Effectiveness of robot-assisted therapy on stroke patients with upper extremity impairment

Marisa Hurley
Pacific University

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Disciplines
Occupational Therapy | Rehabilitation and Therapy

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Effectiveness of robot-assisted therapy on stroke patients with upper extremity impairment

Prepared by: Marisa Hurley, Occupational Therapy Student, Pacific University
E-mail: hurl2557@pacificu.edu
Date: November 16, 2009

CLINICAL SCENARIO:

Robot-assisted therapy refers to a recent trend of using robotic devices for rehabilitation of persons with mild to severe motor impairments as a result of neurologic injury. This rehabilitation approach serves to help persons who cannot be helped with constraint-induced movement therapy which is shown to benefit persons with high-level motor impairments. For patients without active movement in the wrist and hand, many conventional therapy methods have proven ineffective at regaining function in the paretic arm. Robot-assisted therapy is delivered with one of several robots (i.e. MIT-MANUS, InMotion2, MIME) aimed at providing high intensity repetitive movements in a safe environment in order to improve functional and motor recovery in the paretic upper limb. While the specific mechanisms underlying motor recovery and its relationship to cortical reorganization are not well understood, it has been determined through several studies and one particular systematic review (Kwakkel, Kollen, & Krebs, 2008) that there is a positive trend in favour of robotic therapy for improving motor recovery in persons with upper limb impairment.

FOCUSED CLINICAL QUESTION:

What is the evidence that robot-assisted therapy is more effective for stroke patients in the post-acute phase with upper extremity impairment than conventional or no therapy?

SUMMARY of Search, ‘Best’ Evidence’ appraised, and Key Findings:

From four individual studies and one systematic review the evidence is mixed as to the efficacy of robot-assisted therapy in treatment of post-acute stroke patients. Three studies (Finley, Fasoli, Dipietro, Ohlhoff, MacClellan, Meister, …& Hogan, 2005; MacClellan, Bradham, Whitall, Volpe, Wilson, Ohlhoff, … & Bever, 2005; and Fasoli, Krebs, Stein, Frontera, & Hogan, 2003) used a before-and-after design to examine the effects of robot-assisted therapy after no therapy. All three studies concluded that robot-assisted therapy was effective in decreasing motor impairments in the affected upper extremity but the results were really only applicable to patients with severe impairment, not minimal or moderate impairment. For all three studies, the results of improved upper extremity function were
maintained for three months post-treatment. Fasoli et al (2003) compared the use of a sensorimotor robot-assisted program versus a progressive-resistive robot-assisted program and found that the progressive-resistive therapy group showed more significant improvements in wrist and hand movement than that of the sensorimotor group, suggesting that the type of robot-assisted therapy does make a difference in treatment results.

The randomized controlled trial (Lum et al, 2002) found robot-assisted therapy had advantages after 2 months of treatment compared to the control group which received equal intensity conventional therapy interventions. The results found decreased impairment, improved strength, and increased reach extent in the treatment group to surpass the results of the control group though it was not determined whether the same effects of robot-assisted therapy could be duplicated by a human therapist to produce similar results. Differences between the two treatment groups could be accounted for by the difference in content for each group meaning that the results may not be as suggestive as originally thought.

The systematic review also provided mixed results as to the effectiveness of robot-assisted therapy to positively affect both motor recovery and functional ability to complete activities of daily living. Kwakkel, Kollen, & Krebs (2008) included ten well-performed randomized controlled trials of robot-assisted therapy and divided them according to which outcome measurement was used. Seven studies used the Fugl-Meyer or the Chedoke-McMaster Stroke Assessment Scale to evaluate motor recovery. Five studies used the Functional Independence Measure to evaluate activities of daily living. Of the seven studies evaluating motor recovery, only five found statistically significant results suggesting robot-assisted therapy was more effective than conventional therapy methods though four studies reported statistically nonsignificant results of robot-assisted therapy over conventional therapy. Overall, in regards to motor recovery when measured with the Fugl-Meyer or Chedoke-McMaster this systematic review suggests a positive trend toward robot-assisted therapy compared with conventional treatment modalities. There were no reported statistically significant results in favour of the experimental group for the four randomized controlled trials evaluating activities of daily living using the Functional Independence Measure.

