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Advancements in Biomedical Engineering: Innovations in Life-Saving Technologies

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Annotation: The rapidly expanding and undeniably promising field of biomedical engineering is responsible for an impressive and ever-growing number of recent and truly remarkable innovations that are making significantly impactful changes in the realm of healthcare, transforming it in ways previously thought to be unachievable. The primary focus of recent research in this exciting and dynamic domain is the application of these groundbreaking innovations specifically to the thorough examination and in-depth analysis of major surgical procedures. The critical aim is to provide a comprehensive account of the considerable opportunities that are significantly influencing major surgeries, while also concentrating on the vital role of life sciences in the continuous development and ongoing advancement of cutting-edge medical devices, which are crucial for modern medical practice. The interaction and collaboration between engineers and physicians is absolutely essential for the enrichment and substantial enhancement of their respective expertises, fostering a synergistic relationship that greatly benefits both fields. Engineers who are tasked with effectively transferring innovative technologies to the complex and often intricate medical field ought to have a thorough and extensive understanding of medical processes and procedures. It is expected that this in-depth study will significantly increase the awareness of medical factors that are

intricately related to major surgeries amongst engineers, and will simultaneously draw the critical attention of medical staff to the fundamental engineering precepts that lie behind the thoughtful design and vital function of innovative medical devices that they rely upon. Through this important initiative, both engineers and medical professionals can work together more effectively and efficiently, leading to improved patient outcomes and advancing the highest standards of care in surgical practices, thereby promoting a healthier future for all patients and elevating the overall quality of medical care provided in various healthcare settings. [1][2][3][4][5][6][7][8][9]

A comprehensive literature survey that thoroughly covers essential aspects of life sciences is integral to this work, delving deeply into various significant areas such as clinical anatomy, physiology, and pathology that are critically relevant to major surgical procedures. This extensive survey particularly emphasizes fields that are actively developing innovative surgical tools and sophisticated implants, which are vital to significantly improving patient outcomes and enhancing overall healthcare efficiency and effectiveness. The successful translation from rigorous academic research to practical, worthwhile instruments is of utmost importance and should, therefore, be diligently supported by interdisciplinary collaborations, which thrive when initiated early on in the conception stages of new projects. Such collaboration proves to be even more fruitful and beneficial when there is a mutual understanding established; when physicians are well-acquainted with the rationale behind the planned innovations, and when engineers possess a profound comprehension of the complexities and intricacies involved in care processes. Understanding these critical nuances can significantly enhance and effectively streamline the development of advanced technologies that are not only effective but also seamlessly integrate into existing surgical practices in a manner that is both innovative and practical for all involved. Furthermore, such integrations not only allow for enhanced surgical efficacy but also foster a collaborative environment conducive to continual evolution and improvement in patient care methodologies and operational processes, ultimately

benefiting all stakeholders and leading to superior healthcare delivery outcomes. [10][11][12][13][14][15].

1. Introduction to Biomedical Engineering

Biomedical Engineering is defined by the Biomedical Engineering Society as the application of engineering principles to biology and medicine specifically for healthcare purposes, addressing a wide variety of health-related challenges faced by society today. This dynamic and expansive field encompasses a diverse array of exciting subfields, which include, but are not limited to, bioinstrumentation, biomaterials, biomechanics, clinical engineering, medical imaging, cellular engineering, tissue engineering, genetic engineering, systems physiology, and an array of various long-term healthcare strategies. Each of these subfields plays a vital role in advancing our understanding of biology, improving patient care, and fostering innovative solutions to complex medical problems. Given the conventional and well-established curricula of Industrial Engineering, the natural and seamless integration of biomedical engineering concepts into elective subjects would undoubtedly be much more beneficial for students and professionals alike as they navigate the multifaceted challenges within the healthcare sector. This discipline actively strives to apply core concepts acquired as part of industrial engineering, such as essential electrical engineering principles, critical design methodologies, and optimization techniques, to not only the manufacturing of visually impactful products but also the creation of functionally superior solutions designed to effectively address the urgent and critical healthcare needs of our time. Despite the significant contributions made by industrial engineering to the development of an extensive variety of cutting-edge biomedical devices, there remains ample room for the ongoing expansion and increasingly relevant application of its principles and methodologies in this exciting, expansive, and rapidly evolving sector of healthcare technology. Furthermore, the thoughtful and strategic integration of foundational principles from industrial engineering into other engineering fields, such as mechanical and biomedical engineering, could greatly foster the development of even more diverse, innovative, and impactful medical devices. Such advancements may potentially lead to substantial reductions in overall healthcare costs while providing significantly improved patient outcomes across diverse populations. A proposed path to further enhance the importance and applicability of industrial engineering in this vital sector consists of the deliberate and systematic integration of foundational BioE design concepts into the traditional industrial engineering curricula. For this specific purpose, elective subjects that are specifically related to BioE could be thoughtfully added to the curriculum, ensuring that students gain exposure to the latest developments and challenges in the field. Moreover, classes derived from established industrial design principles would pave the way for a cohort of more specialized design subjects, such as those focused on critical biocompatibility theory, emerging cutting-edge bioethics, and essential principles of biostatistics. This approach would not only enhance the curriculum but also provide students with a comprehensive and robust toolkit required for working effectively and innovatively within the complex and intricately woven biomedical landscape that is integral to improving healthcare standards for all. [16] [17][8][18][19][20][21][22]

