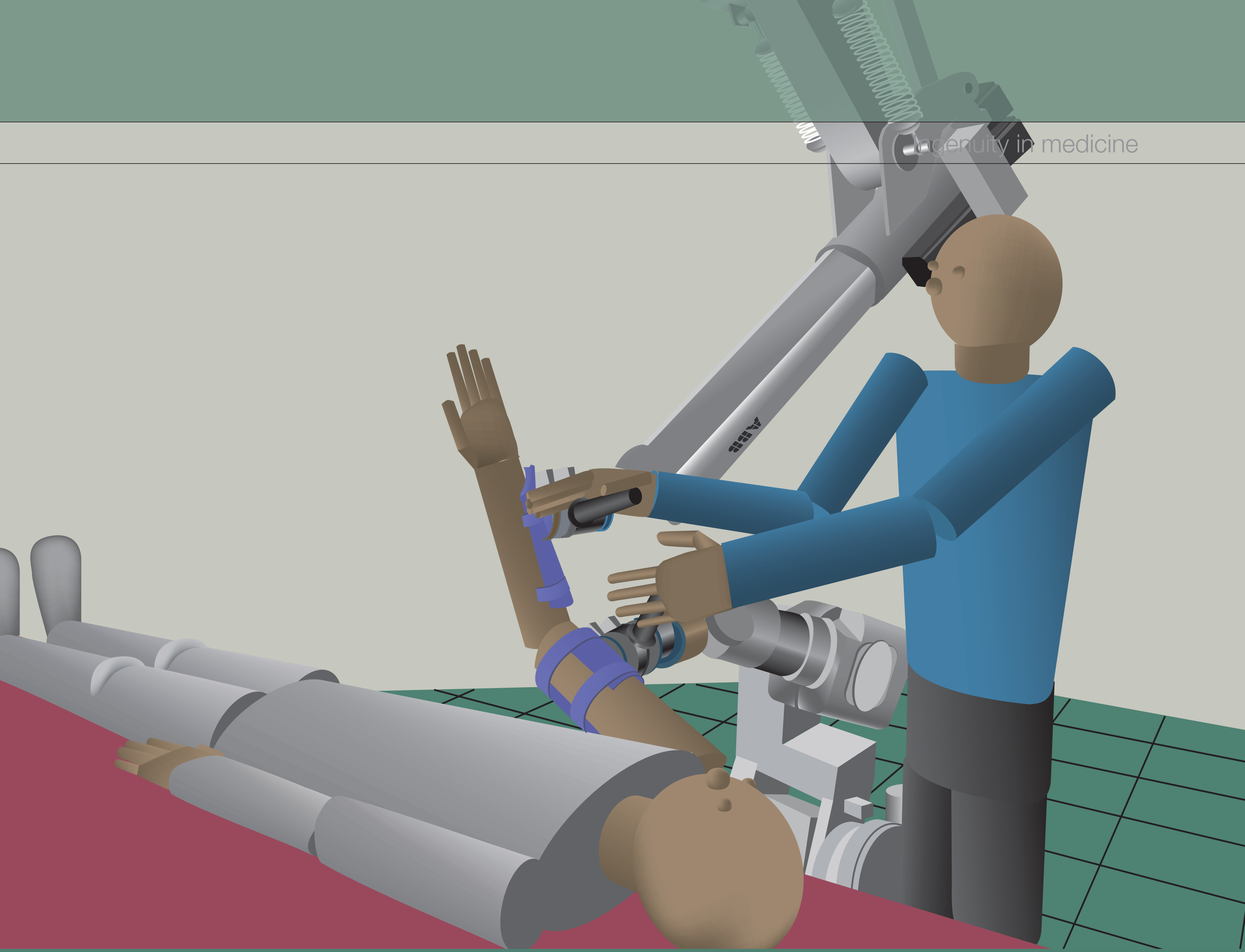

Robots with patients

Can robots really be used to enhance physiotherapy programs alongside their human counterparts?

Andras Toth, Ivan Ermolaev

Industrial robots can perform a wide range of three-dimensional movements. They are accurate, powerful, and compliant, and they can perform many of the highly repetitive tasks required of physiotherapists. The idea of using robots to assist physiotherapists in the treatment of impaired limbs is an attractive one, but is it too simplistic? This question was the subject of a research project based on industrial robots built by ABB. With the advent of mass-produced, highly reliable robots, the prospect of robot-assisted physiotherapy for neuro-rehabilitation is now a reality.

