Robot-assisted upper limb movement promotes improved motor function in post-stroke hemiparesis

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Introduction
The prevalence of stroke in the veteran population is increasing. The resulting loss of upper limb motor function is often resistant to therapeutic efforts. With the dramatic reduction of inpatient rehabilitation length of stay following stroke, it is now critical to develop efficient, scientifically-validated interventions.

Objectives
- to establish the therapeutic efficacy of robot-assisted movement for restoration of lost upper limb motor function following stroke
- to understand the mechanisms by which this therapy promotes motor recovery

Methods
- randomized, controlled, double-blinded clinical trial
- chronic stroke subjects (> 6 months post-stroke) are randomly assigned to a robot or control group
- both groups receive 24 one-hour sessions over two months
- robot group sessions include tabletop tracing of circles and polygons, and a series of 3-dimensional targeted reaching movements, all assisted by a Puma 560 robot arm.
- four modes of robot assistance are used:
  - passive mode: subject relaxes as the robot moves the limb in a predetermined pattern
  - active-assisted mode: subject triggers initiation of the movement with force toward the target and “works with the robot” as it moves the limb
  - active-constrained mode: robot provides a viscous resistance in the direction of movement and spring-like loads in all other directions
  - bimanual mode: subject attempts bimanual mirror-image movements while a 6-DOF digitizer measures movement of the contralateral limb and the robot moves the paretic limb to the mirror-image position with minimal delay
- control group sessions include NeuroDevelopmental Therapy (NDT) - based therapy targeting upper limb function, and 5 min of exposure to the robot with target tracking tasks
- all subjects are evaluated pre and post treatment with clinical and biomechanical measures

Results
1. Both robot-assisted movement and conventional NDT-based therapy improves motor function
- data from 11 robot group subjects and 10 control subjects who have completed the study
- both robot and control groups showed improvement in the upper limb portion of the Fugl-Meyer exam of motor function
- there was a non-significant trend towards greater improvements in the robot group compared to controls

   | Increase in Fugl-Meyer scores following treatment |
   | upper-limb | shoulder-elbow | hand-wrist |
   | robot | control |
   | 5 | 0 |
   | 10 | |

2. Robot-assisted movement may have advantages over conventional NDT-based therapy
- robot therapy targets shoulder and elbow function
- when considering only the shoulder and elbow portions of the Fugl-Meyer exam, robot group improvements were significantly greater than control group improvements (p<0.05)
- no differences between groups in hand-wrist improvements

3. Robot-assisted movement promotes greater strength gains than conventional NDT-based therapy
- data from 9 robot-trained subjects and 9 controls
- robot-trained subjects had significantly greater strength gains in 5 of 8 shoulder-elbow DOFs (p<0.05)

   | Strength increase |
   | elbow-flex | elbow-ext | shoulder-flex | shoulder-ext | rot | abd | add | sh flex | sh ext |
   | robot | control |
   | 14% | 12% |
   | 10% | 8% |

4. In some subjects, robot training resulted in increased activation of paretic muscles and decreased antagonist co-contraction during the training tasks.
- data from a severely impaired subject in an active-constrained forward-lateral reach from lap level to shoulder level
- pre-Tx (blue), no movement was possible
- post-Tx (black), a fraction of the movement was completed
- pre-Tx, biceps (agonist) was strongly activated while middle deltoid (agonist) was silent. EMGs were normalized by the largest rms value observed during MVC testing.
- post-Tx, biceps activation was suppressed and activation of middle deltoid was possible

5. In other subjects, clear improvements in the kinematics of the training tasks was not accompanied by clear changes in muscle EMG patterns. We hypothesize that in these cases, increased activation of paretic muscles was the mechanism. Increased activation of agonist muscles may not be apparent when EMG is normalized by the largest rms value observed during MVC testing.

Clinical Impact
- If it can be shown that robot-assisted exercise has significant therapeutic value, robotic systems can be integrated into clinical practice and used to facilitate many of the exercises that require labor-intensive manual manipulation. This could potentially improve outcomes and increase the efficiency of the clinical staff.
- Greater understanding of the mechanisms by which specific interventions promote recovery will aid in the development of optimal therapies.

Status
An additional 9 subjects with chronic stroke will be tested. Clinical trials with acute and subacute stroke subjects are planned.

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