**CLINICAL BOTTOM LINE:**
The results of this limited evidence-based literature review suggest that occupational therapy research must continue in order to establish the effectiveness of robot-assisted therapy before concluding that it is a successful treatment for stroke patients with upper extremity impairment. The experimental studies used different programs of this intervention and found mixed results as to the efficacy of this treatment approach. The difference between study subjects may lead researchers to conclude that results from one client population may not generalize to another. The overall intensity of robot-assisted therapy programs may allow the client to become more involved in their treatment and recover functional movement more quickly than with human conventional therapy treatments. The maintenance of positive results is not known beyond six months and the mixed results suggest that further research is needed.
Limitation of this CAT: This critically appraised topic has not been peer-reviewed by other independent reviewers and is not an all-extensive review of all the literature available on this topic. In addition, this reviewer does not claim to be an expert on the topic.

SEARCH STRATEGY:

Terms used to guide Search Strategy:

- **Patient/Client Group:** Stroke patients with upper extremity impairment
- **Intervention (or Assessment):** Robot-assisted therapy
- **Comparison:** Conventional therapy
- **Outcome(s):** Improve upper extremity function more with robot-assisted therapy

<table>
<thead>
<tr>
<th>Databases and sites searched</th>
<th>Search Terms</th>
<th>Limits used</th>
</tr>
</thead>
<tbody>
<tr>
<td>OT Search</td>
<td>Cerebrovascular accident, stroke, upper extremity, hemiparesis, robot-assisted therapy, hemiplegia, robot</td>
<td>English language Peer-reviewed articles Published since 2000</td>
</tr>
<tr>
<td>OVID Medline</td>
<td></td>
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<tr>
<td>Rehabilitation Reference Center</td>
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<td></td>
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<tr>
<td>CINAHL</td>
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</tbody>
</table>

INCLUSION and EXCLUSION CRITERIA

- **Inclusion:** Studies were only included if they were in the English language, peer-reviewed, Level I studies, and published after the year 2000; studies where the patient had either moderate or severe impairment from stroke and where robot-assisted therapy was the primary intervention approach being investigated; and participants were adults.

- **Exclusion:** Studies were excluded if an occupational therapist was not included in the authors to assure relevance to the field of occupational therapy; if there was only mild impairment of the upper extremity; if upper extremity impairment did not result from a stroke; and studies with no quantitative measurement of function. While all levels of evidence were searched for, only Level I evidence was used. Also excluded were journal articles where development of robot-assisted technology was described but no intervention occurred.
RESULTS OF SEARCH

Five relevant studies were located and categorised as shown in Table 1 (based on Levels of Evidence, Centre for Evidence Based Medicine, 1998)

Table 1: Summary of Study Designs of Articles retrieved

<table>
<thead>
<tr>
<th>Study Design/Methodology of Articles Retrieved</th>
<th>Level</th>
<th>Number Located</th>
<th>Author (Year)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Systematic Review</td>
<td>1a</td>
<td>1</td>
<td>Kwakkel, G., Kollen, B.J., Krebs, H.I. (2008)</td>
</tr>
<tr>
<td>Randomized Controlled Trial</td>
<td>1b</td>
<td>1</td>
<td>Lum, P.S., Burgar, C.G., Shor, P.C., Majmundar, M., Van der Loos, M. (2002)</td>
</tr>
</tbody>
</table>

For Table x: Characteristics of included studies, see pages 11 and 12.