The defining goals of the field encourage and foster a highly multidisciplinary perspective that is markedly distinct from traditional pure engineering branches, which is exceptionally crucial and increasingly relevant in today’s advanced and rapidly evolving society. Biomedical engineers are deeply dedicated to effectively addressing a remarkably wide array of formidable medical challenges through innovative procedures and sophisticated devices that challenge and push the boundaries of what is currently deemed possible within healthcare. The ongoing and dynamic development of Biomedical Engineering transcends mere technological progress; it comprehensively involves thorough clinical adaptation and meticulous testing processes in order to ensure both safety and efficacy in various applications across diverse healthcare settings. The most fundamental technological advances in the medical sphere predominantly stem from a multitude of engineering principles rather than solely from the biological and chemical disciplines as one might traditionally think or expect. Biomedical Engineering is characterized as a relatively young and dynamically evolving field that successfully melds and integrates complex concepts from mechanical, electrical, and even computer engineering with comprehensive knowledge drawn from the life sciences and medical sciences, creating a harmonious integration of varying domains of expertise. Among the various fields of engineering, Industrial Engineering has enjoyed a notably high level of sustained demand and has garnered professional recognition in the ever-evolving technological industry landscape, a trend that is increasingly likely to expand significantly in the foreseeable future. This informed perspective, combined with a continuously growing demand for multifunctional and technologically complex devices in the realm of modern medicine, suggests a bright and promising future for industrial engineers specifically within the biomedical sector. Here, their expertise and skills will be increasingly valued and sought after by employers in various industries, and it is where their contributions could profoundly impact patient care and clinical outcomes in ways previously unimagined. [23] [18][24][25][26][27][28][29][30]

1.1. Definition and Scope

Biomedical Engineering is a vast interdisciplinary field applying various engineering principles to solve complex biological and medical challenges, especially in the rapidly evolving healthcare sector. This area is experiencing unprecedented growth, focusing on developing innovative technologies to provide life-saving treatments and enhance patient quality of life. It encompasses crucial fields such as medical device development, biomaterials, and regenerative medicine, all vital for improving patient outcomes. The alarming rise in chronic health conditions like diabetes, heart disease, and obesity drives the demand for groundbreaking technologies to improve healthcare standards and reduce service costs. Advancements in the healthcare sector, one of the fastest-growing markets, rely on skilled engineers and specialists dedicated to developing life-saving innovations. Recent studies in Biomedical Engineering include the exploration of advanced technologies aimed at personalizing health treatments. Researchers are investigating the potential use of drones as responsive ambulances, navigating dense urban traffic to enhance emergency medical service speed, crucial during life-threatening situations. Furthermore, advancements are made in wearable and implantable technologies, allowing medical professionals to monitor real-time metrics from patients' organs and gather detailed information about bodily activities, thus translating complex data into actionable treatment insights. Though some health concepts may seem ambitious, they are poised to evolve into practical approaches for delivering healthcare on a larger scale. The continuous evolution in Biomedical Engineering promises limitless possibilities for innovation in patient care, fostering hope for a future with breakthroughs that can significantly enhance the lives of many worldwide. [2][31][15][32][33][7][34][35][36][37]

1.2. Historical Overview

Biomedical engineering is an essential interdisciplinary field applying engineering principles to medicine and biology, aiming to improve healthcare through medical devices, advanced technologies, and rigorous research. Significant technological advances have transformed surgical techniques and patient outcomes, especially in vascular surgery. The integration of engineering in medicine traces back to ancient times, but major milestones began in the early 1950s. Over the 20th century, substantial progress in biomedical technologies has been marked, driven by scientific awareness of their benefits and extensive adoption in real-world applications. Innovations are categorized into diagnostic equipment, therapeutic equipment, and rehabilitation systems. In the early 20th century, funding for rehabilitation was low, and investments in prostheses and walkers declined until the mid-century. Diagnostic device growth is notable, driven by market demands. X-ray discovery in 1895, applied clinically by Albert Hoffa, revolutionized medical imaging. The first significant engineering application in healthcare was the heart-lung machine in the 1950s, aiding coronary artery bypass grafting. The incorporation of X-ray technology facilitated rapid surgical advancements, leading to the first successful kidney transplant in 1954, supported by a dialysis machine used since 1946. In recent decades, remarkable progress in imaging, micro- and nanotechnology, and advanced simulation has propelled device innovation at micro and nanoscale levels. These breakthroughs allow for new microscale devices, such as BioMEMS and micro-invasive therapeutic technologies (MITT). Predictions indicate that enhanced minimally invasive cardiovascular methods will revolutionize interventional diagnostics, therapies, and surgeries with MITT devices. Compared to traditional approaches, MITT offers better treatment options for previously unmanageable diseases, reduces patient morbidity, and cuts healthcare costs while easing pressures on resources. To realize the full potential of MITT, it's vital to explore strategies for advancing these technologies rigorously, ensuring they prioritize safety, efficacy, and equitable healthcare distribution. [23][38]

2. Key Technologies in Biomedical Engineering

Biomedical engineering has furthered the progress of a plethora of vastly embraced life-saving technologies such as artificial hearts, pacemakers, complicated, life-saving drugs and a progression of devices that can manage, repair or replace numerous functions. In simple terms, biomedical engineering is the use of engineering principles combined with the medical and biological sciences to design and create equipment, devices and software used in healthcare. Biomedical engineers have developed a process to create drugs in such a way that they can be controlled and released exactly how and when they need to be in the human body. There is currently a bioprinter that can print skin layer-by-layer to slather onto a burn victim. Biomedical engineers are also designing artificial organs for those in dire need of organ transplants [38].

