Biomedical engineering education – status and perspectives

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Abstract— **Biomedical Engineering programs are present at a large number of universities all over the world with an increasing trend. New generations of biomedical engineers have to face the challenges of health care systems round the world which need a large number of professionals not only to support the present technology in the health care system but to develop new devices and services. Health care stakeholders would like to have innovative solutions directed towards solving problems of the world growing incidence of chronic disease and ageing population. These new solutions have to meet the requirements for continuous monitoring, support or care outside clinical settlements. Presence of these needs can be tracked through data from the Labor Organization in the U.S. showing that biomedical engineering jobs have the largest growth at the engineering labor market with expected 72% growth rate in the period from 2008-2018. In European Union the number of patents (i.e. innovation) is the highest in the category of biomedical technology. Biomedical engineering curricula have to adopt to the new needs and for expectations of the future.**

In this paper we want to give an overview of engineering professions in related to engineering in medicine and biology and the current status of BME education in some regions, as a base for further discussions.

I. Introduction

Progress in the development of medical technology and introduction of new medical devices and equipment into medicine and health care in the past several decades has significantly changed the way of providing medical services or diagnostic, treatment, therapy, rehabilitation and long-term care, and also contributed significantly to the inclusion of measures to prevent and methods of predicting disease. Medical technology is essential and indispensable for achievement of health and well-being of people, and due to increased needs of the (primarily elderly) population became one of the generators of the economy. Research, development and production of new technologies, devices and equipment for medicine and health care is based on knowledge and skills gained in the past few decades in biomedical engineering and by biomedical engineers. Biomedical Engineering significantly contributed to changes in daily health care in clinical settings and at home, and contributes to fundamental knowledge in the field of medicine and biology [1]. Biomedical engineers have an obligation to investigate and develop new technologies and methods in medicine and health, but also participate in building-up of the health system and relevant decisions with regard to the implementation, use and care of the new technologies. Wider community should also direct the research and development of medical technology in accordance with social priorities, such as presented in the European Union in programs Horizon 2020 and Health 2020 [2, 3].

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II. Short History of the BME Profession

Biomedical engineering is a field of engineering sciences that promotes engineering knowledge and knowledge in medicine and biology and improves human health by interdisciplinary activities of engineering and biomedical sciences and in clinical applications [4, 5].

Although there are records of mechanical aids and prostheses for patients [6] and on the electric stimulation by biological sources of electricity (fish) from the time of ancient Egypt nearly three thousand years B.C. [7], the actual development and growth of biomedical engineering began after the invention of the semiconductor electronic component - silicon transistors, 1947 [8], which enabled the development of accurate diagnostic devices small enough and with acceptable power consumption so that they were easily applied in everyday clinical practice. Electronics based on silicon transistors enabled design of implantable devices, where power design and small size low are essential for reliable use so that in 1958 the first electronic pacemaker was implanted to a human [9]. The invention of the microprocessor and their application in medical devices has resulted in significant changes and improvements in the functionality of medical devices, particularly in medical imaging. Most of medical images are obtained from the measured data by complex calculations: it applies to images obtained by computed tomography, magnetic resonance imaging, positron emission tomography, ultrasound etc. The increasing knowledge necessary for the development and operation of medical devices and systems and their complexity have made resulted in biomedical engineering becoming a science area with lots of specialization, just as the medical science (Fig. 1).

