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Innovations Influencing Physical Medicine and Rehabilitation

Robotic and Sensor Technology for Upper Limb Rehabilitation

Iris Jakob, PhD, Alexander Kollreider, PhD, Marco Germanotta, PhD, Filippo Benetti, PhD, Arianna Cruciani, PT, Luca Padua, MD, PhD, Irene Aprile, MD, PhD

Abstract

Robotic and sensor-based neurologic rehabilitation for the upper limb is an established concept for motor learning and is recommended in many national guidelines. The complexity of the human hands and arms and the different activities of daily living are leading to an approach in which robotic and sensor-based devices are used in combination to fulfill the multiple requirements of this intervention. A multidisciplinary team of the Fondazione Don Carlo Gnocchi (FDG), an Italian nonprofit foundation, which spans across the entire Italian territory with 28 rehabilitation centers, developed a strategy for the implementation of robotic rehabilitation within the FDG centers. Using an ad hoc form developed by the team, 4 robotic and sensor-based devices were identified among the robotic therapy devices commercially available to treat the upper limb in a more comprehensive way (from the shoulder to the hand). Encouraging results from a pilot study, which compared this robotic approach with a conventional treatment, led to the deployment of the same set of robotic devices in 8 other FDG centers to start a multicenter randomized controlled trial. Efficiency and economic factors are just as important as clinical outcome. The comparison showed that robotic group therapy costs less than half per session in Germany than standard individual arm therapy with equivalent outcomes. To ensure access to high-quality therapy to the largest possible patient group and lower health care costs, robot-assisted group training is a likely option.

Introduction

Rapid technologic developments have occurred in recent years, particularly the technology of computer- and robot-assisted devices for upper extremity rehabilitation and virtual reality therapy. This applies to research and broadly to different arm rehabilitation devices. Computer- and robot-assisted forms of therapy have proved to be an important component for optimizing rehabilitation of the upper limb [1]. Hesse et al [2] compared robot-assisted group therapy for the upper limb with individual arm therapy and reported similar outcomes for the 2 groups. In particular, 30-minute robot-assisted group therapy in combination with 30-minute individual arm therapy was as effective as a double session of individual arm therapy for restoration of upper limb motor functions, but the robotic group therapy cost 50% less per patient session compared with standard individual therapy. However, the human upper extremity is a complex physiologic and anatomic structure with actuators, sensors, and an end-effector—based kinematic system controlled by a highly sophisticated controller to perform different activities of daily living (ADLs). Reaching, positioning, and grasping are combined, so that most ADLs can be performed in different ways. According to the definition of the U.S. National Bureau of Standards [3], an industrial robot is "A reprogrammable, multi-function manipulator designed to move material, parts, tools, or specialized devices through various programmed motions for the performance of a variety of tasks." A therapy robot can be defined as a reprogrammable and multifunctional manipulator designed to perform different rehabilitation tasks through various programmed motions. Therefore, it would make sense to set up a robotic system that moves the arm and the hand to fulfill this task, similar to locomotion robots used for gait therapy. Unlike the lower extremity, where a specific walking pattern can be defined, a typical motion pattern for the upper extremity does not exist. Because of the

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complexity of the arms and hands and the multitude of motion patterns available, we need to find a different strategy. Similar to the learning of music pieces or the training of movement sequences in sports, therapeutic movements can be broken down into their components: distal repetitive grasping and proximal functional reaching and positioning. From this perspective, it makes sense to use a set of 2 therapy robots, 1 for distal joint and 1 for proximal joint treatment. Another approach to simplify complexity is by decreasing the number of degrees of freedom based on the patient's level of impairment. Robotic devices can be used for motor-driven passive mobilization and active-assisted exercises for severe and moderate impairments, while active exercises can be promoted and guided by feedback from sensor-based devices without motors. Based on the location and severity of impairment of the upper limb and trunk stability, a matrix concept of robotic and sensor-based therapy devices is designed to meet the individual patient's needs. A widely used commercial array of devices is offered by Tyromotion GmbH (Graz, Austria). The array includes 2 robotic devices, AMADEO and DIEGO, and 3 sensor-based systems, PABLO, TYMO, and MYRO (Figure 1). Therapy modalities span from passive mobilization to active-assisted, active, and resisted exercises. To maximize active patient participation during therapy, the use of robots transitions from motor-driven assistance, when it is no longer of benefit to the patient, to sensor-based feedback systems. For the upper limb, 2 robotic and 3 sensor systems cover the entire upper limb and trunk requirements with the right amount of technology and offer impairment-based and task-specific rehabilitation training.