BEST EVIDENCE

The following study/paper was identified as the ‘best’ evidence and selected for critical appraisal. Reasons for selecting this study were:

- It shows the mixed results of robotic therapy common in the current research
- It suggests a positive trend toward robotic therapy
- It is the highest level of evidence and examines only well-conceived randomized controlled trials

SUMMARY OF BEST EVIDENCE

Table 2: Description and appraisal of Effects of robot-assisted therapy on upper limb recovery after stroke: A systematic review by Kwakkel, G., Kollen, B.J., & Krebs, H.I., 2008

Aim/Objective of the Study/Systematic Review: The aim of this systematic review was to examine the evidence for the efficacy of using robot-assisted therapy over conventional treatment to improve motor and functional recovery in patients with stroke.

Study Design: This systematic review initially located 173 articles matching criteria for the literature search. It was then narrowed down to 87 studies which were considered
relevant for further screening of abstracts. That screening resulted in only 44 studies being selected and 34 of those studies were excluded due to an inappropriate research design (ten were critical or narrative reviews and 24 were noncontrolled trials, 1 was a pre-experimental study and 2 were controlled studies that did not measure motor and/or functional recovery of the upper paretic limb), resulting in only ten studies being identified as relevant. This review, therefore, examined ten studies, all randomized controlled trials, with respect to functional recovery (as measured with the Functional Independence Measure) and motor recovery (as measured with the Fugl-Meyer and Chedoke-McMaster Stroke Assessment Scale). As this approach is still recent in its development and implementation, it was appropriate to include only ten studies for review.

**Search Strategy:** The authors performed a literature search on the computer using multiple databases including Medline, CINAHL, EMBASE, Cochrane Controlled Trials Register, DARE, SciSearch, DocOnline, and PEDro. Studies were collected through October 2006. Keywords used in the search included cerebral vascular accident, cerebral vascular disorders, stroke, paresis, hemiplegia, upper extremity, arm, and robot (and all word combinations that began with the term “robot”). These keywords are quite thorough and encompass nearly all, if not all, articles pertaining to this subject matter. The theoretical base for this treatment was not considered in the keywords as it is not fully developed at this point and the theoretical bases of each study may vary slightly. Only articles written in English, Dutch, and German languages were included in the search parameters.

**Selection Criteria:** Inclusion criteria were that (1) patients were diagnosed with cerebral vascular accident; (2) effects of robot-assisted therapy for the upper limb were investigated; (3) the outcome was measured in terms of motor and/or functional recovery of the upper paretic limb; and (4) the study was a randomized clinical trial (RCT). Some of the exclusion criteria for selecting studies included studies that compared the effects of 2 different types of robot-assisted therapy and studies of persons with chronic impairment due to stroke that compared discharge outcomes with preintervention stable scores. Before selecting final studies for the review, each proposed study was rated using the PEDro scale and scored by two of the authors of the review. When no consensus was reached between reviewers, a third reviewer made the final decision. PEDro scores of 4 points or more were classified as “high quality,” whereas studies with 3 points or less were classified “low quality.” Ten studies were considered relevant and appropriate for analysis with the range of the start of therapy going from 1 week after stroke to more than 6 months after stroke. Specific details of each RCT can be found in Table 1 of the systematic review and a similar table of results is attached to this CAT.

**Methods of Analysis:** Studies were analysed according to whether they measured the outcome of functional or motor recovery. Of ten available studies, seven examined motor recovery. All seven of these studies used the Fugl-Meyer Assessment scale to measure motor recovery and one study used the Chedoke-McMaster Stroke Impact Scale. In these studies there were a total of 218 patients with stroke involved. Results of these studies are varied as only five studies reported statistically significant effects for motor recovery in favour of the experimental group and four studies did not report any significant difference between the experimental and control groups. An overall statistically nonsignificant (0.65, 95% confidence interval [CI] -0.02 to 1.33; Z=1.90, P=.06) heterogenous summary effect size [SES] \( \chi^2 = 40.82 \).
P<.001) was found in favour of the robot-assisted therapy. Heterogeneity was due mainly to Hesse and colleagues' study so when not included it showed a homogenous SES ($\chi^2 = 4.35, P= .60$) in favour of shoulder-elbow arm robotics (Z=2.32, P<.026). A meta-analysis of robot-assisted therapy trails on motor recovery can be found in Figure 1 of the document, as replicated below.

