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Briefing

Helmholtz Biomedical Engineering

Medical Technologies of the Future

Biomedical Engineering

Smart prosthetics and custom-tailored immune cells, nano transporters for drugs and AI-supported cell analysis: numerous new technologies are on the verge of breakthroughs in the field of medicine. These advancements combine insights from the life sciences with application-oriented engineering – this rapidly growing international research field is known as "Biomedical Engineering". It has the potential to significantly improve healing and the quality of life for patients and their families.

However, Germany does not yet fully utilize this potential. The development of innovative medical solutions often takes a considerable amount of time, despite Germany offering excellent conditions for this scientific and economic sector.

Thanks to our broad and excellent research base, at Helmholtz we possess the necessary knowledge, data, and high-performance equipment, as well as close connections to industry, to ensure Germany becomes a leading international location for Biomedical Engineering.

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Why Biomedical Engineering?

Worldwide, an increasing number of people suffer from diseases such as cardiovascular disease, diabetes, dementia, and cancer. With Biomedical Engineering, we are able to develop completely new therapeutic concepts to combat these diseases. Biomedical Engineering revolutionizes early detection (prevention), personalized diagnostics, and treatment strategies, making them more targeted and efficient. For example, tissue samples are analyzed down to the molecular level, drugs are administered only when they are guaranteed to help, and are applied locally. Using artificial intelligence, doctors and their surgical teams will soon be able to draw on the experience of thousands of similar cases worldwide.

What is Helmholtz's Contribution?

For many years, we at Helmholtz have been researching and working on the biomedical technology of the future. Our Helmholtz Centers are now pooling their expertise in the "Helmholtz Biomedical Engineering" initiative. In this way we aim to deepen interdisciplinary exchange of ideas and accelerate product discovery and development as well as create companies. To this end, we work closely with industry, promote entrepreneurship, and support biomedical startups. We also invest in the training of a new generation of bioengineers: not only will we offer them ideal conditions for outstanding research, but also teach them the necessary entrepreneurial know-how in specialised doctoral programs and fundamental business formats. At the same time, important ethical questions need to be addressed, such as the consequences of genetic modifications in humans, crops and livestock. The network will transparently inform the public about these topics, thus initiating societal discussions and providing scientific support.

Nine Helmholtz Centers are involved in the task force "Helmholtz Biomedical Engineering":

- German Cancer Research Center (DKFZ)
- German Center for Neurodegenerative Diseases (DZNE)
- Forschungszentrum Jülich
- Helmholtz Munich
- Helmholtz-Zentrum Dresden-Rossendorf (HZDR)
- Helmholtz Center for Infection Research (HZI)
- Helmholtz-Zentrum Hereon
- Karlsruhe Institute of Technology (KIT)
- Max Delbrück Center

A Revolution for Medicine

Experts in Biomedical Engineering research at the intersection of science and technology. They leverage insights from fundamental biomedical research to develop innovative devices, systems, and therapies. These advancements are driven not only by the life sciences but also by numerous other research fields: for instance, data science, which optimizes a multitude of devices through machine learning, or materials science, which develops improved materials to produce human tissue and implants in the laboratory. Additionally, new findings in physics enable increasingly precise sensors, radiation devices, and imaging apparatuses. Biomedical Engineering integrates this knowledge to design marketable products – for the benefit of all patients and society.