In addition to the therapeutic approach mentioned earlier, health economics and funding factors are becoming increasingly important. With the introduction of robots to rehabilitation clinics, many therapists feared being replaced by a machine, but this fear is unjustified. Only in combination with therapists can technology help to cope with future challenges. Stroke rates are increasing worldwide: in 2010, 33 million people were living as stroke survivors, and if current trends in stroke continue, then by 2030 there will be 70 million survivors [4]. Further, stroke is a major cause of serious long-term disability, in which 4 of 5 patients are discharged from care with limited arm function [5]. As a result, stroke is one of the most costly neurologic conditions. For the first year after stroke, the mean total direct health care cost per stroke survivor in Germany is €18.500 (U.S.$21.500), including inpatient and outpatient rehabilitation (37%) and medical care and services (54%). Mean direct lifetime costs are 3.6 times higher than rehabilitation costs within the first year [6]. When considering that indirect cost (eg, lost productivity) is equal to direct cost [7], the overall amount almost doubles. Employment data for physiotherapists in Germany confirm that in clinical practice there are considerably more job vacancies than candidates [8]. In addition to increasing migration to other less physically demanding jobs, the increasing number of patients is promoting the development of new rehabilitation techniques and protocols. Thus, the use of

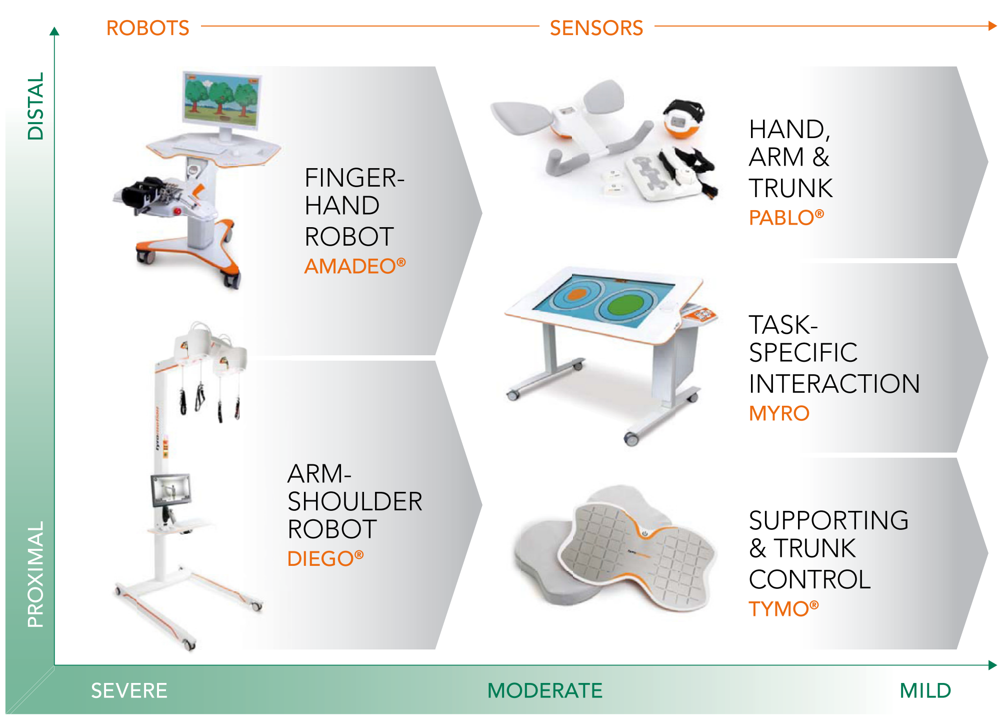

Figure 1. Concept matrix for the application of rehabilitation systems with respect to individual patient needs. Robotic devices with built-in motors and sensors address patients with severe disability and those who need assistance.