Prof. Zbigniew Nawrat
is a physicist. His has a PhD in medical science for his work on the development of an artificial heart, while his DSc (habilitation) was on robotic surgery. He is the director of the Institute of Heart Prostheses at the Professor Zbigniew Religa Foundation of Cardiac Surgery Development in Zabrze. He also works at the Department of Cardiac Surgery and Transplantation at the Medical University of Silesia. He is the founder of the International Society for Medical Robotics, and co-founder of the cardiac support system in Poland and the surgical robot project Robin Heart.

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"People generally associate my name with the first ever heart transplant in Poland. But I know that if I hadn't tried to do it, then four, maybe five years later someone else would have. What I am sure of, however, is that no one else in Poland would have started working on developing an artificial heart. Had I not fought to create this device, a few hundred people would not be alive today because we wouldn't have had ventricular assist devices which saved their lives and wellbeing."

– Zbigniew Religa,
famous Polish cardiac surgeon

LIFE-GIVING

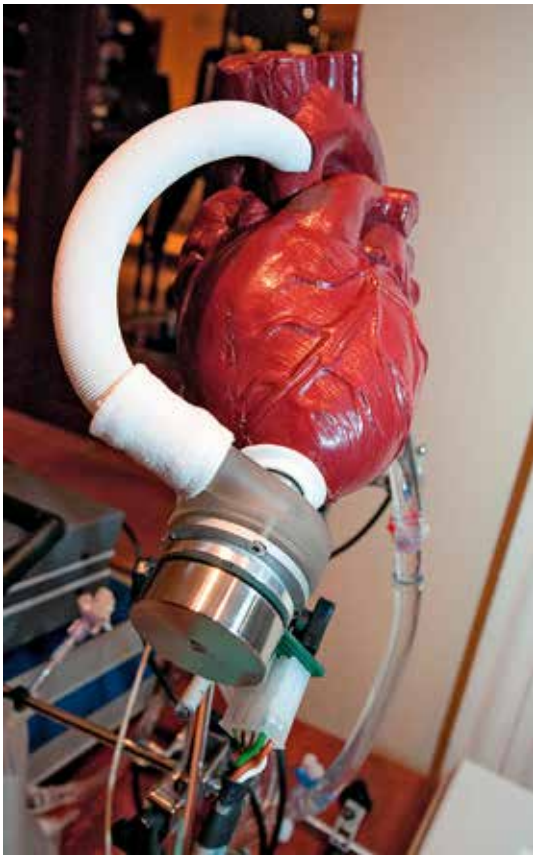
Prof. Zbigniew Nawrat

The Prof. Zbigniew Religa Foundation
for the Development of Cardiac Surgery

We are living longer than ever before – the average lifespan for men in Poland is 73.8 years (four years below the EU average) and 81.6 for women (1.4 years below). According to a report published by the Polish National Institute for Public Health, around 1% of Poland's population dies each year, with 45% of the deaths due to circulatory disease, 25% to cancer and 7% to injuries and poisonings. The 2016 ranking of the Euro Health Consumer Index (EHCI) assessing the quality of healthcare systems placed Poland in 31st place out of 37 countries. In practical terms this means that patients with certain disorders die significantly earlier in Poland than in other countries, such as our southern neighbors the Czech Republic. The Polish healthcare system seriously lacks in transparency, openness and assessment of the effectiveness of treatment by providers; what we do have, unfortunately, is long waiting lists and many missed opportunities to help patients regain their health.

Teachers

I have often wondered what Prof. Zbigniew Religa, my most important teacher, would have made of Poland's healthcare system as it is today. I first met him at a time when he seemed to be able to achieve anything. When he was planning to implant a pig heart into a patient – a last resort treatment – he prioritized phoning Father Tischner (an eminent figure in ethics during the 1990s) before alerting the Health Minister. However, for me his greatest lesson was seeing pa-



POLVAD devices: EXT, ROT and ROT2.

Shown on p. 36: Robin Heart.