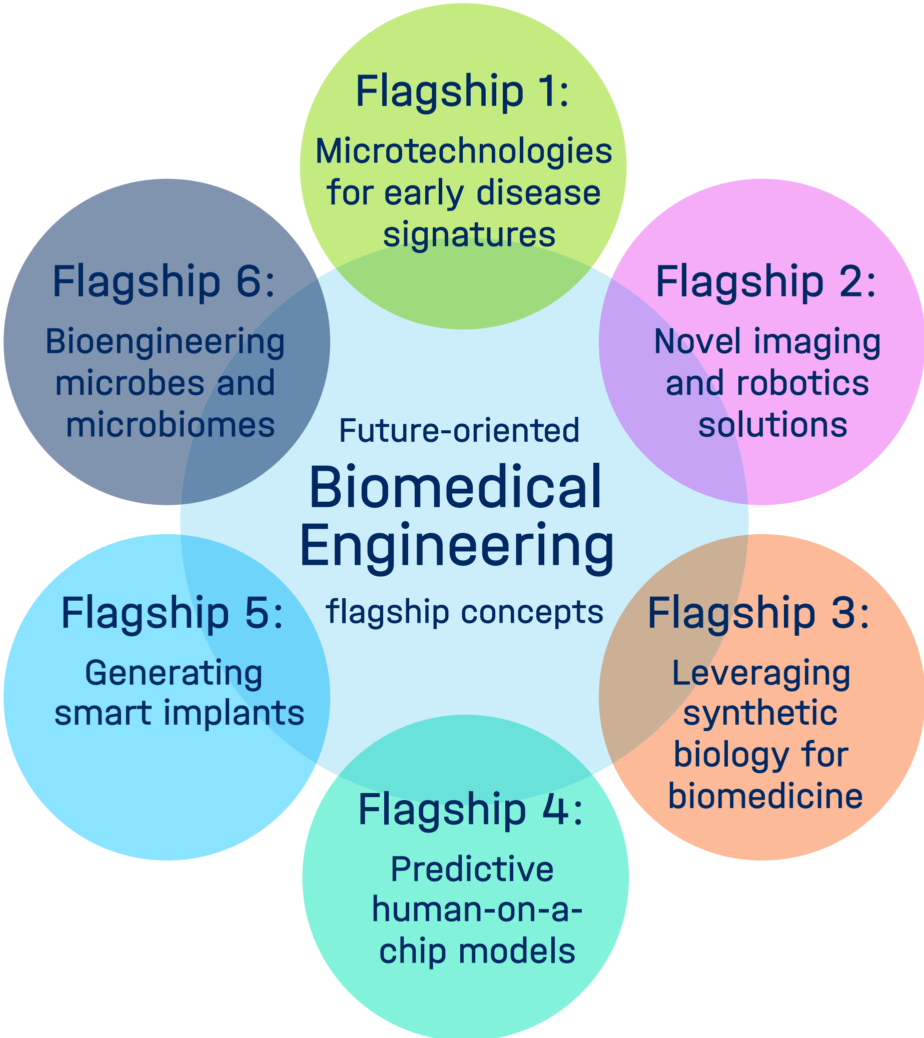
Biomedical Engineering will fundamentally improve the prediction, prevention, diagnosis, and treatment of diseases. This research field provides us with entirely new methods, devices, substances, and tools, which will be far more effective than existing approaches for numerous diseases. Experts anticipate that Biomedical Engineering will revolutionize our medicine. One of the most well-known examples of this is the gene-editing tool CRISPR-Cas9. It allows for the correction or alteration of specific DNA segments within cells – a transformation for a variety of genetically caused diseases. The first therapy utilizing CRISPR-Cas9 technology has just been approved in the EU. It targets patients with sickle cell anemia – a widespread genetic blood disorder that was previously considered incurable.

"We will only solve the great challenges of 21st-century medicine if, similar to modern engineering sciences, a new, solution-oriented generation of bioengineers translates the latest technologies and insights from biomedical research and neighboring disciplines into innovative preventive, diagnostic, and therapeutic procedures across disciplinary boundaries. Helmholtz is excellently positioned for this transdisciplinary exchange."