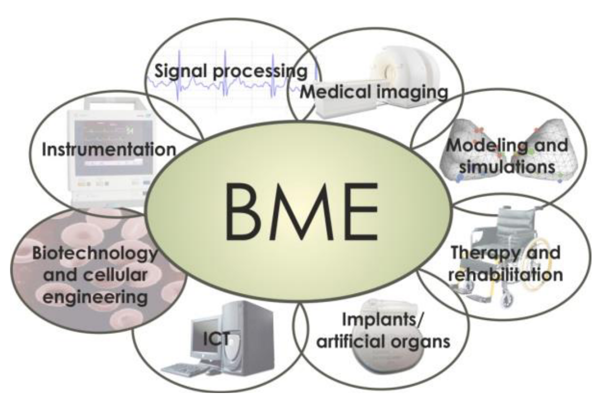

Figure 1. Some of multiple specializations in biomedical engineering

Professional organizations of engineers and physicians with interests in biomedical engineering were founded in many countries in early fifties. The Institute of Radio

Engineers (IRE) established a group to deal with "problems in biology and medicine which might be aided in solution by use of electronic engineering principles and devices" already in 1952. After merging of IRE and the American Institute of Electrical Engineers (AIEE) in 1963, the new Institute of Electrical and Electronics Engineers (IEEE) created the IEEE Engineering in Medicine and Biology Society [10].

At the international level, biomedical engineering is also present over 50 years: the International Federation for Medical and Biological Engineering (International Federation for Medical and Biological Engineering, IFMBE) [11] was founded in Paris in 1959 under the auspices of UNESCO. The first accredited university program of biomedical engineering in the United States started at Duke University in 1972 [12].

III. BME EDUCATION IN EUROPE

Biomedical engineering is a recognized profession within technical sciences in most of the developed countries where higher education curricula in biomedical engineering can be found at all three levels of the European Higher Education Area (EHEA). EHEA is the result of the Bologna Process which was launched in 1999 by the Ministers of Education and university leaders of 29 countries, aiming to create a comparable three cycle degree system for undergraduates (Bachelor degrees) and graduates (Master and PhD degrees) [13]. The main objectives outlined in documents supporting the Bologna Process were as follows [13]:

- adopt a system of easily readable and comparable degrees
- adopt a system with two main cycles (undergraduate/graduate)
- establish a system of credits (ECTS)
- promote mobility by overcoming legal recognition and administrative obstacles
- promote European co-operation in quality assurance
- promote a European dimension in higher education.

The established credit system - European Credit Transfer System (ECTS) is a standard for comparing the study outcomes and students' performance across the European Union and in some neighboring countries. One semester corresponds to 30 credits which are supposed to be equivalent to 1500–1800 hours of study. Introducing ECTS facilitated student mobility since their efforts and outcome became measurable no matter which University in the EU they entered. For BME students, this system is especially important since no higher education or research institution can assure all necessary equipment and support for such complex research as in BME and through the unique credit system they can easily spend one (or more) semester(s) in a laboratory that suits their needs.

In Europe alone, there are more than 300 universities which teach content in biomedical engineering [14]. In countries where the profession "biomedical engineer" is not yet entered into the list of registered professions, biomedical engineering is considered an interdisciplinary area.

IV. ENGINEERING PROFESSIONS IN HEALTH CARE

In recent decades, the development of biomedical engineering was intense and it was shown that the necessary specialization of occupations and fields of work. Though there are slight differences in nomenclature of engineering professions in medicine and biology, the specialization of occupations that appeared after analysis of available sources through web sites of universities, three main profiles could be identified: biomedical engineers, bioengineers and clinical engineers. In terms of scope of work, areas of sub-specialization largely follow the branches as in medicine (e.g. rehabilitation engineer). But, at the educational cycle, a set of some basic areas of knowledge is required for every engineer who works in medicine and health care [14, 15].

International Labor Organization (ILO) in its global classification of occupations - ISCO 08 Code, is citing biomedical engineers as an integral part of the health workforce [16].

A. Differences in definitions of professions

Based on the definition published by respected organizations in the field of biomedical engineering, some similarities and differences between above mentioned occupations are further discussed.

B. Biomedical engineers

Biomedical engineers are working at the interface of engineering, life sciences and healthcare. Biomedical engineers use principles of applied sciences (including engineering, electronics, chemical and computer engineering) and basic sciences (physics, chemistry and mathematics) for applications in biology and medicine [15].