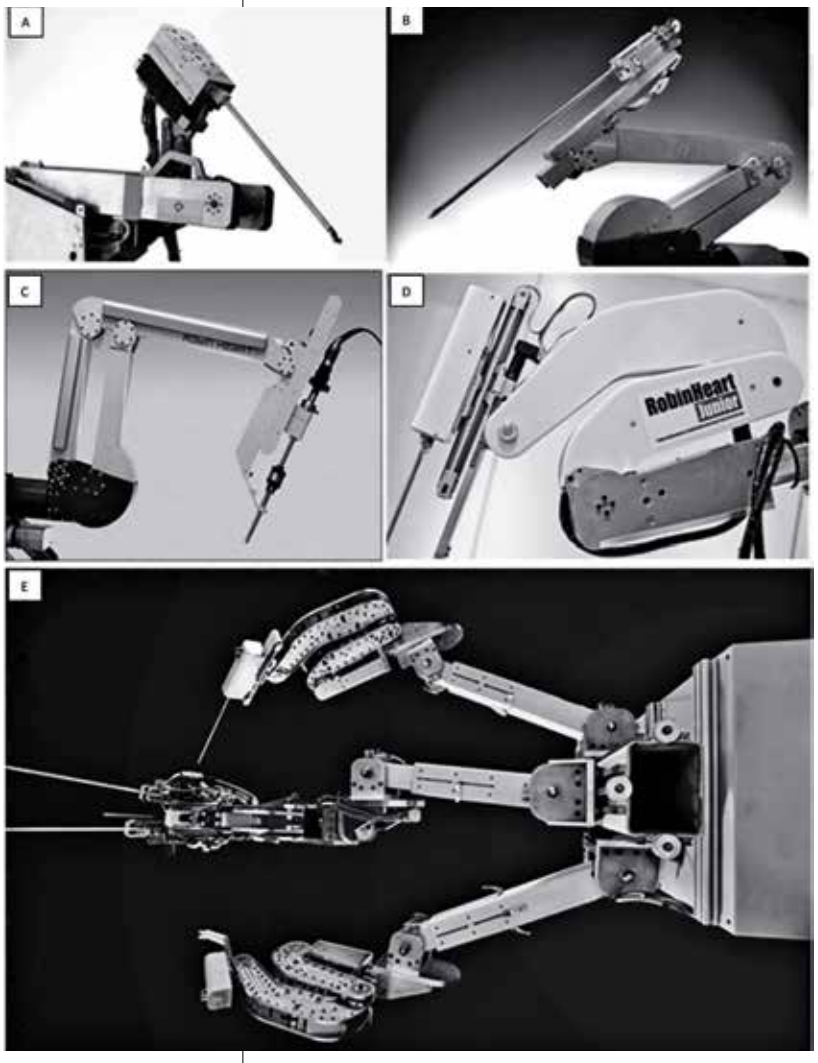
ROBOTS

tients as truly human, with all their weaknesses and greatness. He wouldn't let a patient die even when the only course of action was reaching for unconventional methods, right on the boundaries of what was seen as possible. His attitude had a profound effect on me and many other people who were lucky enough to work with him.

I originally graduated in theoretical physics, but I decided to work in the life sciences, so I started working at the Faculty of Biophysics at the Silesian Medical Academy (now Medical University of Silesia). Dr. Religa started working in Zabrze at a similar time. His patients awaiting heart transplants needed highly specialist equipment – pumps which would do the work of their damaged hearts while they waited for a match, often for several months. This was how I got involved in the development of an artificial heart, working alongside Roman Kustosz. I recruited a university friend to our team, the physicist Zbigniew Małota who specialized in laser technology, because we wanted to study the bloodstream to make sure the pumps caused no damage. I never expected that soon after I would find myself joining surgeons in operating theatres, and that I would spend thousands of hours there running cardiac bypass machines.

