Welcome to the Wonderland of Physical and Engineering Sciences in Healthcare.

The human body can be described as a machine controlled by the world's most sophisticated microcomputer, about the size of a grapefruit and largely self-programmable. The machine is self-propelled in any direction with a forward speed of up to 30 kilometres per hour or so but capable of only transient vertical travel to a maximum height of about 2.5 metres. It is largely waterproof, entirely rustproof and partially immersible. Its control is effected, with automatic feedback, through self-adjusting binoculars and by auditory, olfactory, tactile (from sound, smell and touch!) and taste signals.

The machine is equipped with a pair of sophisticated remote manipulators. It is powered by a wide variety of fuels (ideally unleaded) *via* a multipurpose carburettor that is partly self-regulating. The machine can self-replicate (with assistance from a similar machine), producing a hybrid model. Although no guarantee is provided, a new machine has an expected lifespan of about 70 years.

To a large extent, the machine is self-repairing. However, in the event of a malfunction, diagnosis of the problem (and its correction) should be achieved ideally without lifting the bonnet and with minimal damage to external bodywork or internal components. However, no manuals are provided relating to construction, function, operation or repair. Instead, there is a need to rely on science in general and particularly on Physical and Engineering Sciences.

The International Union for Physical and Engineering Sciences in Medicine (IUPESM) comprises a global network of 60,000 graduate Medical Physicists and Biomedical Engineers in about 100 countries. These dedicated professionals are working to improve health and well-being of people throughout the world, particularly in Developing and Emerging Countries. All members of IUPESM have specialised postgraduate training, many with higher degrees, and there are increasingly national statutory requirements for registration to practise. Their activities include research and development that exploits Physical and Engineering Sciences for the maximum benefit of patients and people with disabilities. Scientific support is provided for clinical colleagues in a wide variety of diagnostic and therapeutic procedures and, in some cases, services are provided directly to patients and the disabled.

IUPESM is committed to improving public understanding of the applications of science and engineering in health care. This brochure, produced with support from the International Council for Science (ICSU) of which IUPESM is a member, is intended to describe in readily understandable language some aspects of the 'Scientific Wonderland', caring for the 'Human Machine'.

We are greatly indebted to Professor Brian Diffey for his primary role in producing the brochure and to members of IUPESM, particularly Professors Dov Jaron, Al Wald and Colin Orton, for their editorial contributions. We hope that you will find its contents of interest.

Professor Keith Boddy
Past President of IUPESM

Professor Jean-Pierre Morucci
President of IUPESM

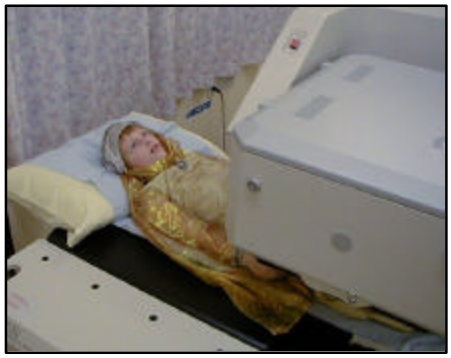
The 20th century was an inspirational period for physics and engineering applied to medicine. The seeds for the rapid growth of Medical Physics and Biomedical Engineering in healtcare were sown in the closing decade of the 19th century by three important discoveries:

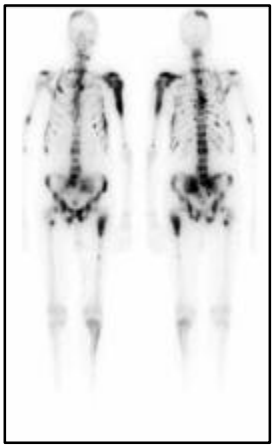
- X-rays by Wilhelm Röntgen in Germany in 1895
- Radioactivity by Henri Becquerel in France in 1896
- The electron by JJ Thompson in England in 1897

As with other aspects of technological development, the underlying principles elucidated by physicists were soon turned into practical applications through the skill of engineers. As we enter the 21st century, Medical Physicists and Biomedical Engineers are continuing to play an essential role in delivering modern, effective health care in a wide variety of ways. The work of these dedicated health professionals takes place in hospitals, in research laboratories, in industrial concerns, in academic institutions, and in governmental organisations. Some of the more recognised activities of physicists, engineers and technologists in hospitals are summarised below.