Biomedical engineers have developed heart pumps with sensors implanted into their hearts that can anticipate a heart attack before it happens. There are implantable devices that can manipulate signals in the brain to prevent a seizure. Biomedical engineering has even made way for a never before seen procedure known as deep brain stimulation that has some promising results for hardcore melancholics or even Parkinson’s patients. Deep brain stimulation uses a pacemaker-like device that is surgically implanted into the skull to send electrical impulses to different parts of the brain, depending on where the mood disorder originates. These individualize settings to manipulate signaling in the brain to prevent or treat mood disorders. [39]

2.1. Biomedical Imaging

Bioimaging makes the checking of the patients' reaction to therapy possible. Bioimaging is the explanation of imaging anatomic information from any area of the body in a non-invasive and secure manner. It is a therapist's chief tool for checking the results of radiation therapy without doing invasive operation. Due to rise in bioimaging technology, bioimaging equipment, especially magnetic resonance imaging and computerised tomography (CT) equipment, is widely used in hospitals and also as standalone systems. Bioimaging is an important innovative imaging technology. It explores how physically and chemically sensitive the properties of light can find the variation of patient health without biopsy. Since its creation at the turn of the 20th century, x-ray bioimaging has given economically low-cost body investigations that are drastic in diagnosis. Nowadays, billions of examinations are given in world hospitals every year, offering provider physicians with the most delicate internal observations. Cancer detection can be more accurate if bioimaging technology is related to many sources. It can work on non-ionized detection of biological tissues with radiofrequency (rf) and microwaves. So podcasts are now used to check the affection in a human body. According to the World Health Organisation (WHO), around 7.6 million fatalities a year are because of cancer and this number is extreme an increase day by day for longtime. Cancer detection for the case of bioimaging is non-invasive and has minimal side effects [40]. [40][41]

2.2. Biosensors and Wearable Devices

Imagine your watch monitoring your heart rate and sweating, or a patch giving real-time updates on your body temperature. What once seemed like science fiction has now become reality, with wearable biosensors and devices poised to change healthcare. A variety of wearable biosensors and devices are being developed that can sense different biophysical and biochemical signals. Most devices can only measure one type of signal, such as heart rate, but are emerging efforts to create integrations capable of monitoring multiple biological signals in one system. Wearable devices are expected to more be comfortably and unobtrusively used for continuous health monitoring. This review highlights recent advances in development and innovations of various types of biosensors and wearable devices. Now, researchers are striving to develop personalized medicine with wearable devices that provide real-time health status and diagnosis of the user [42]. Cutaneous signals approach vital physiological processes, making biosensors a transcendent ubiquitous monitoring technology for healthcare applications. Epidermal bioelectronics have demonstrated high contrast and skin-conformal recordings in in-vivo studies. Reusable bioresorbable electrodes are used for concurrent surface electromyography while preventing electrode delamination and irritation. Printing assembled multifunctional devices on cutaneous membranes yield dry interfaces of similar tangential modulus. Sweating rate, sweat loss, and hydration are quantified from time-domain analysis, indicating a statistical robustness of sweat metrics under various conditions. Biofidelic mechanical softening and chemical dissolution of materials facilitate device water solubility in vitro. Dipole antennas enhance battery-mediated systems with real-time localization and monitoring of bioresorbable devices through GPS and 2.4-GHz wireless communication. [43][44]

2.3. Regenerative Medicine

Tissue Engineering is the key for Regenerative Medicine advances to obtain new wet tissues, such as skin, muscles, blood vessels, small and large bowels, and internal wet organs; tissue engineering may be an answer for the replacement of bones. The challenge of replacing non and wet functional units has been retained for a long time; basic research focused on understanding the laws of Darwin's evolution and the genotype-phenotype relationship. Biological and artificial materials are characterized by their mechanical properties; in this context, soft or hard tissues can be replaced by using thin or voluminous implants. Priests, barbers, and other healers implanted poker and wooden sticks in broken bones, with a mortality rate of 9 patients out of 10; at the time of dissection, a few years later, the bones were found to be healed and the stick covered by functional laminar bone tissue. To keep the focus on the arts, in the Renaissance, the Italian artists Botticelli and Antonio del Pollaiolo tried to understand the artistic attitude by performing pathologies, among which aortic aneurysms; the models, wooden made, simulated soft biological matter and were cannulated with brass tubes [45].

Engineered tissues and their substitutes are believed to offer the opportunity to improve healing processes and enhance the quality of life in a clinically relevant manner. As an Italian saying goes, "Bell' e buon principio fatica," which means excellent and good beginnings require efforts. In this spirit, Regenerative Medicine allied to its bio-artistic Action has given its beginning in Italy—where biomedical engineering was somehow already born—embarked on a long, and apparently weary, journey. Biohybrid systems linking biocompatible electronics to the human body leads to several applications in life sciences and electronics. At the same time, a disruptive technology has emerged that allows for direct coupling of electronics to biological tissue. Bio-hybrid systems are rather focused on hard or fibrous tissues due to the physical form of conventional electronics. A realization of multifunctional brain-silicon interfaces implanted over a macroscale has opened new opportunities to take advantage of soft electronic materials, as well as a strategic location in neuralcepts [46].

3. Innovations in Medical Devices

Biomedical Engineering encompasses and modifies a broad range of disciplines to solve clinical or medical needs in the biomedical sphere. Biomedical engineers are supposed to possess the necessary knowledge for this multidisciplinary approach, but they are also asked to learn and innovate continuously due to the innumerable possibilities of innovation and evolution that the biomed field offers. Among these opportunities, the innovation in the field of medical devices is the one with the highest visibility and coverage. The main purpose of this section is therefore to give an overview of the improvements in the medical device field that have a greater impact and diffusion. [47]

There are numerous examples of groundbreaking innovations and products in the biomedical engineering arena that meet highly different medical needs, from surgical equipment to prosthesis, from general medical equipment to high-technology medical devices. These developments span production technology, operative principles, material science and performance of these innovative products. On the opposite side, due to the lack of competitive coverage and specific knowledge of several medical fields, there are also numerous cases where simple and intelligible solutions to known clinical problems have not been investigated [48]. Beyond specific and basic needs that require training in the specific field, there are certain common needs that frequently arise but are not efficiently approached due to a lack of systematic attitude towards the clinical problem. For these conditions, it is analyzed how a standard approach would help to identify simple, intuitively and effective solutions. [49]