Foundation

Prof. Religa's tenure in the US gave him the idea of creating a foundation which would allow him to pursue his dream to develop and introduce state-of-the-art equipment and technologies in cardiac surgery. The Foundation of Cardiac Surgery Development (FCSD), raising funds and providing an open and creative working environment, was created in 1991. The organization has been led by Dr. Jan Sarna since its inception, and it now bears the name of its founder. It runs the Institute of Heart Prosthetics – an interdisciplinary research and development center with three laboratories (Artificial Heart, Bioengineering and Bio-



cybernetics) bringing together engineers, physicists, chemists and biologists working together to develop materials and equipment for treating patients with heart disorders. We have moved all research into artificial hearts to the institute, where we are also working on developing artificial heart valves, biotechnological methods of reviving the heart, surgical simulations and medical robots.

Artificial heart

At the outset of my career, I worked at the Department of Biophysics at the Silesian Medical Academy in Zabrze; we solved membrane transport equations with potential applications in the development of artificial kidneys. I joined Prof. Religa's Cardiac Surgery Department when the need arose to develop a device which would aid patients awaiting heart transplants.

That's how I ended up at the Artificial Heart Laboratory, and founded the Biofluidics Laboratory, later renamed the Biocybernetics Laboratory, and finally at the FCSD. At the Artificial Heart Laboratory I designed a blood pump acting as an artificial ventricle to aid damaged hearts. We started our work on an artificial heart with simple models and anatomical studies. We developed a system for testing our models, and after conducting experiments on animals we started clinical trials. Our work into artificial valves followed the same pattern. Heart failure caused by poor functioning of valves, which direct the blood flow within the heart, can be treated by repairing the valves or replacing them with prosthetics. Work on replacement valves has been ongoing for almost 60 years at many labs around the globe, following two main directions: mechanical valves (tilting disc and bileaflet valves, replacing the original caged-ball design) and biological. Material for biological valves can be obtained from animals (after the tissue has been chemically processed to overcome immunological barriers) or from human cadavers. The valves are set in stents which make implantation easier, or in a natural form without structures supporting the leaflets. Our great achievement was the development of a stent mitral valve using a fresh homograft – the first solution of its kind in the world.

An artificial heart is implanted to replace the patient's own heart, so it needs to be anatomically designed to fit each patient, since it is completely responsible for the blood circulation in the body. Ventricular assist devices can be fully implanted (for example small electric rotary pumps) or external, connected to the patient's heart and circulatory system with cannulas, and worn outside. Pumps can be driven electrically (such as rotary pumps) or pneumatically. Pulsating membrane blood pumps, driven pneumatically, have played an important part in Poland and beyond, showing that it's possible to save patients with heart failure, and keep them alive by pumping blood around the body while patients' hearts recover or are pending transplants. Until we were able to assist damaged hearts for long periods (several months), we had no idea that it was even possible for them to recover from damage and return to their hemodynamic function. Of course in all stories of inventors and doctors, the real heroes are patients. I remember one patient in particular, Tomasz Gruszczyński from Bielawa, who came to the hospital in Zabrze with heart failure following complications of flu. His condition was so serious that there was a real risk he wouldn't live long enough for a donor heart. We used emergency transport to import a Berlin Heart pump from Germany, which kept him alive until Prof. Religa attempted a transplant in May 1991. The story had a huge impact on me, and inspired me to develop the POLVAD ventricular assist device. It's an unusual contraption with an asymmetrical geometry which we designed to optimize blood flow using our extensive experience in laser visualizations of biofluidics. Following animal tests, we introduced

POLVAD into regular use in cardiac surgery. Since then they have helped to extend the lives of almost 400 patients until a transplant became available; one patient was fitted with one for almost two years.

When Tomasz returned to the hospital two years later because his transplant was rejected, he was the first patient to benefit from POLVAD. I was extremely apprehensive about seeing my project in action at last. Sadly, although the device worked fine, Tomasz didn't survive the surgery. His story and our part in the development of POLVAD will stay in my memory forever. The first surgery was later described in the media as an engineering success but a medical failure. I disagree with this; in heart transplants it's either a success for the patient, or a failure for the entire team.