Medical Imaging

One broad area in which Medical Physicists and Biomedical Engineers make major contributions is medical imaging. Physicists and Engineers are often part of multi-disciplinary clinical and research teams that develop and apply a variety of imaging modalities used in the diagnosis and management of numerous medical conditions. For example, in nuclear medicine patients are injected with trace amounts of radioactive materials, which are selectively taken up in specific organs. Gamma rays emitted by the injected material are then used to form an image of the target organ. The tests are especially useful in diagnosing bone cancer and heart disease.





A patient undergoing a bone scan with a gamma camera (above); a normal bone scan (far left) and a bone scan of a patient with cancer (near left), with the areas of cancer indicated by dark areas ("hotspots") on the scan.

Other ways to image inside the body resulted from the development of ultrasound scanners in the 1960s, X-ray CT (computed tomography) scanners in the 1970s, MRI (magnetic resonance imaging) scanners in the 1980s, and PET (positron emission tomography) in the 1990s. None of this progress would have been possible without the dedicated work of Medical Physicists and Biomedical Engineers.

Physiological Measurement

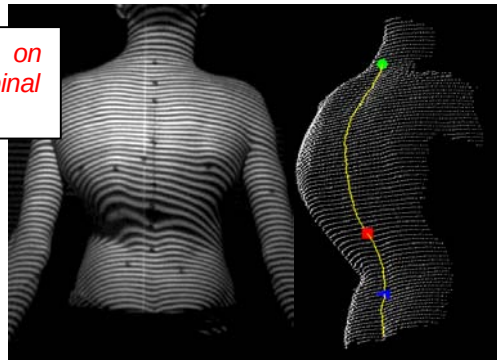
The ability to study the function of different organs depends very much on the innovative skills of Medical Physicists and Biomedical Engineers. Here, the goal is to make such measurements with the least amount of patient discomfort; in other words, to use non-invasive techniques whenever possible. In order to meet this objective, physical scientists must understand the physiological processes involved, apply physical principles to measure these processes, and then collect and analyse the data generated. Today, there is available a wide range of diagnostic measurements in medical specialties that include:

Ear, Nose & Throat
Vascular surgery
Neuroscience
Ophthalmology
Gastroenterology
Orthopaedics
Rheumatology
Cardiology
Chest Medicine
Urology
Plastic Surgery
Dermatology

One example of physiological measurement, which also includes an imaging modality, is vascular ultrasound. This procedure is used for measuring blood flow throughout the body. It is especially important in detecting the narrowing of arteries in the neck, which puts patients at risk of stroke.

A patient undergoing a Doppler ultrasound scan of blood vessels in his neck

Measuring a patient's back shape on computer to monitor the progress of a spinal deformity



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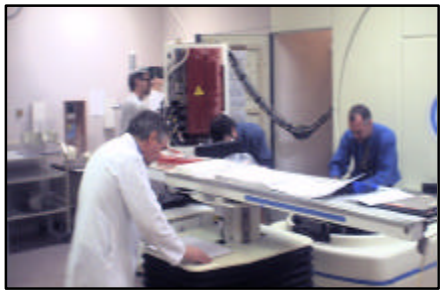
Making measurements of how physiological and anatomical changes occur in disease can help in clinical diagnosis and management.

A magnetic nerve stimulator first developed by Medical Physicists and Biomedical Engineers for the assessment of diseases such as Multiple Sclerosis.

Scientific & technical support in treatment

As an example of how Medical Physicists and Biomedical Engineers provide scientific and technical support in the treatment of patients, consider cancer, one of the leading causes of death throughout the world. Cancer is treated by surgery, chemotherapy, or radiotherapy, either alone or in combination. With radiotherapy, patients are exposed to calibrated high doses of carefully directed ionizing radiation. The medical physics team has a vital role working alongside doctors and radiographers to ensure the integrity of the radiation beam.