Biomedical engineers bridge the medical and engineering disciplines by providing comprehensive health care services. Biomedical engineers design and manufacture innovative devices (e.g. medical instrumentation, artificial limbs and organs, imaging devices, and improve the processes of genomic tests, and the creation and application of drugs) [17]. As stated in the career guide of the IEEE EMBS, biomedical engineers use their expertise in biology, medicine, physics, mathematics, engineering sciences and communication in order to make the world healthier. Challenges created because of the diversity and complexity of living systems seek creative, skilled and imaginative people working in a team of doctors, scientists, engineers and business people, in order to monitor, restore and enhance normal body functions [18].

The World Health Organization (WHO) describes the work of biomedical engineers as follows: Trained and qualified biomedical engineers are needed for designing, assessment, regulation, maintenance and management of medical devices present in health systems around the world. Biomedical engineers knowledge and skill levels are ranging from the design and evaluation of medical devices at higher levels, up to the very technical work at lower levels (hands-on) , such as regular service and maintenance [16].

C. Bioengineers

The profession named Bioengineering and/or Biological Engineering is younger then biomedical engineering and emerged with the realization of the possibility of manipulation of living cells. Biological engineering is based on molecular biology and on engineering principles used in the design, synthesis and analysis at the cellular and molecular level, as opposed to biomedical engineering, which uses traditional engineering principles in order to analyze and solve problems in medicine, and that solutions need not be based the use of living cells [19].

D. Clinical engineers

Clinical engineers are professionals who support and enhance patient care by applying engineering and managerial skills to healthcare technology, as described and elaborated by the American College of Clinical Engineering [20]. Clinical engineers are trained to solve problems when working with complex human and technological systems of the kind found in health care facilities. Clinical engineers have the function of technological systems manager for medical equipment including very often, and information systems in health care facilities. In hospitals, clinical engineers provide valuable feedback on the operation of medical equipment and contribute to the research and development from their direct experience. Often they work in teams with nurses and other health professionals in the assessment of new concepts and products, as well as in clinical trials.

E. Other engineering professionals in medicine and biology

Research closer to computer science applied in medicine and biology resulted in development of research fields biomedical informatics, bioinformatics and health informatics. The authors consider these fields to be specializations of biomedical engineering.

V. International collaboration

As already mentioned in the previous paragraph, the WHO is counting on support from biomedical engineers in achieving its goals under the Universal Health Coverage Strategy. At the Second Global Forum on Medical Devices held in Geneva in November 2013, international collaboration to increase access to high-quality, safe, and appropriate priority medical devices was fostered with participation of main stakeholders in health care. The participants analyzed progress in increasing access to safe and effective medical devices Development of Human Resources for Health was discussed in a number of presentations and workshops as well [yyy]. However, safety of using and producing medical devices and systems is still a highly paramount aspect for improvement.

A. Safety of medical devices and systems

When comparing the definitions of these three engineering professions , can be observed many similarities . The main difference in building their careers is that clinical engineers mostly work in health institutions, in direct contact with healthcare professionals and patients, and their actions have a direct impact on treatment outcome. One of the tasks of clinical engineers is ensuring the immediate safety of patients and medical equipment operators in their environment. They are responsible for ensuring the proper operation of the devices, including their calibration. Immediate safety means preventing unintended consequences of the use of a medical device, such as electric shock, ionizing radiation, non-ionizing radiation, injuries, etc. The proper operation of the device or its accuracy, means meeting all technical characteristics and functions defined by the producer, which in practice means that diagnostic devices provide measured results (not only numerical but measured curves and medical imaging) within the limits of accuracy and therapeutic devices provide outputs that are also within the declared limits of accuracy. Malfunction of diagnostic device can lead to a completely wrong diagnosis, excessive output to some unwanted damage of tissue, and too small to ineffective therapy. WHO estimates that worldwide there are over 1.5 million different medical devices, which can be classified in more than 10,000 generic groups. The need for specialization is probably obvious to everyone, especially for people who daily come into contact with the devices and must know the principles of operation of the device so they could be properly maintained. Part of health facilities, especially small ones, do not have their own clinical engineering departments, but business is outsourced to external service providers.

