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Editorial

A Historical Perspective to Biomedical Engineering and Biomedical Engineering Education in Turkey

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We are proud to present an international journal in the field of biomedical engineering, an emerging engineering field that is dedicated to improve health and quality of life by using engineering technology and knowledge.

While the term "biomedical engineering" is relatively new considering the long history of science and engineering, efforts to improve health and raise the quality of life of individuals through engineering means are as old as mankind. Looking at the numerous exciting branches of the great biomedical tree, we notice historical milestones in almost every branch that are worth mentioning.

9000 thousand years ago, in today's Pakistan, stone age men used drills, that had flint tips and were rotated with bowstrings, to remove the cavities from the decayed teeth of their "patients" to soothe their pain [1]. Makers of these drills can be considered as the first "biomedical technicians".

Ancient Hindu text *Rigveda* mentions about *Viśpalā*, who was a female warrior (or possibly a horse), who supposedly obtained the first prosthetic leg ever: "*Straight ye gave Viśpalā a leg of iron that she might move what time the conflict opened*" [2]. While the quote is an allusion, it reveals how far back the idea of prosthetics run in human history. On the other hand, the wooden prosthetic toe discovered in an ancient Egyptian grave is very real and dates back to 1000 B.C. It is fixed to the forefoot with a textile lace and believed to be oldest functional prosthetic [3].

Simple surgical knifes have been used for millennia. Widely considered as the father of surgery, the ancient Indian physician and philosopher *Susruta* invented many specialized surgical tools around 600 B.C. and described them in detail in his celebrated work *Susruta Samhita* [4]. Famous for his rhinoplasty operations, he used tools that were equivalent to today's speculums and endoscopes. *Al-Zahrawi* of Cordoba in Moorish Spain lived 1500 years after Susruta and was the most influential surgeon of the middle ages. Recognized as the "father of modern surgery", the works of *Albucasis* (that was his Latinized name) influenced Christian Europe for 500 years [5]. He also developed more than 200 surgical instruments including a bladder probe to confirm the existence of a stone and a *lithotrite* to crush stones inside the bladder. Today technology allows us to perform surgical procedures with robotic surgical systems.

An actual prosthetic leg made of bronze and wood, discovered in Italy, dates back to 3^{rd} century B.C. It was a simple prosthetic that did not account for the motion of the knee joint [6]. Yet, the prosthetic forearm of *Götz von Berlichingen*, a German knight who lived in 16th century, had a high degree of freedom of motion since the fingers of the prosthetics can be fixed at different angles [7]. That way, he could grab his sword or shield with his artificial limb and continue his profession as a soldier of fortune. The artisans of this era were designers who brought solutions to engineering problems.

Diagnostic imaging started with the discovery of X-rays by the German physicist *Wilhelm Konrad Röntgen* in 1893. Since then, a variety of imaging techniques including CAT, MRI, PET and ultrasound have been developed and widely used in medical practices. Advancement in imaging technology has brought with itself a whole new biomedical research field that deals with what to visualize, how to visualize, how to process and/or categorize the images for diagnostic purposes.

Centuries before modern biomaterials, see shells, ivory, plants, animal teeth were used to make dental and orthopedic prosthetics. Ancient Chinese (circa. 2000 B.C.) replaced missing teeth with bamboo pegs, while Mayans implanted sea shells for the same purpose and achieved osseintegration [8]. Mayans also used wood as intramedullary nailing material to stabilize bone fractures [9]. Ivory was the biomaterial of choice for *Themistocles Glück*, a German surgeon, when he devised the first total knee prosthesis in 1890 in Berlin [10]. Today different types biocompatible materials (some natural but many artificial) are used in many tools and devices that come into contact lenses with the body. These are not only dental and orthopaedic prosthetics but include stents, contacts, artificial heart valves, ocular implants, bone plates and many other devices and tools implanted in the body.

Almost a century after the Italian scientist Luigi Galvani discovered the "animal electricity" in a dead frog's leg in 1791 [11], Wilhelm Einthoven, a Dutch physician, managed to measure bioelectricity of the heart at the turn of the 20th century and became the inventor of *electrocardiography* [12]. Hodgkin and Huxley quantified the electric action potentials in nerve cells and uncovered a big secret of the nervous system, for which they received the Nobel Price in 1963 [11]. Today, we can measure the bioelectricity of the brain, muscles and eyes as well thanks to the technological advancement in the field. Bioelectricity and bioelectrical measurement for diagnostic purposes is still an active research area for biomedical engineers.

Biomedical engineering is a very diverse field that includes a wide variety of topics from medical devices to algorithms as diagnostic tools, from mathematical models of human physiology to engineering human tissues, as exemplified above in a historical context. The historical examples also reveal the presence of a researcher with a medical background in many of these milestones. Biomedical engineering, as we understand the field today, bring people from technical and medical backgrounds together towards a cooperative research effort, since a biomedical engineer alone cannot be aware of the engineering problems a medical professional faces in his/her practice, and the medical professional alone cannot devise a solution to these engineering problems. The interdisciplinary nature of the biomedical engineering is the very soul of the discipline.

The need for biomedical engineers led to the formation of biomedical engineering programs in the Western World in the 70's. The first accredited biomedical engineering undergraduate programs in the US were established in 1972 at two universities, Rensselaer Polytechnic Institute (RPI) and Duke University. Since then, the number of programs accredited by Accreditation Board for Engineering and Technology (ABET) grew to around 130 in the US [13]. This number includes bioengineering programs and other programs that have a different name but a biomedical engineering scope. In Europe, just like in the US, biomedical engineering programs started in the 70's. A study done in 2012, revealed that there were, at that time, around 300 undergraduate and graduate programs in 40 countries including all European countries, Armenia, Azerbaijan, Georgia, Israel and Turkey [14].