Otmar D. Wiestler
President of the Helmholtz Association

Medical Technologies of the Future

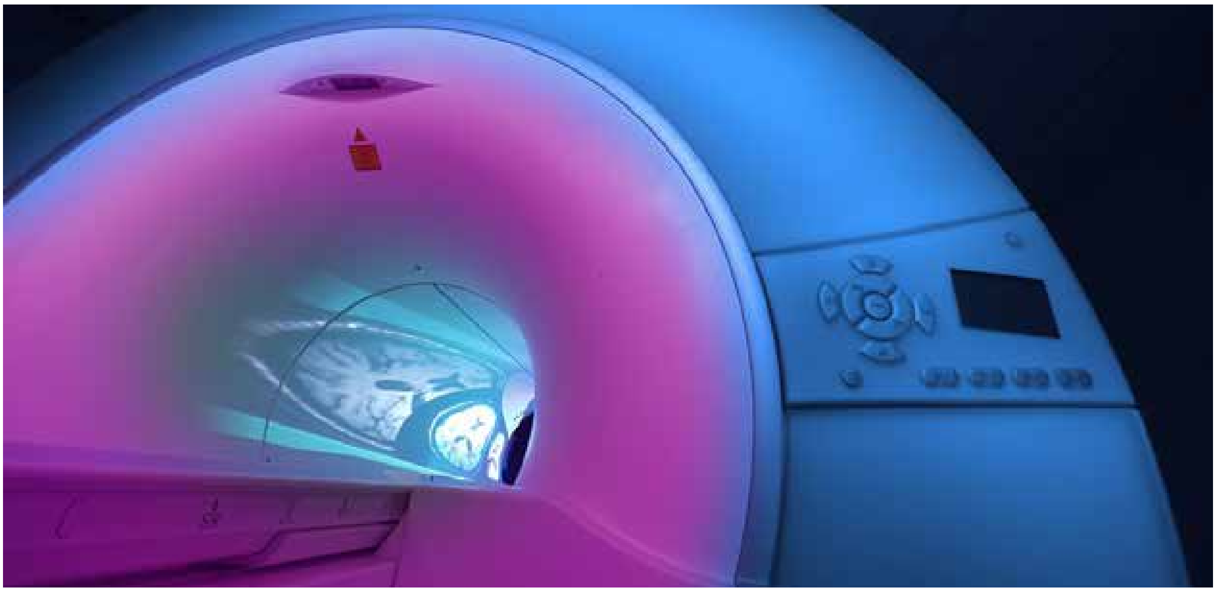
With "Helmholtz Biomedical Engineering", we aim to bring similar successes across the entire breadth of 21st-century medicine. Our activities are divided into six main focus areas:



1. Micro- and Nanotechnologies for Early Detection

We are developing new diagnostic methods to detect diseases before symptoms manifest. This includes identifying new biomarkers, refining single-cell analysis, and designing practical microfluidic platforms. These systems, which function like miniature laboratories, can perform thousands of tests on small tissue samples. This is particularly useful in cancer treatment, as tumors can vary greatly from person to person, requiring individualized therapies. Microfluidic platforms enable this by testing how extracted tumor cells from patients respond to various drugs. Within a short time, they reveal which treatments the malignant cells respond to best.