3.1. Implantable Devices

Battery-free and Wireless Technologies for Cardiovascular Implantable Medical Devices: Recent technologies have shown impressive progress in the sensing capabilities of miniaturized implantable devices, particularly in the field of cardiac and neurological sensors. Yet, they still require induction powering [50]. Decades of experience and knowhow has accumulated in all major indications. This implies that the demand for harvesting small amounts of RF energy is met [51]. The battery lifespan of an implantable middle ear device is strongly affected by the energy consumption of data communication. For every stimulation event, new data on the actuation is sent out from the bone anchored electronics. An expected outcome was a much more patient-adapted treatment as the crucial information on the result of each stimulation was sent to the ENT. In the beginning, nearly all electronics run from the energy stored up in a small compartment in the device housing, the battery. In any case, long-term implants finally need to become self-sustainable. In such devices the energy source, for example a battery, is implanted as well as the sensor, but the replenishment is much trickier than near field electromagnetic! Today, there is a plethora of biomedical devices that can improve the quality and extend a patient’s life expectancy. To support patients, there are various devices that monitor the state of their organism, for instance pacemakers, defibrillators, glucose sensors and thus take the appropriate clinical steps. Patients at risk of heart attacks can implant cardioverter defibrillators (CDI), which operate in case of any problem. In the 2018, it was noticed that the majority of implanted CDI rely on this method. For this reason, funded R&D in this direction could lead to valuable results. In sum, powered from induction technology can be adequate only for a minority of biomonitoring sensors and a different technology has to be developed. Here a challenge for the development of an appropriate sensor powering method. Long-term tests of the quality and stability of the designed power supply method show promising results. The developed prototype inside test systems; with Stark antenna coaxial system outside. [52][53]

3.2. Robotic Surgery Systems

Robotic surgery systems facilitate the placement of a large number of optical fibers within the patient’s tissue by exploiting a single, fully automatic reorientation setup and a multi-arm high precision robot. An excitation laser delivered through an optical fiber can induce the fluorescence of a specific molecule, which can provide invaluable insights, for example, concerning the stage and state of tumor aggressiveness. Robotic systems have been developed to perform procedures under visual stereoscopic control. An additional approach allows the re-alignment of body parts after surgery. Surgical intervention is, in general, required to cure or alleviate various medical conditions, such cancer. Unfortunately, in a significant proportion of cases, access to the targeted area is difficult and the risks higher [54]. For beneficial or detrimental reasons, a disease can cause stiffness changes to soft tissues. Also, a situation of dynamic equilibrium, delicate for the survival of the patient, exists. Some approach which has been more attractive in recent years is the use of a surgical robot. A robot is an extremely versatile and precise machine, consisting of a set of retargetable actuators able to move and position bodies accurately within a 3D workspace. Difficult and extremely delicate surgery tasks could be successfully performed on human subjects with great advantages for both the surgeon, with reduced stress for long-lasting operations, and the patient, with less blood loss, pain, and trauma. Compared to traditional open surgery, the access is often done through small incisions. Some minimal invasive techniques require also the body being insufflated by some gas to enlarge body cavities while accessing operation sites. The subject is maintained in a still condition so that movements related to affections of heart or liver would not change the geometry of the internal organ under examination. For long-lasting operations, this may cause tissues to set into a new shape, hardly reversible even at the end of the procedure [55][56]. In abdomen and thoracic surgery, the risk of having its peritoneum or pleura accidentally perforated by surgical tools is always present. The stiffness of organs under surgery might considerably change with respect to conventional values so that, if cut, a stronger “yielding” effect may occur and an artificial rupture, previously not present, may spread. Because of the presence of tumors, not clearly detectable as they are under reflow state, damaging parts of the patient, like mechanical properties, are likely sponsored, or bold and tiny visible surgical targets are hard to reach. This may cause under promising results where the spread of otherwise controlled malignant tissue growth becomes in a critical stage. [57]

3.3. Artificial Organs

Human diseases wreak havoc on the organs and tissues of the body as it progresses, rendering these organs ineffective or unviable. Medications and treatments are useful for controlling and slowing the progression of diseases. Still, in certain cases, the only hope of survival is either a transplant of the affected organ or a transplant of cells that secrete the missing metabolite. As a result of the rapid advancement of technologies, the traditional method of healing is redefined. The convergence of materialistic engineering with life sciences leads to the start of recombinant tissue and full artificial organs [58]. As the demand for implant organs surpasses the number of available organ swaps, researchers build bio-operated organs as congested systems comprised of living biological material. Three primary types of bioengineered organs are identified: artificial organs filled with artificial cells, nascent bioengineered organs, and full bioengineered organs that are artificial reactionary engineering structures of biological cells and constituents that fulfil the roles of their functional homologues. Machine learning tools render a potential to generate patient-specific cellularization models and regulator designs to modernize the construction of full bioengineered organs in the future [59]. Organs, which are a complicated machinery of biochemical and biological processes, play an essential role in human life. Organs and tissues in the body perform a myriad of indispensable tasks to guarantee the survival of humans, e.g., heart pumps blood all around the body, the liver is necessary for metabolism and detoxification, and lungs perform oxidative metabolism and metabolic exhalation. When diseases disturb this operation of organs, it causes difficulties in humans, resulting in suffering and sometimes causing death [60].

