical engineering the focus was on cardiac prosthetics. Today, thanks to advances in technology and materials, it is possible to create prosthetic limbs that are comfortable, easily attached, with a pleasing look and are functional (Bronzino 2012). New to biomechanics and biomedical engineering is the field of neural prosthetics that studies and creates devices controlled by functional electrical stimulation (Bronzino 2012). These devices may one day eventually help people with spinal cord injuries regain the function of their limbs. Other examples of studies in this area that those about heat transfer in biological systems studied by Liang Zhu (2009), and John Chato (Nebeker and Geselowitz 2002). This deals with the transfer of heat throughout the entire body to complex issues involving cryosurgery. David Elad, Shmuel Einav (2009), Shu Chien, Edward Merrill, and Robert Mates (Nebeker and Geselowitz 2002) study the flow properties of blood, covering from the flow of blood in arteries and veins to the modeling the flow of individual cells in the blood. Biomechanics includes the study of the physical interactions between ligaments, tendons, and muscles as well as gait analysis (Palladino and Davis 2012).

Biomedical Imaging

The ability to see organs and bones inside the body revolutionized diagnostic medicine. Biomedical imaging commenced with the invention of Wilhelm Roentgen's X-ray imaging in 1895. Over time, advances in the field led to the development of ultrasound in the 1940's and 50's and infrared imaging in the 1960s (Nebeker 2002). In the 1970's, advances in medical imaging such as computerized axial tomography (CAT) scanners, nuclear magnetic resonance (NMR), and positron emission tomography (PET), along with other technological advances were blamed for the increase cost in health care (Nebeker 2002). The 1980s saw the adoption of magnetic resonance imaging (MRI) along with improvements to existing imaging technologies (Nebeker 2002). Also included in this category are optical microscopy for viewing samples taken from the body at the cellular level and the use of devices inside body cavities such as those used in colonoscopy and endoscopy (Richards-Kortum 2010).

Biomedical Instrumentation and Biomedical Sensor

This is the development of instruments and sensors to measure, record and in certain instances manipulate biological signals (Richards-Kortum 2010). Examples of such instruments are the electrocardiogram (ECG) electroencephalogram (EEG), pulse oximeter, and the most famous of them all, the pacemaker (Enderle 2012, Pannizzo 1984, Richards-Kortum 2010). Biosensors are often used to monitor and record biological signals that often help with diagnostics. Examples include electrodes and microelectrodes, and thermistors (Mendelson 2012). Advances in the developments of electronics, transducers, and computers have been the force behind developments in this field. From creating accurate high priced equipment to the development of lower cost devices that are smaller, mobile, and equally accurate as its larger high-cost predecessor. This involves improvement in display, sensitivity, accuracy, and reproducibility of sensors and instrumentation.

Biomaterials and Drug Delivery

Biomaterials are materials designed for use in creating devices for assisting in the repair, replacement, and restoration of body function (Richards-Kortum 2010). As such these materials come in contact and often interact with body fluids. Some examples of what biomaterials are used for include but not limited to joint replacements (knee, hip, etc.), coronary stints, catheters, wound dressings, degradable sutures, and scaffolds for cell and tissue transplants. Biomaterials are also being used to create implantable devices that provide a controlled and timed release of drugs into the body for various treatments. There are four types or classes of biomaterials. These are ceramic/glasses, metals, polymers and composites or mixtures of the materials just listed (Kuhn 2012). The challenge comes with the material reaction to the body and its fluids. If it is designed to break down, it needs to do so into safe and non-toxic components once it has served its purpose. If it is replacing a joint, then it is preferred that the material maintains is structural integrity and continues to function for an extend period of time.

Biosystems Engineering and Physiology

This is the quantitative modeling of physiological systems. This includes the modeling of biological functions from the organ level down to the cellular and molecular level. Modeling is used to help analyze gene and protein expressions and as protein-protein interactions (Richards-Kortum 2010). It is a valuable tool to find suitable targets in drug therapy, often predicting the viability of a drug before it is even tested in animals or clinical trials. In this instance, advances in technology and computer science were vital in the development and success of this field, however, that does not mean this field is new. In the 1968 status report of biomedical engineering by Stark et al., it talks about the advent of the PC in the field and comments on how biological model simulations have been done on analog computers since the late 1930's.