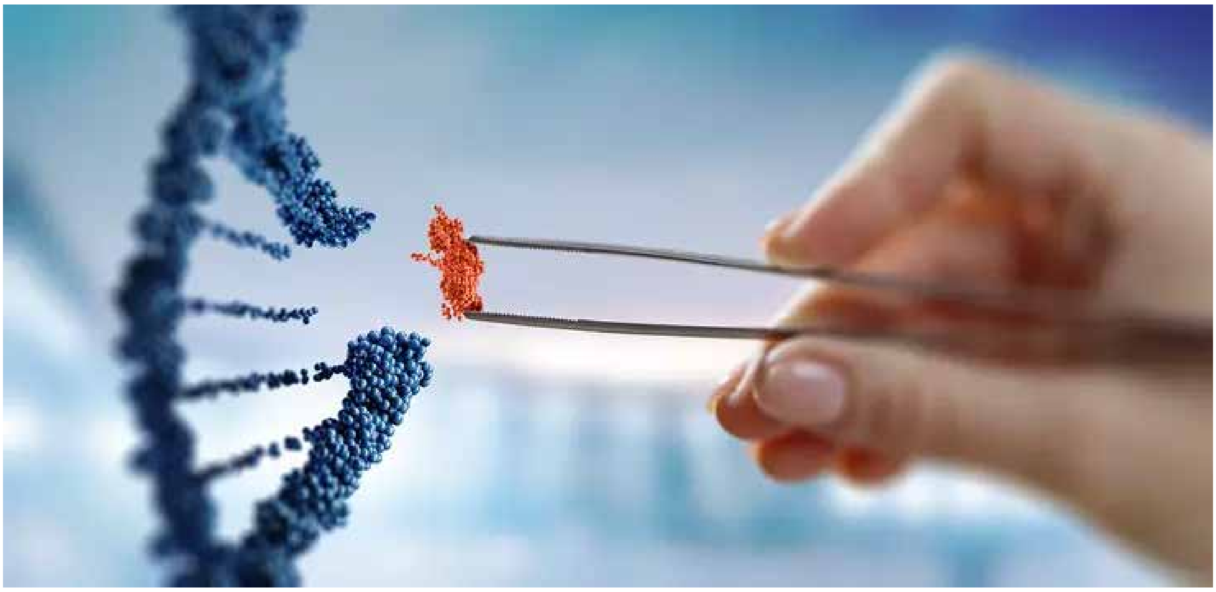
2. Novel Imaging and AI Diagnostics



New AI Tool for brain tumor diagnosis: enhancing brain tumor imaging analysis with artificial intelligence (image: Forschungszentrum Jülich/Ralf-Uwe Limbach).

We are working on new imaging techniques to accurately locate and display disease sites with high resolution, even in real-time. This allows for better planning and control of surgical interventions. We are developing the necessary devices, innovative contrast agents, and biosensors. Some of these systems are designed for easy home use by patients to monitor their own health metrics. Others provide doctors with an unprecedented wealth of information, enabling them to make decisions about individualized therapies. We are also developing AI systems that reliably analyze imaging data and extract information for therapy and diagnostics. These systems compare the available data with numerous similar cases worldwide, thus identifying the treatments with the highest success rates. Such technologies democratize access to modern medicine, as they can analyze data from patients living in remote or less developed countries, and facilitate access to the procedures and their results.

3. Synthetic Biology and Gene Therapies



The CRISPR-Cas method allows for targeted removal, insertion, or deactivation of DNA segments (image: Sergey Nivens/Shutterstock).

We are developing methods to remove damaged or superfluous gene sequences from cells, using tools such as the CRISPR-Cas9 gene-editing system. This radically new approach aims to treat and, if possible, cure diseases at their source – the cells and genes. To achieve this, we research diseases at the molecular level and develop innovative methods to replace damaged molecules, tailored to each individual patient. For these personalized therapies, we also design specialized AI programs that pre-test which customized proteins, biomolecules, or genetic programs are particularly suitable for patients. Additionally, we are developing optimized delivery systems to transport the therapeutically effective cells and genes to the desired target region within the body.

4. Human-on-a-Chip

We are improving predictions about disease progression and therapy effectiveness by developing tiny experimental systems that mimic the human body. These systems are known as Human-on-a-Chip. To create them, we cultivate miniature organs (or tumors), place them on a microchip, and connect them with tiny channels to replicate the human circulatory system. These models can also be individualized by developing organ-like microstructures from patients' tissue samples. This allows us to study the interactions between different organs, analyze their cooperation in various diseases, and test the effectiveness of new drugs. To realize these completely novel models, we are working on a variety of innovative technologies, including microfluidic systems, gene sensors, and 3D bioprinting, which enables us to create tissues from living cells or other biomaterials.

5. Smart Implants

We are creating a new generation of implants made from innovative biomaterials that can replace tissues, be customized to meet individual patient needs, and be monitored using smart technologies. To achieve this, we use so-called digital twins: we design an implant first as a digital model. This allows us to test its functionality and potential complications before use in the patient. Additionally, we can determine which materials are best suited for the implant. We are also developing sensors for the implants to monitor important health data, such as the healing process, and to signal an alarm if complications arise from the implant.

6. Microbes and Microbiome

Bacteria in the human body are specifically modified to protect humans from diseases (image: Design Cells/ Shutterstock).

We harness the potential of the bacteria in our bodies and modulate individual microbes to protect humans from diseases. These modified microbes can produce novel antibiotics, repel pathogens, or specifically target and destroy cancer cells. To make them function this effectively, we need to gain a deeper understanding of the structure and functionality of microorganisms, both individually and within their complex interactions in the microbiome. Additionally, we are developing innovative methods to adapt bacteria for therapeutic use. In patients, these adapted bacteria could restore balance to the microbiome in the human gut or ward off pathogens.

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