Out of the ten available studies, five examined functional recovery using the Functional Independence Measure. There were 139 patients with stroke involved in this analysis. None of the studies reported significant effects for ADL (functional recovery) in favour of the experimental group. A homogenous nonsignificant SES was found ($\chi^2 = 0.50, P>.05$) for robot-assisted therapy. A meta-analysis of robot-assisted therapy trails on activities of daily living can be found in Figure 2 of the document, as replicated below.

**Original Authors’ Conclusions:** Analysis of these studies shows a positive trend toward robot-assisted therapy in regards to the 218 patients with stroke when
measured with the Fugl-Meyer assessment scale or the Chedoke-McMaster Stroke Impact Scale. Methods of analysis were appropriate when calculating a summary effect size for a group of quantitative studies. Recovery occurred primarily in the proximal upper limb more significantly than when compared to conventional treatment modalities. Due to the calculation of summary effect sizes (SES) according to a random effects model, heterogeneity was determined in one calculation due to a larger confidence interval. The Hesse and colleagues study did not measure proximal shoulder and elbow movements as the other studies had which affected that one calculation of results.

Overall, the “significant, moderate SES of upper arm robotics on motor control based on FMA and CMSA scales denotes a mean overall change of 7% to 8% in motor control of the upper limb in favour of the robot-assisted therapy.” (p. 117)

As for the effect of robot-assisted therapy on functional recovery, as measured by FIM scores on ADLs, there were no noted significant improvements in any study. The authors suggest that this may be due to the inappropriate nature of the FIM at measuring the dexterity of the upper paretic limb. It is suggested that other assessments such as the Wolf Motor Function Test or the Jebsen Test may be more effective at drawing out changes in upper paretic limb dexterity due to robot treatment.

The authors of this review concluded that high intensity robot-assisted therapy creates more movements in patients than elicited by other forms of therapy such as electric stimulation, free reaching, and neurodevelopmental therapy. These high intensity repetitive movements are likely what make robot-assisted therapy effective. More research is still needed to determine if efficacy with this treatment comes from these high intensity training or to the treatment modality itself. It is also important to consider the cost-effectiveness of this treatment approach though more research is necessary in order to obtain this information. Through all of this data collection the authors have concluded that robotic assisted devices have the potential for eliciting improvements in proximal upper limb function with stroke patients. More research is needed to determine any potential for improving functional recovery as evidenced through activities of daily living.

Limitations of this study are noted by the authors in their final discussion. One limitation is the possibility of the same clients participating in multiple studies included in this review which would stifle data collected and decrease generalizability of results. Also, the authors complied the Fugl-Meyer and Chedoke-McMaster scores since both are based off Brunnstrom stages of recovery; however, both assessments measure different dimensions of motor function and so compiling them together may create a dimensionless SES. Another limitation is in the compiling of different methods of robot-assisted interventions to obtain one overall effect size. The problem with this is that different robots deliver therapy differently and focus on different areas of upper limb function and so results may be difficult to interpret as to which system is most effective. This is a similar problem for the control group as each control group received a different type of treatment and pooling them together as one treatment may give inaccurate results as to the efficacy of conventional treatment methods. These limitations all imply the need for more quality randomized controlled trials to be performed. There may have been more quality studies in other languages not included in this review which may be one last important limitation.
Critical Appraisal:

