Robotic Therapy and the Paradox of the Diminishing Number of Degrees of Freedom

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KEYWORDS

• Robotic therapy • Rehabilitation robotics • Stroke • Impairment-based therapy • Functional-based therapy • Degrees of freedom

KEY POINTS

- Robot-assisted therapy for the upper extremity has already achieved class I, level of evidence A for stroke care in the outpatient setting and care in chronic care settings.
- At least in the US Department of Veterans Affairs (VA) health care system, robot-assisted therapy for the upper extremity has not increased the total health care utilization cost.
- Functionally based robotic training did not demonstrate any advantage over impairment-based robotic training.
- The paradox of diminishing number of degrees of freedom (DOFs) suggests an approach to tailor therapy to a particular patient's needs.

INTRODUCTION: DISRUPTIVE TECHNOLOGY

Three years ago, the authors discussed the concept of disruptive technology and rehabilitation robotics (parts of this review have been published elsewhere).[1] As

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described then and replicated in this article, disruptive technology is a term coined to characterize an innovation that disrupts an existing market or way of doing things and creates a new value network. The concept was introduced by Christensen and colleagues, who described the concept in 1996 as "Generally, disruptive innovations were technologically straightforward, consisting of off-the-shelf components put together in a product architecture that was often simpler than prior approaches.[2,3] They offered less of what customers in established markets wanted and so could rarely be initially employed there. They offered a different package of attributes valued only in emerging markets remote from, and unimportant to, the mainstream." Eventually with improvement, borrowing from Malcolm Gladwell, the moment of critical mass (the threshold or the boiling point) is reached and the old practices and existing value network abandoned in favor of the new one, also referred to "the tipping point."[4]

UPPER EXTREMITY ROBOTIC THERAPY: THE TIPPING POINT

Since the publication of the first controlled study with stroke inpatients,[5] several studies have been completed with both stroke inpatients and outpatients demonstrating the potential of robotic therapy for the upper extremity. These results were discussed in different meta-analyses (for example, in Refs.[6–8]) and led to the 2010 American Heart Association (AHA) guidelines for stroke care: "Robot-assisted therapy offers the amount of motor practice needed to relearn motor skills with less therapist assistance… Most trials of robot-assisted motor rehabilitation concern the upper extremity (UE), with robotics for the lower extremity (LE) still in its infancy… Robot-assisted UE therapy, however, can improve motor function during the inpatient period after stroke." AHA suggested that robot-assisted therapy for the upper extremity has already achieved class I, level of evidence A for stroke care in the outpatient setting and care in chronic care settings. It suggested that robot-assisted therapy for upper extremity has achieved class IIa, level of evidence A for stroke care in the inpatient setting. Class I is defined as "Benefit >>> Risk. Procedure/Treatment SHOULD be performed/administered" (where >>> indicates that "much larger than"); class IIa is defined as "Benefit >> Risk, IT IS REASONABLE to perform procedure/administer treatment" (where >> indicates "larger than"); and level A is defined as "Multiple populations evaluated: Data derived from multiple randomized controlled trials (RCTs) or meta-analysis."[9]

The 2010 VA/Department of Defense (DOD) guidelines for stroke care came to the same conclusion endorsing the use of rehabilitation robots for the upper extremity but went further to recommend against the use of robotics for the lower extremity. More specifically, the VA/DOD 2010 guidelines for stroke care "Recommend robot-assisted movement therapy as an adjunct to conventional therapy in patients with deficits in arm function to improve motor skill at the joints trained." More needs to be done, however, particularly for the lower extremity, as stated in the VA/DOD guidelines: "There is no sufficient evidence supporting use of robotic devices during gait training in patients post stroke" and "Recommendation is made against routinely providing the intervention to asymptomatic patients. At least fair evidence was found that the intervention is ineffective or that harms outweigh benefits."[10]

Currently the largest single study of upper extremity robotics confirms these endorsements for the upper extremity. The multisite, independently run, VA trial CSP-558 (Robotic Assisted Upper-Limb Neurorehabilitation in Stroke Patients [VA ROBOTICS]), on upper extremity rehabilitation robotics, using the commercial version of the MIT-Manus robot for shoulder and elbow therapy together with corresponding antigravity, wrist, and hand robots,[11] included 127 veterans with chronic stroke at least 6 months post–index stroke with an impairment level characterized by very severe to