VI. Conclusion

Engineering jobs are present in medicine and health care, primarily through research, development and manufacturing of medical products, devices and systems, but is increasingly encountered in clinical settings. Thanks to the safe production and maintenance, unintended consequences of medical devices are rare, but concern about the immediate security and safety of the device is necessary and appropriate to the care of water professionals engineering profession. Innovation methods for training in evaluation and
calibration of medical devices are needed in order to guarantee patient safety. Safety has to be considered as an ethical matter and entered in the education process of the biomedical engineers.

Acknowledgment

This paper has been prepared with support of the Education and Accreditation Committee of the IFMBE.

References

[1] Flexman JA, Lazareck L. Biomedical engineering and society: policy and ethics. Conf Proc IEEE Eng Med Biol Soc. 2007: 6156-8.

[2] http://ec.europa.eu/programmes/horizon2020/h2020-sections

[3] http://ec.europa.eu/programmes/horizon2020/en/h2020-section/health-demographic-change-and-wellbeing

[4] The Whitaker Foundation, Definition of Biomedical Engineering, 2006, http://www.bmesphotos.org/WhitakerArchives/glance/definition.html

[5] Imperial College London, Definition of Biomedical Engineering, http://www3.imperial.ac.uk/pls/portallive/docs/1/51182.PDF

[6] Finch, J. et al. Biomechanical Assessment of Two Artificial Big Toe Restorations From Ancient Egypt and Their Significance to the History of Prosthetics. JPO Journal of Prosthetics & Orthotics doi:10.1097/JPO.0b013e31826f4652

[7] Heidland A, Fazeli G, Klassen A, Sebekova K, Hennemann H, Bahner U, Di Iorio B. Neuromuscular electrostimulation techniques: historical aspects and current possibilities in treatment of pain and muscle waisting. Clin Nephrol. 2013; 79 Suppl 1:S12-23.

[8] "The Nobel Prize in Physics 1956". Nobelprize.org. Nobel Media AB 2013. Web. 20 Apr 2014. <http://www.nobelprize.org/nobel_prizes/physics/laureates/1956/>
[9] Larrson B, Elmqvist H, Ryden L, Schüller H. Lessons from the first patient with an implanted pacemaker. PACE 2003;26:114-24
[10] IEEE EMBS, http://www.embs.org/about-embs/our-history
[11] IFMBE, International Federation for Medical and Biological Engineering, www.ifmbe.org
[12] Duke, Biomedical Engineering, http://www.bme.duke.edu/undergrad
[13] European University Association, http://www.eua.be
[14] Pallikarakis N, Bliznakov Z, Miklavcic D, Jarm T, Magjarević R, et al. Promoting Harmonization of BME Education in Europe: The CRH-BME Tempus Project // Proceedings of 33rd Annual International Conference of the IEEE EMBS, Boston, 2011, 6522-5
[15] IEEE Engineering in Medicine and Biology Society (EMBS), http://www.embs.org/about-biomedical-engineering
[16] International Labour Organization, International Standard Classification of Occupations ISCO-08, 2012, http://www.ilo.org/wcmsp5/groups/public/---dgreports/---dcomm/---publ/documents/publication/wcms_172572.pdf
[17] Biomedical Engineering Society (BMES), http://bmes.org/content.asp?contentid=40
[18] World Health Organization, Biomedical engineering training worldwide, http://www.who.int/medical_devices/support/en/
[19] Masachusetts Institute of Technology, Biological Engineering FAQ, http://web.mit.edu/be/programs/be_faq.shtml
[20] American College of Clinical Engineering, Clinical Engineer (defined), http://www.accenet.org/default.asp?page=about&section=definition
[21] Second WHO Global Forum on Medical Devices, http://www.who.int/medical_devices/2nd_gfmd/en/