Ingenuity in medicine

The physical rehabilitation of patients suffering from spastic hemiparesis (paralysis on one side of the body) is a great challenge. The paralysis can be induced by a number of causes, including brain hemorrhage or infarct (stroke), trauma, tumor, multiple sclerosis, and birth defects. The most common cause is stroke, which can result in permanent damage. Stroke is one of the most common major neurological disorders affecting Europe's citizens, with 80 percent of survivors having significant neurological impairment and 31 percent needing help in everyday activities. In the European Union (EU), the average incidence is between 150 and 400 per 100,000 population, but there is wide regional variation. In the Netherlands, the incidence is 526, and in Sweden, it is 941 per 100,000. In Middle Asia and in the new independent states of the former Soviet Union, the incidence is 600, whereas in the United States it is 214 per 100,000. It is necessary to improve the medical care of these patients, not only in the field of acute therapy, but also in the area of rehabilitation.

1 The REHORAB Theraputic System

- a Housing
- b IRB 140 industrial robot
- c IRB 1400H industrial robot
- d Upper-arm instrumented orthosis
- e Lower-arm instrumented orthosis
- f Couch
- g Operating panel
- h Patient enabling device ("dead man's lock")

Stroke patients have been shown to respond positively to the passive movement of their impaired limbs: the brain can be retrained and a degree of functional recovery can be achieved. In the case of the upper limbs, passive movement involves a physiotherapist simultaneously grasping the patient's elbow and wrist and then repeatedly flexing the patient's arm for 40–45 minutes. For effective rehabilitation, this passive exercise should be repeated twice a day over a period of at least a month, and followed by several months' active exercise, in combination with an active physical contribution from the physiotherapist. Such levels of care are often unavailable, but even in cases where patients have ready access to trained physiotherapists, treatments could be enhanced by the assistance of robots.

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The beginnings

The history of rehabilitation robotics goes back to the 1980ies. However, because of their perceived poor accident record and heavy motion patterns, industrial robots were then deemed unsuitable for use in rehabilitation robotics. It was only in 1999 that researchers at the Budapest University of Technology and Economics in Hungary had the idea of using standard, full-scale industrial robots for human therapeutics. The REHAROB project was the first in the world to target the use of standard, mass-produced, industrial robots for the physiotherapy of spastic hemiparetic stroke patients. An international consortium, comprising organizations from Hungary, the UK, Germany and Bulgaria, was set up and began work on developing a commercially viable, two-arm robotic system. The aim was to supply personalized, three-dimensional, upper-limb motion therapy for patients suffering from spastic hemiparesis and other limb disabilities. The initial work was co-funded by the European Commission and its participants, and a follow-up project was funded by the Hungarian Medical Research Council.

The REHAROB Therapeutic System

Commercial success of the project will be dependent on the use of commercially available sub-systems. Consequently, the REHORAB system was developed around two co-operating ABB industrial robots that could be programmed by demonstration (teaching-in) using force/torque measurement. These robots are reprogrammable manipulators that can move a part or tool through a prescribed path at a defined velocity and orientation. In a therapeutic role, their capabilities can be used to move the arm of a patient, but here, there is the additional complication of patient and operator safety to consider. For this reason, components for the REHAROB Therapeutic System were selected from certified, reliable and mass-produced devices and the system was fitted with multiple and redundant safety devices. In addition to these measures, the REHAROB team also reduced the maximum speed of the robots from 3 m/s to 0.25 m/s.

The prototype of the REHAROB Therapeutic System is shown in 1 and the instrumented orthoses (custom-made braces) that hold the patient's upper and lower arm during therapy are shown in 2a. The orthoses are equipped with the standard six degrees-of-freedom force/torque transducer and a safety release mechanism. The safety release can be triggered by an emergency signal from either the patient, the physiotherapist, or the system. The machine responds by immediately disconnecting patient's limb from the robots, while continuing to support it in the orthoses, as shown in 2b.