Molecular and Cellular Engineering

Biomolecular engineers often have training in chemical engineering and they focus on the changes of the chemical components in the biological system (Saltzman 2009). Biomolecular engineers focus on drug therapies and drug delivery as well as the interaction of macromolecular complexes. Examples of this include the study of biological nanomotors to development of vaccines or controlled drug delivery devices. Cellular Engineering takes the work done by biomolecular engineers down to the cellular level. Cellular engineering is the modification of biochemical reactions to improve cell properties (Richards-Kortum 2010). One of the focuses of cellular engineering is cell signaling which is how the cells communicate with each other and their environment and how the breakdown in that communication affects the body.

Tissue Engineering and Regenerative Medicine

According to Nebeker (2002), tissue engineering is one of the newest specialties in biomedical engineering. This group of engineers works to develop less expensive and less invasive methods of tissue repair, organ development as an alternative to organ transplants, and wound healing (Richards-Kortum 2010, Saltzman 2009). The ultimate goal is to use the patients own cells to grow, develop and repair damage to tissue and organs in their own bodies. Some of the topics currently under exploration and development are cellular therapies, skin grafts, and extracorporeal bioartificial organs (McClelland et al 2012). Some of the challenges for tissue engineers is controlled cell growth, functionality, and vascularization of cells for oxygenation once the tissue wall reaches a certain thickness (Richards-Kortum 2010).

This is just a brief overview and snapshot of a rapidly growing, diverse and cross disciplinary field of biomedical engineering.

Bibliographic analysis results

Due to biomedical engineering's cross-disciplinary nature, there are multiple databases that can be searched. Searches could be done in engineering, chemistry, biology, kinesiology, physics, or medical databases for research and information. A search in a general database, such as Academic Search Complete, might help the user figure out which subject databases would be the best place to start. If the user is dealing with any ethical issues involving biomedical engineering, then they could extend the search to news and social science databases as well.

To determine the institution performing the most research, the journals most published in, the most cited articles, and the major authors in the field, the following search was performed in Web of Science mid- July 2019.

Using the Topic field of Web of Science these keywords were included: "Artificial organs" OR "Bioelectric phenomena" OR "Bioinstrumentation" OR "Biomaterials and drug delivery" OR "Biomechanics" OR "Biomedical imaging" OR "Biomedical instrumentation" OR "Biomedical optics" OR "Biomedical lasers" OR "Biomedical sensors" OR "Biomedical systems analysis" OR "Biomolecular engineering" OR "Biosignal processing" OR "Biosystems engineering" OR "Biosystems physiology" OR "Clinical engineering" OR "Diagnostic equipment design" OR "Medical device design" OR "Medical imaging" OR "Molecular engineering" OR "Cellular engineering" OR "Physiological modeling" OR "Radiation imaging" OR "Rehabilitation engineering" OR "Prosthetics design" OR "biomedical and Surgery" OR "Systems biology and bioinformatics" OR "Tissue engineering" OR "Regeneration medicine". The search produced 121,501 citations, from 1918 to 2019; of those 112,851 or 92.88 percent were from the last 18 years, 2001-2019.

The Most Cited feature sort was used to find the top 20 cited articles. Web of Science's Analyze Results function was used on the results of the search to determine the top twenty institutions, journals and authors based on the number of papers. No effort was made to try and determine if the results for authors were due to multiple authors with the same last name and initials. A Citation Report was run on the top 50 results for each category to determine who the top twenty were for each. Clarivate Analytics Journal Citation Reports were used to look up the Impact factor for the 20 top cited journal titles.