Validity: This systematic review is a rather well-inclusive search of available research articles on this subject matter as they searched through a wide range of articles on the available topic and narrowed it down to studies that were so similar. Their selection of articles in only English, German, and Dutch may have had a slight limiting effect on available studies though not enough to significantly affect the results. Their utilization of PEDro scores for determining methodological quality may also be inappropriately influencing selection of some studies. It is important to consider the PEDro score of an article in order to acknowledge if the randomized controlled trials were well-done. However, there is no information given as to why authors of this review chose 4 or higher as a cut-off score for a “high quality” study. There are a possible 10 points for RCTs using the PEDro scale and so a score of 4 may not be well-done at all, depending on which areas points are accumulated in. It may have been more appropriate for Kwakkel, Kollen, and Krebs to include which PEDro sub-test items they were most interested in ensuring that their studies scored on to let the audience know that studies being chosen are, in fact, well-done methodologically. A score higher than 4 for “high quality” would better differentiate “high quality” studies from “moderate” and “low” quality studies, represented by a PEDro score less than 3. This may limit some studies from inclusion though it would weed out studies that are not as methodologically sound as the authors desired.

Interpretation of Results: Results are well-documented in stream-lined tables, making it easier to evaluate the original RCT’s outcomes and results. Outcomes of interest were similar in all RCTs evaluated in the review though motor recovery outcome measurements (Fugl-Meyer and Chedoke-McMaster) were compiled together though they measure different functional movements as the Chedoke-McMaster evaluated wrist-hand motion and the Fugl-Meyer evaluated both proximal and distal motion. This may inappropriately influence results if the treatment is less effective for wrist and hand motions than for proximal shoulder and elbow motions resulting in a smaller effect size. In calculation of effect size for motor recovery a statistically nonsignificant effect size of 0.65 was found in favour of the robot-assisted therapy though it is not a strong enough indicator to conclude a positive trend though it is strong enough to suggest further research for clarification of efficacy. Results regarding functional recovery evaluating ADLs with the Functional Independence Measure appropriately concluded that there were no significant improvements in the experimental group. This may, however, be due in part to the limitations of the FIM at appropriately analysing distinct upper extremity motions necessary to complete certain components of ADL activities.

Summary/Conclusion: This systematic review, while not all-inclusive of all available randomized controlled trials, was well-done and evaluated the included studies appropriately leading to the appropriate conclusion that more research is needed to determine efficacy of this treatment approach. There are, as always, limitations with this review and future research should attempt to address and correct those limitations. More randomized controlled trials need to be done in order to determine the mechanisms of motor recovery and cortical reorganization in order to more effectively determine which aspects of robot-assisted therapy are beneficial for improving impairment in stroke patients. This review should incite researchers to do more studies to examine this link and to demonstrate that moderate-to-severe
Impairments in stroke patients can be improved functionally with methods more effective than those used in conventional therapy. A future systematic review should include studies with similar outcome measurements (to avoid compiling two different, possibly dissimilar, measurements), similar populations (i.e. same type of stroke, same impairment level at baseline), and a more functional outcome measurement tool than the Functional Independence Measure in order to better establish a connection between robot-assisted therapy and functional recovery in ADLs.

**IMPLICATIONS FOR PRACTICE, EDUCATION and FUTURE RESEARCH**

All of the five studies synthesized in this CAT concluded that there are potential benefits of robot-assisted therapy on upper extremity impairment in stroke patients. Those benefits may not be well-understood or well-documented in all studies which is why there is a need for more research. The most common problem in these studies is the small sample size which may result in an insignificant effect size. The systematic review critiqued herein provides further evidence for the need for more research, particularly in relation to determining the cost-effectiveness of this treatment approach. It is necessary to determine if the cost outweighs the benefits of this modality. From all included studies benefits can be determined as: (1) potential for improving motor recovery in the paretic upper extremity, (2) increased compliance, and (3) delivering highly repetitive and functional movements which may not be as effective when replicated by a human therapist. Future research needs to determine if there are certain stroke populations that this therapy approach works better with. This may, perhaps, be an appropriate time to consider qualitative research approaches such as single-subject research design in order to determine if this approach is appropriate for one patient that is not benefitting from conventional therapy and risks being discharged from therapy due to lack of progress. In this situation, however, it would be important to choose an appropriate outcome measurement to appropriately detect any changes in functional recovery, something the FIM was not able to do. It is also important to consider in future research if this modality is effective enough to risk spending so much money on. The cost of this treatment approach, as well as the potential for harm, was not discussed in any study though the MIT-MANUS robot averages around $65,000 for the wrist robot and $70,000 for the planar (shoulder) robot. That is a very high cost for purchasing equipment that does not have an established and well-agreed upon rate of success with patients. It is important for practitioners to have the evidence for efficacy before considering whether or not to use this with their own patients.
REFERENCES