Robot-mediated therapy is set up in three main steps: the physiotherapist programs the robots by demonstrating a number of basic exercises, with the patient in place. Individual exercises are then edited to suit the patient's needs and combined to produce a tailored, complex therapy program. Finally, the robots play back the program, allowing the physiotherapist to change the order, the speed, and the number of repetitions for each step 3. Because the patient is present during the programming phase, each therapy regime is perfectly suited to the patient's needs and the REHAROB Therapeutic System can administer the program without the personal supervision of medical staff.

> All participants showed a significant improvement in their condition according to a number of impairment and disability indicators. Patients found the robotic exercises as effective and calming as traditional manual passive physiotherapy.

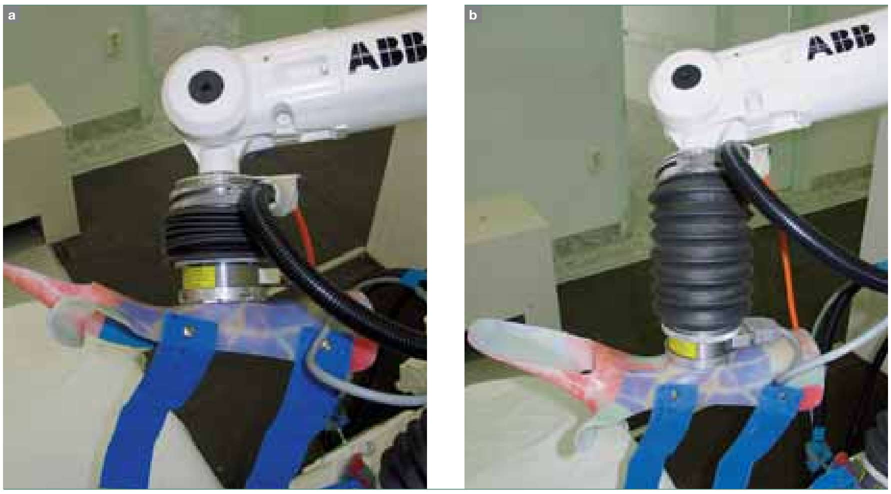
Robots are very flexible products, but since they are fixed to the housing of the Therapeutic System and work co-operatively, there are some limits on patient weight and height. Patients must weigh no more than 150 kg and must be between 160 cm and 190 cm tall. The height restriction is imposed by movement limitations on the robot arms rather than by safety issues: If the patient is too short or too tall, the robot arms will not be able to accommodate the appropriate range of movements for the therapy program. Such problems will be identified in the programming stage by a "joint of out of range" signal to the therapist during teaching-in.

Clinical trials

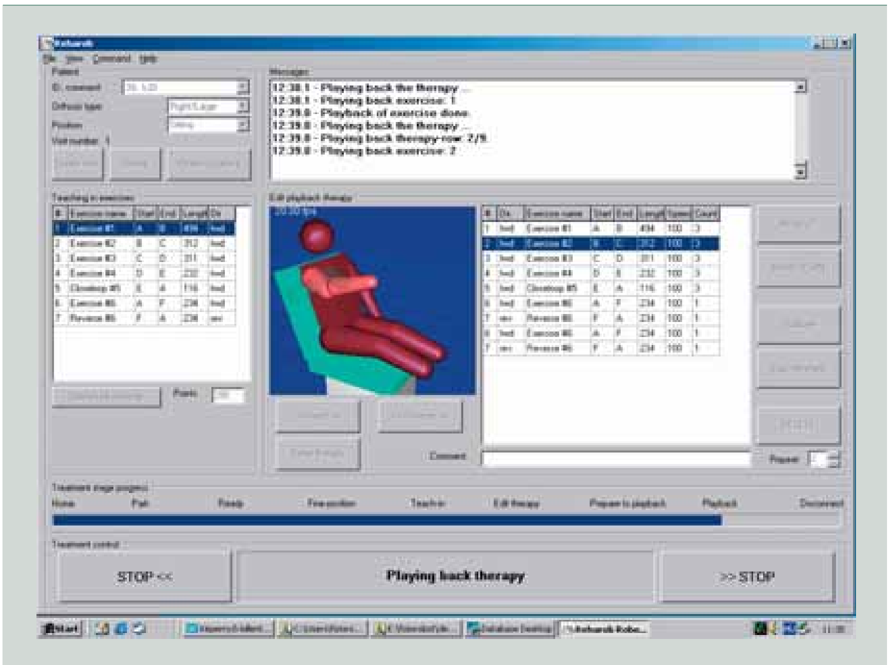
Clinical trials of the REHAROB Therapeutic System were carried out at the National Institute for Medical Rehabilitation, Budapest, Hungary, in compliance with the Declaration of Helsinki [1] and both local and national scientific and research ethics committees. The first trial, which was carried out over a period of four months, demonstrated that the robotic physiotherapy system worked safely and reliably, that patients were not afraid of the robots and that physiotherapists had no difficulty in learning how to operate the system. Twelve participants, suffering from varying degrees of disability, were subjected to a combined total of 240 robot-mediated physiotherapy sessions (20 thirty-minute sessions each). All participants showed a significant improvement in their condition according to a number of impairment and disability indicators[1]. Patients found the robotic exercises as effective and calming as traditional manual passive physiotherapy.