4. Advancements in Drug Delivery Systems

In recent years, there have been remarkable advancements in drug delivery systems to treat and prevent disease more effectively. Nanotechnologies and microfluidics have shown great promise in the development of novel materials for drug delivery [61]. Specifically designed nanoparticles (NPs) or microstructured devices are generated to carry magnified drug content and to provide sustained delivery. Mobilizing cell and microenvironment responses through drug delivery has potentially constituted a dominant strategy in fighting against disease burdens for a long period. Developments in drug injection formulations, microfabricated drug delivery tools and conceptual design of embedded medicine frameworks have been reported to drive the availability of drug and increase compliant patient behavior in predefined administration procedures. An effective and accurate platform for the successful delivery of drug agents should provide appropriate stimuli and improve on the arrangement of drug supply in lethal ranges. Advantages of the system are meant to be used as a means of aligning and enhancing the efficacy of drug agents. A diverse and developing armamentarium of drug therapy has already been shown to prevent the spread of the lesion zone burden by inducing the death of malignant cells [62]. Nonetheless, the use of traditional pharmacokinetic therapeutic agents is not without a bundle of difficulties. Concerns about compliance for prescribed drug regimen behavior may not be missed and drugs may become less effective over time. The ability to deliver the drug target cells or tissue may be inadequate due to biological barriers of prominent or immune systems. It is not unusual for drugs to be inactive or degraded during absorption by the gastrointestinal tract or via the blood circulation because the size and physio-chemical properties of the molecule are not suitable. Traditional folklore, through injection or ingestion, has a tendency for a burst of drug release to be carried out rather than released continuously. Burst release is usually increasing cytotoxicity and side effects that can even worsen the disease or create a new adverse. The drug's clinical viability can often be limited by its poor solubility, stability or undesirable release profile. The patient must take medication on a daily basis, which eventually raises the burden or inconvenience to the patient, or remember to inject them on a daily basis. [63]

4.1. Nanotechnology in Drug Delivery

Mobilizing cell and microenvironment responses through drug delivery potentially constitutes a prevailing strategy to fight against disease [61]. Aspects of an effective drug delivery system are seen to be not only the delivered substance itself, but also the delivered amount. Delivering a therapeutic to a diseased site first requires improving the bioavailability of administered drugs. An additional improvement came in the appeals coplication growth of nanoscale carrier particles. This early deployment was known as nanotechnology. It sought to create and engineer physical structures that were provided to drugs in special ways. In this way, it was hoped, new kinds of drugs could be engaged, cleared round or through some erstwhile impermeable barriers. Outbacks, other than engineered structures did not effect spells their shortest linear dimension in tens of type 'o nucleons, were not noticeably changed by the body. These nanometer-sized materials were not only particles. There were cotton fibers, screen-printed electrodes, a host of polymers, dendrimers, and many other molecular constructs. All of these were advertised and explored under the same rubric as the particles. [64]

From the beginning, concerns were raised regarding the life and safety of nano materials. On the one hand, some critics charged that these new drugs and drug systems were being rushed to market without sufficient evidence of their safety. Product approval was often based on in vitro studies in which cells were exposed to nanoscale particles or in vivo studies in which animals were intratracheally administered extremely high doses which did not approximately reflect reasonable human exposure from a sporadic. Other studies were carried out with gradient glasses or surgical blade; the results of these studies bore little resemblance to the behavior of the actual nanoscale products. The fears of these critics were grounded in the hundreds of history reports of nanometer-sized materials that brought present dangers to humans and the environment. Efforts to use nanoparticles in food and agricultural applications caused particular dread because a large array. In recent years efforts to produce drugs with nano formulations have driven exploration of a diverse range of materials. In addition, efforts to fabricate engineered particles have led to the development of many new materials-Methods of these could nonetheless be disastrous if they began to interact with the human body [65].

4.2. Targeted Drug Delivery Systems

Drug delivery systems (DDS) have shown great promise in improving the diagnostic and therapeutic effects of drugs. The tissue damage, tumors, or drugs that have limited side effects should be targeted at the site of infection. Success for pharmaceuticals is possible with these goals. Targeted drug delivery (TDD) is becoming increasingly important to enhance drug pharmacodynamics and reduce their side effects in the treatment of various diseases. The concept of TDD was first presented in 1926 using an implantable miniature osmotic pump with a drug reservoir balloon. Over the past few decades, many types of TDD have been developed that include, but are not limited to, passive-targeted, active-targeted, stimuli-triggered, carrier-based, and vehicle-guided systems [66]. In the passive targeted TDD, EPR effect relies on the form of circulatory retention. Extended retention in the circulatory system can be provided using liposomes with a suitable size range. The development of mechanisms of clinical translation faces many challenges for these TDD. After intravenous injection, very few targeted drug delivery systems can achieve high targeting efficiency. Resistance to macrophages is one of the key reasons for this failure. Animal and human systems both have operators. Optimally, targeting moieties also have to be selective for cells and should be non-toxic. So, if nanoparticles are ingested by the macrophage, then the nanoparticles expose those delivery systems to the risks affecting the macrophages, resulting in failure of the drug to be delivered correctly/clearly. With clearance of macrophages, the resulted nanoparticle may not be maintained for a sufficient time to reach its target. Cancer cells, macrophages, and other cellular faults of the disease also affect unintended effects by the off-targeting action of the majority of available targeted drug delivery systems. [67]