### Table x: Characteristics of included studies

<table>
<thead>
<tr>
<th>Study 1</th>
<th>Study 2</th>
<th>Study 3</th>
<th>Study 4</th>
</tr>
</thead>
</table>

**Intervention investigated**
- Study 1: Robot-assisted therapy with InMotion2
- Study 2: Robot-assisted therapy with MIME system
- Study 3: Robot-assisted therapy with MIT-MANUS (progressive-resistive and sensorimotor groups)
- Study 4: Robot-assisted therapy with InMotion2

**Comparison intervention**
- Baseline evaluation with no treatment.
- Conventional therapy
- Baseline evaluation with no treatment
- Baseline evaluation with no treatment

**Outcomes used**
- Study 1: Upper-limb motor function (shoulder and elbow) was measured with the Upper-limb Motor Status Score, Wolf Motor Function Test, Motor Power Assessment, and Fugl-Meyer.
- Study 2: Function, strength, and reach were measured by the Fugl-Meyer, Barthel Index, FIM, torque measurements of strength, and a computer digitizer measuring reach.
- Study 3: Muscle spasticity, synergistic and isolated movement patterns of upper-limb; grasp; strength (shoulder and elbow); upper extremity motor function; and pain. Measured by Modified Ashworth Scale, Fugl-Meyer test of motor power, Medical Research Council test of motor power, Motor Status Scale, and self-reports of pain by the client.
- Study 4: Motor performance of upper limb measured with Wolf Motor Function Test, Motor Power Assessment, Fugl-Meyer UL Assessment, Self-Administered Stroke Impact Scale, aiming error, mean speed, peak speed, and movement duration

**Findings**
- Study 1: Significant improvement in Fugl-Meyer scores and
- Study 2: Compared with the control group, the treatment group had higher rates of
- Study 3: The Fugl-Meyer test indicated statistically significant and large effect
- Study 4: Following robot-assisted therapy treatment the following results were

Prepared by Marisa Hurley (11/16/09)
| Motor Power Assessment scores were noted for the subjects with severe impairment. Subjects with moderate impairment also had statistically significant results on the Motor Power Assessment. In the moderate group there was a positive trend for the Fugl-Meyer and Wolf Median Time though not statistically significant. The Wolf Functional Ability measure indicated a small but significant improvement in the group with moderate but not severe impairment. | decreased impairment, improved strength, and increased reach extent. The two groups, however, were not matched in terms of content so some results may be misinterpreted. The treatment group had significantly greater improvements on the proximal and distal portions of the Fugl-Meyer compared with the control group but after 6 months of treatment there were no differences between groups. The robot group had significantly greater gains in FIM scores at 6-month follow-up. The robot group also had significantly greater improvements in proximal arm strength and reach extent than the control. | of therapy as well as the Motor Status Scale score for shoulder and elbow, and the MRC tests of motor power; Motor Status Scale score for wrist and hand found a statistically significant but moderate effect. Discharge pain was not statistically significant when compared to shoulder pain at admission. A nonsignificant and small effect of robotic therapy on muscle tone was found by the Modified Ashworth Scale. Findings also suggest the progressive-resistive group had a statistically significant and large effect compared with the sensorimotor group on the MSS wrist and hand score. | obtained: statistically significant improvements in the Fugl-Meyer Assessment score and Motor Power Assessment; no significant changes found on the Wolf Motor Function Test or Stroke Impact Scale; significantly reduced aiming error and movement duration; increased mean speed and mean peak:speed ratio. At 3-month follow-up upper extremity impairment was not statistically different compared with posttreatment levels. |
Characteristics of studies included in the systematic review by Kwakkel, Kollen, & Krebs (2008)