Following the conclusions of the first clinical trial, the system's force controller, the graphical user interface, the instrumented orthoses, and the patient enabling device ("dead man's lock") were modified in the FIZIOROBOT project. To investigate the effectiveness of the new system, a controlled clinical study was made on the FIZIOROBOT, following the same ethics approval procedure used in the initial trial. In this investigation, 30 patients with hemiparesis were

2 The instrumented orthoses of the REHAROB therapeutic system



3 The human machine interface of the REHAROB operating panel



Ingenuity in medicine

randomly divided into two groups of 15, the robotics and the control group. Patients in both groups received 30 minutes of Bobath-therapy[2] on each of 20 consecutive workdays. Members of the robotic group received an additional 30 minutes of robot-mediated therapy on each of the same 20 days. These patients received a combined total of 150 hours of robot-mediated therapy, during which no adverse events occurred. Several parameters were measured to assess the effectiveness of the treatments. There was a significant improvement in the mean modified Ashworth score[3] of shoulder aductors in both groups, but a more marked improvement was seen in the robotics group. For elbow flexors, the same score did not change in the control group and, while a small improvement was observed in the robotics group, this change was not statistically significant. However, overall results showed that, for the majority of measured parameters, improvements observed in the robotics group were better (higher mean values) than those seen in the control group.

4 A patient undergoing robot-mediated physiotherapy at the National Institute for Medical Rehabilitation, Budapest, Hungary

The future of REHAROB

The system is about to be upgraded with a new controller from ABB: A single IRC5 Multimove control unit will replace the two S4C Plus controllers. The next task will be to obtain medical certification from the Hungarian authority, ORKI, which will allow the system's use in regular robotic therapy. Depending on the outcome of a second controlled trial, which is planned for 2007, Dr Gusztav Arz, the REHAROB project coordinator, expects the system to be optimized and prepared for mass production. A detailed market survey will be carried out prior to the system's market launch. Dr Arz adds that "Embryonic business plans are drafted, but it is very likely that external contributions will be required for the production and marketing of REHAROB."

> The robots also help to monitor patients' progress by keeping detailed records of exercise regimes and patient responses.

The REHAROB Therapeutic System offers the potential for biomechanical and physiotherapist-administered upper-limb treatments based on intelligent physiotherapy. The role of the robot is not to replace the physiotherapist, but rather to widen the treatment options. The robots also help to monitor patients' progress by keeping detailed records of exercise regimes and patient responses. This helps to refine treatment programs and could be used to develop rehabilitation strategies for other neuro-motor impairments. The development of new treatments will be the focus of future work, once medical certification has been obtained and the REHAROB Therapeutic System is in regular clinical use.

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Footnotes
1) Indicators include range-of-movement measures, FIM (functional independence measure), self-care score and the Barthel index of the activities of daily living.
2) The Bobath therapy is a widely-used interdisciplinary approach to the treatment of patients with impaired motor function caused by damage to the brain or spinal cord [2]
3) A six-point rating scale used to measure muscle tone.

References
[1] "http://www.wma.net/e/policy/b3.htm"
[2] Bobath B. Adult Hemiplegia: Evaluation and Treatment. 3rd edition. Butterworth-Heinemann. Oxford. 1990