Of all cancers in the United States, pancreatic cancer has the lowest survival rate. In part, it is responsible for broad dissemination once approached by diagnosis. In the treatment, surgery performed including the total pancreatectomy and then blood insulin treatment, face a high risk of surgery and unavailability following treatment. Various studies have tried to develop micro-sized carriers aimed at improving tissue penetration for delivery of nano-sized drug carriers. Using non-biological transport systems in bio-phase which provides an endogenous means is easier to avoid unwanted capture by phagocytes. Among them, cell-mediated drug delivery and target systems, because of their native biology specificity and efficacy enhancement, received considerable attention in the treatment of many diseases. In cell-mediated drug delivery, an excellent review of the advances and potential pitfalls that this field faces can be found. [68][69] The highlighted features of this review include the state-of-the-art design of various types of cell-mediated and targeted drug delivery constructs, and the thorough analysis of various molecular mechanisms underlying them. Since there is an urgent requirement for a sequence of cell types and technologies capable of transforming successful clinical options to patients, the development of this field will be discussed, the direction of research will be proposed, and strategies that can reduce unwanted immune effects will be suggested. A detailed review of the macrophage-mediated system, the most studied cell type in targeting delivery systems, has been made while critically assessing those aspects which may be acquired by the various cell types under consideration to guide the design of future optimal constructs. These are endothelial cell lining of blood vessels and channels, the drug-delivering system in the surroundings of a specific mode of tumor or infected tissue. Needed, a new and inventive multidisciplinary strategy that can lead to less public and more effective solutions in situations such as continuing disease sites is being prepared. It is believed that the cellular biology of targeting cell types and the development of these efforts will enable the movement of future capital. [70][71]

5. Biomedical Engineering in Disease Diagnosis

Humans have attempted to find new ways to detect diseases much earlier than cancers. As time goes on, a myriad of emerging products designed by biomedical engineers is invented to get up-to-date standards of living around the world. This paper undertakes a single disease as a case study to elaborate on how scientific findings can be corporately utilized in clinical applications. Dengue will be used as an example as it is a case study selected by the engineering group in the National University of Malaysia. Up to now, up to 45,000 people in eight countries, such as Singapore, Indonesia, Malay, and Thailand, were infected with Dengue. Biomedical engineering approaches will then be discussed with the project teams from Khon Kaen University in Thailand and the National University of Malaysia on the detection and cure of several diseases, such as dengue, malaria, cholera, schistosomiasis, lymphatic filariasis, ebola, leprosy, leishmaniasis, and American trypanosomiasis (Chagas) [72]. Non-invasive techniques that have been used to detect vectors such as mosquitoes and flies will also be discussed. Moreover, within the rapidly relaxing technological world, implantable technology for safety management will be used to detect professional and amateur monitor gravitation disorders, together with the link to joint systems and neuro-senses. [73]

5.1. Point-of-Care Diagnostics

Engineers are the conduit between modern advances, such as machinery and microcontrollers, and the practical applications that ameliorate society. Biomedical engineers have the unique obligation to funnel these advances into technologies that can heal the sick and improve the health of the general public. Moreover, the field also encompasses creating innovative tools and methodologies to aid the treatment of medical conditions. The following will examine three prominent instances in which engineers have created pioneering innovations. [74]

One technology proliferating throughout the field is point-of-care diagnostics. Initiatives range from designing a new pancreatic cancer marker created through the conjunction of a cellular automata kinetic model with experiments to proliferating telemedicine to subtype neurological diseases [75]. One distinctive diagnostic device is a lens-free imaging technology with numerous alternative point-of-care applications. The microchip has the capability to perform multiple diagnostic tests on only a single drop of blood through lenses and a pinhole diametrically opposed to the blood sample. A technique relying on the refractive index of various detection regions has been developed to multiplex the detected locations beyond the multiplexing factor afforded by imaging alone. [76]

5.2. Biomarker Discovery

Despite advances in understanding of disease mechanisms and numerous attempts to deploy new technologies in clinical settings, the translation of this knowledge into clinical practice is severely limited and complex disorders continue to pose an unsolved problem. Often, this is due to the multifaceted disease nature, which has defied earlier reductionist conceptual approaches. Solutions may lie in considering diseases from a systems perspective and employing tools such as biomarkers. This mini-review describes the principles of novel bioinformatic algorithms that can aid fast development of novel protein biomarker blood tests. Such tests can help identify predisposition to specific diseases, diagnosing diseases before intuitive symptoms appear, being helpful in both standard and intensive care and in risk assessment and monitoring [77]. Furthermore, response of the organisms to treatment or progression of diseases can be better monitored, and thereby medicine safety and efficacy can be improved. Also, biomarkers are useful for understanding pathophysiologic processes and the correlation of molecular changes with a specific disease can be better comprehended [78].

6. Biomedical Engineering in Rehabilitation and Assistive Technologies

Biomedical engineering is an ever-growing field of research and innovation, leading to life-saving innovations in healthcare and contributing to advancements in other fields like agriculture, artificial intelligence, and environmental sciences. Innovations like telehealth services, AI-controlled bionic limbs, and life-supporting implants are becoming more common and accessible, but so are new personal drug delivery mechanisms, smart contact lenses, and self-repairing prosthetics. The research being carried out in biomedical engineering is ever-evolving, resulting in new technologies and bioactive systems, but also contributing to advances in other fields such as molecular diagnostics, gene editing, and neuroscience [1]. As technology advances, people are looking to merge engineering with other disciplines like biotechnology, agriculture, genetics, and drug delivery, but also with other technologies such as 3D printing, sensors, and nanotechnology. This research is fostering collaboration among different disciplines, institutions, and countries and prompting the need for ethical reviews, specific funding, and professional training. The Journal of JMIR Rehabilitation and Assistive Technologies aims to provide a platform for such research, focusing on new health innovations and emerging technologies in areas linked with the field of rehabilitation [79].