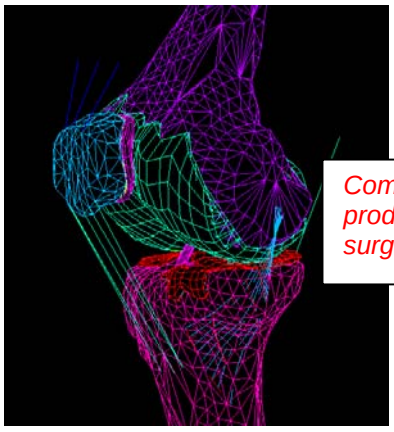


Some of the activities of medical physicists and technologists in radiotherapy:

- *measuring the X-ray output from a linear accelerator to ensure that the correct dose of radiation is administered to patients (left)*
- *carrying out calculations of radiation dose distribution to tumours irradiated with high energy X rays (centre)*
- *maintaining and repairing radiation treatment machines (right)*

Medical physicists and biomedical engineers work alongside other clinical staff in supporting treatment for diseases other than cancer. For example, phototherapy with ultraviolet radiation is used to treat patients with skin diseases such as psoriasis. Here physicists have an important role in ensuring patients receive the prescribed dose of UV radiation.

A medical physicist measuring the intensity inside a whole body ultraviolet cabin used for the treatment of skin diseases



Before a patient undergoes an operation, a surgeon may ask a medical physicist or biomedical engineer for specific tests to be done to enable the surgery to be targeted more effectively.

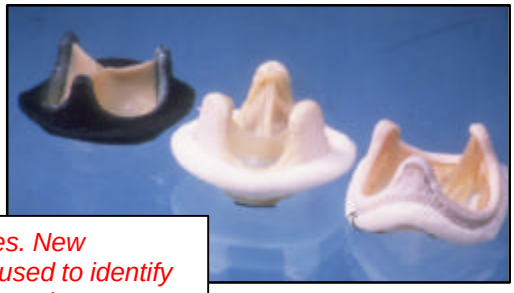
Computer simulation of a knee joint produced in order to predict the effects of surgical procedures on function of the joint.

More and more, technology is playing an increasingly vital role in planning and carrying out all types of surgery. The various imaging techniques described here are essential to the surgeon for demonstrating the area of pathology to be excised.

Using light to measure tissue oxygenation as a means of deciding on the level of amputation in a patient suffering from peripheral vascular disease

Minimally invasive surgery (laproscopy) significantly reduces the actual invasive nature of surgery, allowing a faster and less-stressful convalescence by the patient. Lasers are used in many types of surgery, providing precise and less traumatic incisions, and also allowing both destruction of diseased tissue and the joining of healthy tissue. And, of course, there is the cardio-bypass machine, allowing surgeons to operate directly on the heart, saving literally hundreds of thousands of lives throughout the world. The implanted pacemaker and defibrillator are also in widespread use to overcome electrical conduction problems of the heart. All of these life-saving devices, and many others, are the fruits of collaboration between the medical community and physical scientists represented by Medical Physicists and Biomedical Engineers.

Implantable devices are used to replace or augment defective or failing organs within the body. Medical Physicists and Biomedical Engineers have made outstanding contributions in developing these devices.



Biomedical engineers have designed prosthetic heart valves. New materials have been developed and computer simulations used to identify possible areas of failure in the framework and leaflets of the valves.

From simple, but vital, screws and plates to help mend broken bones, to actual joint and heart valve replacement and the implantable insulin pump to treat diabetes, to the yet to be perfected artificial heart, implants are improving the function and prolonging the lives of countless patients.

Development and use of Clinical Instrumentation

When patients are admitted to hospital, numerous tests are often required. In terms of both automating these tests to make them more efficient and economical and the actual design and development of these tests, Medical Physicists and Biomedical Engineers play a vital role. Perhaps one of the first such instrument developed was the electrocardiogram, which measures the electrical activity of the heart. Likewise, the electroencephalogram measures electrical activity of the brain, and the electromyograph measures electrical activity of muscles. Numerous other instruments are used in all of the medical specialties to measure and characterize patient status. Even measurements of blood and tissue composition may automatically carried out by analytical instruments designed, developed and operated by Medical Physicists and Biomedical Engineers.

The first ECG recording (left) and a modern ECG monitor (right)

The data collected by these many tests are included in the patient record. Even for a relatively brief hospital stay, an enormous volume of data may be accumulated. The ability to record, store, retrieve, and analyze data from a variety of sources and in numerous formats has become a major concern in providing efficient patient care. With the aid of computers and specific computer programs such as databases, expert systems, and computer aided diagnosis, Medical Physicists and Biomedical Engineers are devising ways to make the most efficient use of information related to each patient, both to benefit that particular patient and to conduct epidemiological studies.