Table 1: Top Twenty organizations performing research

# of Papers	Organizations	Organizations	Times Cited
1928	Harvard University	Harvard University	139807
1404	University of Michigan	Massachusetts Institute of Technology (MIT)	117350
1299	Chinese Academy of Sciences	University of Michigan	78569
1274	Massachusetts Institute of Technology (MIT)	National University of Singapore	58186
1263	University of Pittsburgh	University of Pittsburgh	53431
1022	Stanford University	Rice University	46851
1020	National University of Singapore	Duke University	46509
991	University of Toronto	Stanford University	41974
951	Shanghai Jiao Tong University	University of Pennsylvania	38208
897	University College London (UCL)	University of California Los Angeles	37131
853	Sichuan University	University of Toronto	37024
852	Duke University	Columbia University	34561
834	University of California Los Angeles	Tufts University	33374
828	University of Pennsylvania	University of Washington	32548
775	Georgia Institute of Technology	Chinese Academy of Sciences	32545
762	Univesidade do Minho	University of California Berkeley	31349
752	University of Washington	Georgia Institute of Technology	31347
740	Columbia University	Northwestern University	29232
717	Johns Hopkins University	University London Imperial College of Science, Technology, and Medicine	29200
707	Nanyang Technological University	Case Western University	28297

Table 1 shows the top twenty institutions for biomedical engineering based on the number of papers and times cited. Table 2 shows the top twenty journal titles based on number of paper, and times cited. It may be worth noting that while some of the proceedings for various organizations ranked high in number of papers, they were not heavily cited. Another point of interest is that many of the journal titles are representative of biomedical engineering's sub-disciplines. The title of the journals also demonstrates biomedical engineering's multidisciplinary nature. There are titles in engineering, biology, medicine, kinesiology, and physics. The impact factor for the top twenty most cited journals is provided in Table 2. It was also noticed that for several of the top cited journals, the number of cited articles began to accelerate between the years 2002 and 2004 and continue to increase, which could be interpreted as an increase in research productivity in the last sixteen years. This also coincides with the tremendous increase of papers published in the last nineteen years.

Table 2: Top Twenty Journals

# of Papers	Journals		Impact Factor	Times Cited
2680	Biomaterials	Biomaterials	10.273	282156
1903	Journal of biomechanics	Journal of biomechanics	2.576	65055
1873	Proceedings of SPIE	Acta Biomaterialia	6.638	61355
1757	Journal of Biomedical Materials Research Part A	Journal of Biomedical Materials Research Part A	3.221	57322
1553	Tissue Engineering Part A	Tissue Engineering	3.508	56066
1537	Acta Biomaterialia	Spine	2.903	39983
1173	Journal of Tissue Engineering and Regenerative Medicine	Biomacromolecules	5.667	36649
1007	Material Science Engineering C Materials for Biological Applications	American Journal of Sports Medicine	6.093	31335
961	Clinical Biomechanics	Tissue Engineering Part A	3.616	30511
938	Spine	Clinical Biomechanics	1.977	24086
783	Tissue Engineering	Annals of Biomedical Engineering	3.474	23757
758	PLOS One	Journal of Orthopaedic Research	3.043	21686
757	Annals of Biomedical Engineering	Journal of Experimental Biology	3.017	19960

672	Medical Physics	Biotechnology and Bioengineering	4.260	18781
650	American Journal of Sports Medicine	Journal of Materials Science Materials in Medicine	2.467	18306
649	IFMBE Proceedings	Material Science Engineering C Materials for Biological Applications	4.959	16623
636	Journal of materials Science Materials in Medicine	Journal of Biomedical Materials Research Part B Applied Biomaterials	2.674	15926
620	Journal of Orthopaedic Research	Journal of Biomechanical Engineering Transactions of the ASME	2.025	15354
602	Journal of Biomechanical Engineering Transactions of the ASME	Tissue Engineering Part B Reviews	6.512	15276
597	Journal of Biomedical Materials Research Part B Applied Biomaterials	Journal of Tissue Engineering and Regenerative Medicine	3.319	15909