6.1. Prosthetics and Orthotics

Researchers are beginning to delve deep into the biological systems, leading to prosthetic devices that closely mimic natural limbs [80]. During the same process it is also known how to create. It is of great assistance to the integration with biological systems. Several advanced materials and manufacturing techniques for prosthetic device components are required, so that the end product exhibits certain biomimetic characteristics. This approach helps to achieve lost functionality and movement with a natural sense of purpose and through it, xi-life love to prosthetic device efficiency and acceptance are provided. Detection of the recent biomimetic trends bio true from a wide transformation. Soft robotics, which imitates soft-bodied organisms, is widely regarded as a cutting-edge research topic, thus allowing for a level of flexibility and adaptability unprecedented in rigid-bodied robots. The implementation of a novel mechanism called Variable Stiffness Parallel Elastic Actuation (VSPEA) provides a revolutionizing development of the prosthetic knee joint, the construction of which is critical to the rehabilitation of the lower limbs. By doing with this work current and prospective progress in prosthetic and orthotic tools are encouraged to be accommodated, also recognized as p&o tools to avoid repetition. Also discussed are the challenges that arise in their design and manufacture, emotional constraints, design considerations, and inquiries into future trends, thus together serving as a resource for people to explore in prosthesis technology. [81][82][83]

6.2. Brain-Computer Interfaces

Brain-computer interfaces (BCIs) are systems that can bypass conventional channels of communication to provide direct connections between the brain and electronic devices. BCIs acquire brain signals, analyze them, and translate them into commands for output devices that carry out desired actions. BCIs do not use normal neuromuscular output pathways. The basic components of a BCI include the following: (1) a brain-signal acquisition system, (2) signal preprocessing and feature extraction, (3) signal translation, and (4) device or system control [84]. Brain-computer interfaces translate brain signals into output signals without involving neuromuscular activity, although those activities produce and effect both input and output signals. The main goal of BCI technology is to take brain signals produced by the intent and evoke command about controlling the movement of a cursor, prosthesis, or other device. Users need to be instructed and trained about how to generate brain signals to manipulate parameters of the devices to be controlled. The fact that different types of brain signals can be used for BCI control many a wide range of possible applications. Modality or level of invasiveness makes connections according to BCI's between the brain and the external world. Those connections might be direct or indirect. Most research focuses on noninvasive systems record electroencephalographic (EEG) signals from electrodes placed on the scalp. New and emerging technologies for BCI include electrocorticography (ECoG), subdural electrodes, and epidural electrodes, are direct connections as they interface with the brain or dura [85]. Dipole layer, local field potentials, and reflect the aggregate summation of cortical postsynaptic neuronal potentials. By comparison, magnetic intracranial (depth) EEG is also considered noninvasive even though it requires drilling a hole through skull bone. [86]

7. Ethical Considerations in Biomedical Engineering

Clinical research ethics is mainly concerned with the ethical matters related to living organisms used for medical research purposes, especially the human elements of such research. Therefore, clinical ethics is the concern of both personal ethics, such as honesty, sincerity, and trustworthiness, and protocols assigned strictly by the medical professions. These formal protocols are both deontological and need-based ethics. Deontological ethics is necessary to regulate the good behavior of all participating roles and to protect the patients participating in any clinical research. Meanwhile, need-based ethics is necessary to distribute the justice of medical benefits among the patients; otherwise, patients could also be exposed to research. Hence, clinical research has different ethical considerations compared to other forms of research [87][88]. However, personal ethics, based on the good nature and intellectual perception of the individual researcher, are essential, as they contribute to inquiring the sound knowledge. Research ethics are related to personal ethics and are particularly necessary for the production of sound knowledge and scientific progress. Thus, execution of experimental research wishes to acquire the sound and objective results from the experiment would naturally adhere to the proper method of conducting the experimental research and speaking about such results. Nevertheless, research all-too-often deviates from the respectable path. Academic misconduct refers to many forms of imprudence, fabrication, falsification, and plagiarism in proposing, performing, and reviewing research and in reporting research results. The policy of academic integrity demands scientific honesty in the work of every researcher. All valid forms of scholarly work in the investigation of conducting, collecting, and interpreting data should be done with integrity, transparency, and the unbiased truthfulness [89]. Therefore, unpublished work is not properly referenced. Being unethical can either cast a negative impression on the platform or serve as a counter-influence to the scientific community. It is strictly inappropriate to steal, reproduce, translate, or republish any entries without the approval of the original copyrights. [90]

7.1. Privacy and Data Security

Biomedical engineering is often praised for its role in creating medical equipment, which is credited with saving countless lives. In yet another advancement in this field, engineers have developed a breathable prosthetic skin that already shows immense promise in treating burns. However, much like the back-end of medical devices in hospitals, privacy issues continue to play a significant role in how electronic equipment will be integrated into medical treatments outside of hospitals [91]. As engineering innovations continue to create life-saving technologies, the privacy complications introduced by these technologies will force a greater convergence of engineering and legal professionals. Regardless of the emerging challenges, biomedical engineering has and will continue to work hand-in-hand with doctors in the healthcare industry, and from each of their individual perspectives, the end goal is clear in saving as many lives as possible. However, the means each field takes to reach that point differ in the manufactured time frame of their work. Medical devices must consider the privacy of patients who increasingly employ network-connected electronic medical equipment at home and on their person. In defense of this shift toward a convergence of engineering and law, the longitudinal effects of implementing new technologies in the industry may ultimately save even more lives, albeit less directly [92].