I believe that my personal encounter with biomedical engineering gives some clues about how the perception of biomedical engineering evolved in Turkey through the years. Hence, I would like to blend the story of biomedical engineering in Turkey slightly with my personal story.

The first academic unit founded in Turkey in the field of biomedical engineering is the *Boğaziçi University Biomedical Engineering Institute*. It was established in 1983 and offers masters and Ph.D. programs in Biomedical Engineering. *Middle East Technical University* in Ankara started some biomedical-related graduate programs in mid 1980's. In 1992, I earned a government scholarship to pursue a Ph.D. study in the field of biomedical engineering in the US and got an acceptance from RPI. At that time, there were only a couple of graduate programs offered in the field in Turkey. Not surprisingly, before my travel abroad, I often encountered the question "What is medical engineering?" when I told people why I was going to US. At that time, most people, even those in medical professions, had a very faint idea, if any at all, about biomedical engineering.

In Turkey, the first biomedical engineering department offering an undergraduate degree is founded at the nations's capitol at Başkent University in 2000. When I returned back home in 2004, biomedical engineering as an academic discipline had a much broader recognition compared to a decade ago. Researchers with medical background were much eager than before to cooperate with engineers in biomedical-related projects.

The difference between biomedical engineering and *bioengineering* is vague and both terms are often used exchangeably within academic circles throughout the world. Yet, in Turkey, bioengineering programs usually have a curriculum that has fewer engineering courses and more biology, biochemistry and genetics content. Currently, more than 30 public and private universities in the country offer undergraduate programs in biomedical engineering. We can add to this list more than 20 undergraduate degrees offered in bioengineering. Almost all of these universities offer graduate programs in the related field as well [15].

Defining a core curriculum for biomedical engineering has been a problematic issue, in general. As Linsenmeier et al points out, many academic staff in biomedical engineering departments have degrees in other fields, such as electrical or chemical engineering, and there is always a tension among them about how much of the "other" engineer's field should be taught within undergraduate curriculum. On the other hand, two surveys which have been done in 2004 and 2019 among US biomedical engineering programs consistently revealed the presence of a de facto core curriculum. Courses offered in the following topics have been required at least by 75% of all programs surveyed and can be considered to constitute a de facto core curriculum for biomedical engineering undergraduate programs [16]:

- Freshman engineering
- Physiology (2)
- Additional biology (2)
- Senior design (2)
- Mechanics (2)
- Instrumentation
- Circuits
- Computing
- Statistics
- Materials
- Transport (*)
- Signal analysis (*)

The number two indicates that the related topic is typically covered in a two semester course. The asterisk indicates that the related topic entered the list after the 2019 survey. A principal component analysis show that there is a high probability that courses of certain topics coexist in the surveyed curriculums. The topics that are likely to be grouped are [17]:

- Instrumentation, Fluids, and Transport
- Signals, Solid Mechanics, Quantitative Physiology, and Control
- Biomaterials and Tissue Engineering
- Computer Programming and Quantitative Molecular and Cellular Biology

In general, the undergraduate biomedical engineering programs in Turkey lack the topical diversity outlined above with the historical examples and the de facto curriculum. The pioneering institution of the field in the country, namely the Biomedical Engineering Institute of Boğaziçi University, was founded by the faculty of electrical engineering of the same university, which caused an electrical engineering bias in the developed curriculums. Opening a new department and/or a program in a university requires the approval of the *Council of Higher Education* (abbreviated as YÖK in Turkish). When a university intends to open a biomedical engineering program, the tendency is to make it resemble an existing (i.e. previously approved) program to increase the approval chance of the program by YÖK, which usually causes the shortcomings of the existing programs to be transferred to the new programs. Also, it is often the case that the program is made to match the background and academic interests of the available academic staff. In Turkey, we very often see academic staff with a science (e.g. chemistry or physics) background rather than an engineering one in biomedical engineering departments.

U.S. Bureau of Labor Statistics reports 19.300 active biomedical engineering jobs in the US in 2020 and foresees an average growth of 1400 in job openings per year for the next decade [18]. Since the gross domestic product (GDP) of US is 29 times larger than the GDP of Turkey, it is safe to conclude that the number of biomedical and bioengineering programs is greatly inflated in Turkey and they provide job prospects only for a small fraction of their graduates. An analysis of the university entrance data in the last few years reveals that most universities could not even come to close to filling their enrollment quota in biomedical engineering. The academic entrance requirements for the biomedical engineering departments gradually become weaker due to the elevated supply and low demand from the incoming high school graduates. The job market for biomedical engineers is very shallow with only a limited number of hospitals and medical device importers offering employment opportunities [19]. R&D jobs are only a handful. Medical product manufactures seem to prefer graduates of classical engineering programs (e.g. mechanical and electrical engineering) over biomedical engineers. These observations indicate that existing biomedical engineering programs (graduate and undergraduate) should be reevaluated by higher education authorities both with respect to their number and their content to ensure that the number of students enrolled should be compatible with the employement potential and the graduates have the right qualifications to satisfy the needs of potential employers, especially the medical device and supply manufacturers.

We sincerely hope that our new journal provides a quality environment for biomedical engineering community to publish their work and build a commendable reputation in time.

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