Table 3: Top twenty authors

# of Papers	Authors		Times Cited
537	Reis RL	Langer R	43153
382	Zhang Y	Mikos AG	28950
377	Liu Y	Kaplan DL	23631
369	Wang Y	Hutmacher DW	21497
341	Li Y	Reis RL	21228
309	Wang L	Khademhosseini A	20619
305	Boccaccini AR	Ramakrishna S	20110
305	Wang J	Vunjak-Novakovic G	17875
293	Mikos AG	Boccaccini AR	16205
290	Kaplan DL	Okano T	12094
269	Li J	Mano JF	11469
269	Mano JF	Atala A	10522
269	Zhang L	Zhang Y	7936
255	Zhang J	Yang J	7931
250	Khademhosseini A	Wang Y	7897
242	Liu J	Liu Y	7551
238	Ramakrishna S	Li Y	7551
237	Yang J	Athanasiou KA	7234
236	Zhang X	Lee SJ	6769
231	Lee J	Chang J	6166

Table 3 shows the top twenty authors based on the number of papers and times cited. The results show that twelve authors appear in both lists. The list of top producing authors based on the number of papers published includes institutions located in the following countries: China (10), USA (6), Portugal (2), South Korea (2), and Germany (1). For the most cited authors, the report shows they are from institutions located in the following countries: USA (10), China (5), Portugal (2), South Korea (2), Australia (1), and Japan (1). Although selecting only the top twenty authors and the top most cited ones is a small sample, this data provides an indication of which are the most active countries. The top twenty most cited articles in the field can be found in Table 4, seventeen of these papers were published in the last nineteen years.

Table 4: Top twenty cited research articles as of July 2019 in Web of Science

Times Cited	Journal Articles
6755	Langer, R. and Vacanti, J.P. 1993. Tissue Engineering. *Science* 260(5110): 920-926.
4552	Zuk, P.A., Zhu, M., Mizuno, H. et al. 2001. Multilineage cells from human adipose tissue: Implications for cell-based therapies. *Tissue Engineering* 7(2): 211-228.
3455	Allendorf, M.D., Bauer, C.A., Bhakta, R.K. et al. 2009. Luminescent metal-organic frameworks. *Chemical Society Reviews* 38(5): 1330-1352.
3160	Hutmacher, D.W. 2000. Scaffolds in tissue engineering bone and cartilage. *Biomaterials* 24(S1): 2529-2543.
3111	Stuart, Martien A. Cohen, Huck, Wilhelm T.S., Genzer, Jan et al. 2010. Emerging applications of stimuli-responsive polymer materials. *Nature Materials* 9(2): 101-113.
3010	Karageorgiou, V., Kaplan, D.2005. Porosity of 3D biomaterial scaffolds and osteogenesis. *Biomaterials* 26(27): 5474-5491.
2926	Lee, K.Y. and Mooney, D.J. 2001. Hydrogels for tissue engineering. *Chemical Reviews* 101(7): 1869-1879.
2844	Lutolf, M.P. and Hubbell, J.A. 2005. Synthetic biomaterials as instructive extracellular microenvironments for morphogenesis in tissue engineering. *Nature Biotechnology* 23(1): 47-55.
2744	Gibson, Daniel G., Young, Lei, Chuang, Ray-Yuan et al. 2009. Enzymatic assembly of DNA molecules up to several hundred kilobases. *Nature Methods* 6(5): 343-U41.
2716	Drury, J.L. and Mooney, D.J. 2003. Hydrogels for tissue engineering: scaffold design variables and applications. *Biomaterials* 24(24): 4227-4351.
2699	Greiner, Andreas. and Wendorff, Joachim H. 2007. Electrospinning: A fascinating method for the preparation of ultrathin fibres. *Angewandte Chemie-International Edition* 46(30): 567-5703.