By the time Prof. Religa passed away in 2009, several more patients were given the opportunity to live long enough to receive transplants thanks to POLVAD. We modified pneumatic pulsating pumps as part of the National Artificial Heart Programme, and today they are made by the Foundation of Cardiac Surgery Development under the name Religa Heart. At any given time, between ten and twenty patients are kept alive using POLVAD at the Silesian Centre for Heart Disease in Zabrze and five other clinics in Poland; we also use HeartMate and HeartWare, developed in the US, and the pediatric device Berlin Heart.

Robin Heart

In 1999, Prof. Religa was visited by Prof. Friedrich Mohr from Leipzig, who carried out the second ever (after France) surgery using the da Vinci robot. I asked him whether it was time we should start developing a robot of our own, and Prof. Religa was enthusiastic about the idea. The robot, nicknamed Robin Heart, was the first tool developed by my team at the Foundation; its functionality is rooted in experience we gathered during cardiac surgery to improve its effectiveness in the future. Using the robot allows surgeons to carry out minimally invasive procedures without opening up the patient's chest cavity, instead inserting surgical tools via small apertures and controlling them with a specially designed console. Before we could develop such a sophisticated tool, we spent several months recording surgeries and analyzing surgeons' movements in minute detail.

During the first phase, we made three models: Robin Heart 0, 1 and 2. This was followed by the prototype Robin Heart Vision used to control the position of the endoscopic visual tracking system, and in 2010 we introduced the modular Robin Heart mc2. The full robot replaces three people at the operating table: first and second surgeons, and the assistant holding the visual tracking system. We have also introduced the mechatronic Robin Heart Uni System, which can be easily removed from the main robot's arm and controlled using a hand grip. Animal experiments conducted in 2009 and 2010 confirmed the effectiveness of the device and control panel. The Robin Heart Vision robot, as an arm for controlling the position of the endoscopic camera, meets all the expectations of the medical team, and work is ongoing on its clinical implementation. The next generation of single-arm robot, named Robin Heart PortVisionAble, for control of endoscope position/orientation with new functional robot properties (as a lightweight, mobile robot) will be used clinically in 2018.

As well as developing robots, our team is the first in Poland to apply virtual reality technology in medicine. We have created a virtual operating theatre used for planning surgeries and training surgeons on using our robots. We are also continuing our work on computer simulations of surgeries and educational and teaching positions for practitioners of minimally-invasive and robotic surgery.

Interestingly, the word "robot" is one of few Slavic words which have entered the international lexicon, having been first coined by the Czech author Karel Čapek in 1920. I hope that Polish medical robots will become a trademark of our state-of-the-art technologies and our utmost care for our patients. We use the word "robot" to describe artificial organs, tools aiding the human body or replacing humans in certain tasks. The Polish artificial heart and Robin Heart robots are perfect examples of the effectiveness of our multidisciplinary approach to solving the problems of contemporary medicine. Robots are used in all remote surgeries – those where the surgeon and the patients aren't in the same room and the surgeon conducts the procedure using remote manipulators. Robots are also the only practical solution of standardizing surgical procedures. Due to being minimally invasive, they may even be the only way of helping certain patients. Following the widespread success of telecommunications and telemedicine, surely the time has come for "teleaction" – remote action, in which our movements are implemented by distant robots.

Humans are living increasingly longer and healthier lives, and it's up to us and our research whether our grandchildren will be able to say the same thing. We continue to strive to improve our health and happiness, and medical technologies are essential in achieving this. Scientific discoveries may be rooted in pure curiosity, but it is those that arise from the need to help others that offer the greatest breakthroughs. Sometimes we are lucky enough to combine both.

Zbigniew Nawrat

The project's R&D was originally financed by the Polish Ministry of Science and Higher Education's funds, followed by the Polish National Centre for Research & Development and several EU projects, including STIFF-FLOP and INCITE.

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