7.2. Informed Consent

The importance of written and other forms of communication that form the bedrock of the concept of "informed" in consultation cannot be overemphasized. The information needs of patients must be tailored, according to the peculiarities of each individual patient and so, the forms must be varied and those forms must be made available that operate optimally for the individual. There is an increasing interest in the feedback provided by patients about their comprehension of the informed consent process. There is now a need to establish techniques to help audit these forms for their comprehensibility, as well as their standard of information [93]. This will benefit clients, and also offers protection to the medical practitioner. Therefore, the clinical set up should encompass the assurance that what has been documented as being said, is in fact what was said, and that the patient was fully aware of what he/she was signing (technically and otherwise). Unfortunately, this scenario is not common, as practitioners tend to utilize multifunctional forms, in and out of their capacity, where options relating to the clients specific condition are instead circled, and the blank spaces that should be filled in, accordingly, are left starkly vacant. [94]

8. Future Directions in Biomedical Engineering

Each year, the Editors of the Biomedical Engineering Online journal publish the best articles that have passed a rigorous peer review process. Each article is evaluated for the novelty of its contribution to the field, adherence to sound scientific principles, and clear communication in the manuscript. The top ten articles published in Biomedical Engineering Online are noted for their subjective assessments as the Editor's choice for each year. These have been collected in Biomedical Engineering Online as a "Highly accessed" collection assembled for easy reading and appreciation [95]. Researchers and professionals practicing in this rapidly developing discipline should find these best articles valuable for keeping them well informed. Biomaterials and bioengineering are set to dramatically alter healthcare in the 21st century. On one hand, healthcare will have to answer the demands of an increasingly sophisticated, subtle and critical patient/society whose general wellness expectation and life quality are changed. The general trend of the developed countries is to search for "The Third Medicine". An advanced medicine will address physical, mental and emotional aspects of the patient. The trend in the undeveloped countries is directed towards the implementation of minimum medical services for a general patient population that do not require excessive costs. On the other hand, healthcare is to counterbalance the increasing costs with respect to the national GDP. It is obvious that this is not merely a problem of money. [38] Further, there is continuous concern for the availability and the effective use of the most suitable medical resources. Biotechnology is firmly believed to provide to a large extent much effective means by which biomedical problems of the future will be met. One prominent feature of biotechnologies is tissue engineering and, more recently, an even more ambitious approach termed regenerative medicine. [96]

8.1. Emerging Technologies

Healthcare is a field which is developing very fast with an annual capacity to introduce a number of new technologies, diagnostic and therapeutic practices for speedy recovery and increased chances of survival of patient populations. Measurement, biomaterial, biotechnology, imaging, computer modeling and simulation, medical electronics are all imbedding unidirectional effort to develop and improve healthcare, in policy making and management. The core healthcare need is witnessing a paradigm shift from organ replacement to organ regeneration. Automation in biomedical laboratory is being seen as new smart revolution for elite patient healthcare and control. Any future device or kit need patient to visit clinic physically would not be liked [97]. Clinical informatics data mining and warehousing capabilities are to be developed and be made accessible through different browser technologies. Medical Imaging and biosensors are two rapid industrially developing ancillary healthcare sectors. Both can witness average annual growth of 10%. Process automation includes the complete clinical and diagnostic measurement up to synthesizing new imaging and involve expert diagnosis except final therapy. Healthcare is developing fast with support of annually developing IT and its allied fields. Healthcare concerns with two large economic sectors, assessed over 2% of GDP and employed over 7% of the workforce, in most of the countries. Throughout the developed and developing world, populations are getting old and in epidemic numbers, diseases like cancer, diabetes and heart diseases are invading irreversible sections. The emergent world called for new technologies, diagnostic and therapeutic practice that worked to achieve speedy recovery and increased chances of survival [38]. It is expected, generally speaking, that the field of healthcare would have developed in its capacity to introduce, on average, about 3 new technologies a year, adequate for creating demand, technological innovation or import to supply met. Japan, for example, seems currently to have too many new technologies in its pipeline, suggesting that there is scope for a more selective process of introduction. At the same time, it is anticipated that the slew of new technologies, mainly, medical electronics computer modeling & simulation, biomaterials and biotechnology, will have taken place within the developed and in an increasing number of developing countries, would require the health services of these countries to learn to regulate, evaluate and – wherever possible – decentralize such technologies. [98]

8.2. Interdisciplinary Research

Two decades into the twenty-first century, revolutionary medical technologies and practices have paved the way for what seems like the start of an era of unprecedented desire in transformative care. Biomedical engineering is at the core of this era's crucial advancements. Engineered materials for biocompatibility and therapeutic drug delivery, vaccines, organ and tissue transplants; micro- and nano-technologies for minimally invasive diagnostics, surgery and image-guided therapies; cell and tissue engineering; brain implants and their algorithms; genetic and cell-based therapies; 3D and 4D bioprinters: these are but a few examples of the recent developments and life-changing technologies that have garnered significant attention from the media and at the same time exposed broad public unfamiliarity with the technical (as well as ethical, societal, and political) details of such technologies [99]. However, both bioengineers and the users of their innovations are currently facing questions whose answers lie at the identifying edge of the existing knowledge. These discoveries, and thus their communication, involve a lot of overlapping topics in biology, engineering, and mathematical sciences. As a discipline, Biomedical Sciences is designed to help portray these complexities. Unfortunately, until quite recently, these questions and gaps were addressed only at a very advanced, state-of-the-art level of technical expertise, which is generally largely inaccessible to the lay public. Biomedical engineering advances should therefore tackle a delicate challenge of popularising the technical discussions across a wide range of non-professional audiences, while emphasizing those technologies and approaches that are most directly or inevitably affecting us as users, citizens, patients and ethicists. [100]

Conclusion

During the last century, we have the privilege to witness, as well as development and grow in the field of medicine which is no less than phenomenal. In many ways, the development in the field of medicine has been an index, as well as driving of, the technological strides that have marked the 21st century. Indeed, the march of technology, and the new world of the 21st century are sometimes epitomized by the latest advances made in the science, as well as practice of, medicine. It would be interesting to speculate how future human doctors, and their human patients, will respond to the current multifaceted incredible anatomy chemistry and circuitry of an MRI. And there is little doubt that as the field advances and the technology becomes robust, and the cost becomes down, machines like the MRI stand a good chance of beginning a new era of radiant imaging, and at the same time, changing the fine art of medical diagnosis, as well as poorer second opinion crafted by the intuition and experience of doctors still struggling and a great need to keep this powerful alliance.

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