Physics and engineering provide help to patients of all ages. A baby attached to a new electrical imaging system that has been developed by Medical Physicists to assess lung function in premature infants.

A specially-designed carrier to allow this disabled lady to be with her baby

Rehabilitation of physically-impaired patients requires the design and manufacture of devices such as wheelchairs, eating aids and communication aids. In many instances such devices are not commercially available and need to be designed and made by Biomedical Engineers and Technologists. This process involves visiting and assessing patients in the community in order that the device is customised to their needs. Without these technical aids, institutional care is the only alternative in many instances.

The design of artificial limbs requires the application of biomechanical techniques such as gait analysis and finite element analysis to design a match between the needs of each particular patient to the physical properties of the prosthetic device.

Gait analysis allows difficulties with walking to be studied

Powered prosthetic devices, now well advanced in development, offer much improved performance to patients who require artificial limbs. This is another area in which Medical Physicists and Biomedical Engineers provide expert knowledge.

Most Medical Physics and Biomedical Engineering departments have mechanical and electronic engineering facilities that are used to design and develop novel medical instrumentation to attack problems whose solution is essential to the development of cost-effective clinical services.

A medical technologist making a technical aid for a disabled person

Medical Equipment Management

These services interface with doctors and nurses to ensure that they can use their equipment with confidence – providing safe and fully functional equipment in the right location at the right time.

A Biomedical Engineer explains to a nurse how to operate a patient monitor

Quality Assurance services

When patients come to a hospital for an X-ray or a hearing test, for example, they want to be assured that the equipment is safe and operating correctly. Ensuring this is called *quality assurance*.

A team of Medical Physicists and/or Biomedical Engineers provides a range of activities such as acceptance inspections for new equipment (e.g. X-ray sets, CT scanners) followed by on-going regular checks on performance factors such as radiation dose and image quality.

Making quality assurance measurements on an X-ray CT scanner

Quality assurance is carried out on diagnostic ultrasound machines, especially with regard to image quality and acoustic output. The latter is particularly important for ultrasound machines used to image babies in the womb.

Newly developed medical devices are evaluated, such as patient monitors, sometimes on behalf of commercial companies or governmental agencies.

Evaluation of a new type of audiometer

Radiation Protection

Medical Physicists play a vital role in hospitals in ensuring that patients and staff are protected against unnecessary exposure to radiation.

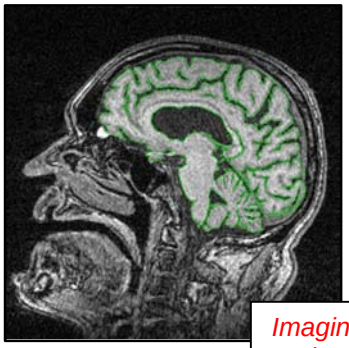
A technologist preparing dosemeters to be worn by hospital radiation workers.

Ways in which this is done include environmental surveys in departments where X-rays and radioactive materials are used, in monitoring the radiation doses received by patients, who come for radiological examination or treatment, and by staff who work in these departments.

Innovations

Medical Physicists and Biomedical Engineers are able to bring attitudes of intellectual rigour and quantitative precision to develop innovative technology that can offer improvements throughout the entire healthcare system. When such developments become commercially available, it is through a process known as technology transfer. This process ensures that the advantages of medical devices newly developed within a local environment are propagated throughout the healthcare field, to the benefit of all patients.

Research & Development



R & D is a multi-faceted activity that ranges from fundamental studies to the development of practical applications. Medical Physicists and Biomedical Engineers, often in collaboration with clinical colleagues from a wide range of disciplines, carry on this work in a variety of setting, including; hospitals, academic institutions and industry The results of successful research are published in peer-reviewed journals and presented at national and international conferences.

Imaging research aimed at improving our understanding of how the brain changes in Alzheimer's disease

Education and Training

Medical Physicists and Biomedical Engineers are often involved in teaching and training a wide range of other healthcare workers. These include not only physicians but also other professional staff, such as radiographers, speech therapists, technicians and nurses.