2608	Mathew, Simon, Yella, Aswani, Gai, Peng et al. 2014. Dye-sensitized solar cells with 13% efficiency achieved through the molecular engineering of porphyrin sensitizers. *Nature Chemistry* 6(3): 242-247.
2485	Hoffman, A.S. 2002. Hydrogels for biomedical applications. *Advanced Drug Delivery Reviews* 54(1): 3-12.
2385	Hagfeldt, A. and Gratzel, M. 2000. Molecular photovoltaics. *Accounts of Chemical Research* 33(5): 269-277.
2253	Tomasek, J.J., Gabbiani, G., Hinz, B. et al. 2002. Myofibroblasts and mechano-regulation of connective tissue remodelling. *Nature Reviews Molecular Cell Biology* 3(5): 349-363.
2170	Rezwan, K., Chen, Q.Z., Blaker, J.J. et al. 2006. Biodegradable and bioactive porous polymer/inorganic composite scaffolds for bone tissue engineering. *Biomaterials* 27(18): 3413-3431.
2151	Gref, R., Minamitake, Y., Peracchia, M.T. et al. 1994. Biodegradable long-circulation polymeric nanosphers. *Science* 263(5153): 160-1603.
2147	Zhang, SG. 2003. Fabrication of novel biomaterials through molecular self-assembly. *Nature Biotechnology* 21(10): 1171-1178.
2146	Lopez-Sanchez, Oriol, Lembke, Dominik, Kayci, Metin et al. 2013. Ultrasensitive photodetectors based on monolayer MoS2. *Nature Nanotechnology*.8(7): 497-501.
2082	Nair, Lakshmi S. and Laurencin, Cato T. 2007. Biodegradable polymers as biomaterials. *Progress in Polymer Science* 32(8-9): 762-798.

Recommended Basic Sources

As demonstrated in this study, biomedical engineering is covered by a wide range of disciplines, therefore searching multiple related resources is highly recommended. The following is a non-comprehensive list of reference resources specifically on biomedical engineering and a sampling of related resources that that can be used for a basic exploration of the subject. In addition, general information can also be found in basic reference resources like the *McGraw- Hill Encyclopedia of Science and Technology*.

Biomedical Engineering Reference works:

Encyclopedia of Biomedical Engineering. 3 vols. (online) Amsterdam: Elsevier, 2019.

Encyclopedia of Biomaterials and Biomedical Engineering. 2nd ed. 4 vols. New York: Informa Healthcare, 2008.

Wiley Encyclopedia of Biomedical Engineering. 6 vols. Hoboken: John Wiley & Sons, Inc., 2006.

Encyclopedia of Biomaterials and Biomedical Engineering. 2vols. New York: Marcel Dekker, Inc., 2004.

Standard Handbook of Biomedical Engineering & Design. New York: McGraw-Hill, 2003.

The Biomedical Engineering Handbook. Boca Raton: CRC Press, Inc., 1995.

Examples of Related Reference Works:

Encyclopedia of Medical Devices and Instrumentation. 2nd ed. 6 vols. Hoboken: John Wiley & Sons, Inc., 2006.

The Williams Dictionary of Biomaterials. Liverpool: Liverpool University Press, 1999.

Encyclopedia of Sensors. 10 vols. Stevenson Ranch: American Scientific Publishing., 2006.

Encyclopedia of Bio Process Technology. 5 vols. New York: John Wiley & Sons, Inc. 1999.

Conclusion

Biomedical engineering is a very complex area; we have found that some of its major sub-subject domains are: biomechanics; biomedical imaging; biomedical instrumentation and biomedical sensor; biomaterials and drug delivery; biosystems engineering and physiology; molecular and cellular engineering; and tissue engineering and regenerative medicine.

This complexity is demonstrated by the wide variety of publications from several different fields found, as well as its international output. The bibliometric analysis also shows that it is a very active field of research and discovery with a clearly noticeable increase in production since around 2001. Although this exploratory analysis has limitations, it provides a good representation of the state of biomedical engineering today.

Finally, new science librarians and LIS students should be aware that this complexity imply that a variety of databases that can be used to search the literature including Biosis Previews, Compendex, Inspect, PubMed, Scopus, ScienceDirect, SciFinder, SpringerLink, Wiley Online Library, and many others. Their use will depend on the research topic in consideration; as a rule of thumb, a comprehensive search will require retrieving bibliographic data from several sources.

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