<table>
<thead>
<tr>
<th>Reference</th>
<th>Stroke Type</th>
<th>Severity (F-M [UL] at baseline)</th>
<th>Start of RT/CT (E/C)</th>
<th>Type of Intervention (E/C)</th>
<th>Intervention Categories</th>
<th>Daily (min) RT (E/C)</th>
<th>Daily (min) CT (E/C)</th>
<th>Mean age (years) (E/C)</th>
<th>Outcome</th>
<th>Author conclusion</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aisen 1997</td>
<td>Hemorrhagic, ischemic</td>
<td>13.8/17.1</td>
<td>2.8/3.3wk</td>
<td>RT vs. robot exposure (control)</td>
<td>MIT-MANUS</td>
<td>60/0</td>
<td>±0/10</td>
<td>58.5/63.3</td>
<td>F-M</td>
<td>FIM Significant difference in motor recovery (acute patients)</td>
</tr>
<tr>
<td>Burgar 2000</td>
<td>All types</td>
<td>24.8/21.8</td>
<td>26.5/26.4 mo</td>
<td>RT vs. neuro-developmental therapy</td>
<td>MIME</td>
<td>36/0</td>
<td>0/36</td>
<td>64.4/63.3</td>
<td>F-M</td>
<td>FIM Significant difference in motor recovery (chronic patients)</td>
</tr>
<tr>
<td>Kahn 2000</td>
<td>?</td>
<td>?</td>
<td>&gt;6 mo</td>
<td>RT vs. unassisted, unrestrained reaching exercises</td>
<td>ARM Guide</td>
<td>?</td>
<td>?</td>
<td>?</td>
<td>Ch McM</td>
<td>Repetitive movements seem to be the primary stimuli to recovery</td>
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<tr>
<td>Volpe 2000</td>
<td>Hemorrhagic, ischemic</td>
<td>8.6/10.5</td>
<td>22.5/26.0 days</td>
<td>RT vs. robot exposure (control)</td>
<td>MIT-MANUS</td>
<td>60/0</td>
<td>0/12</td>
<td>62/67</td>
<td>F-M</td>
<td>Improvement of the motor performance of the exercised shoulder and elbow</td>
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<tr>
<td>Fasoli 2004</td>
<td>Hemorrhagic, ischemic</td>
<td>8.6/10.5</td>
<td>9/10 days</td>
<td>RT vs. robot exposure (control)</td>
<td>MIT-MANUS</td>
<td>60/0</td>
<td>0/12</td>
<td>62/67</td>
<td>F-M</td>
<td>Intensive therapy leads to better recovery after stroke</td>
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<tr>
<td>Study</td>
<td>Type</td>
<td>Time</td>
<td>Treatment</td>
<td>Time/Intensity</td>
<td>Outcome</td>
<td>p-value</td>
<td>Comments</td>
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<tr>
<td>Lum 2002</td>
<td>All types</td>
<td>24.8/26.6 mo</td>
<td>RT vs. neuro-developmental therapy</td>
<td>MIME</td>
<td>36/0</td>
<td>0/36</td>
<td>63.2/65.0</td>
<td>F-M</td>
<td>Significant difference in motor recovery</td>
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<td>Hesse 2005</td>
<td>Ischemic (first stroke)</td>
<td>7.9/7.3 wk</td>
<td>RT vs. electrical stimulation</td>
<td>Bi-Manu-Track</td>
<td>20/0</td>
<td>0/20</td>
<td>65.4/64.0</td>
<td>F-M</td>
<td>Superior improvement in upper limb control and power</td>
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</tr>
<tr>
<td>Daly 2005</td>
<td>Hemorrhagic, ischemic</td>
<td>21/23 &gt;12 mo</td>
<td>RT vs. functional neuromuscular stimulation and motor earning</td>
<td>InMotion Shoulder-Elbow Robot</td>
<td>90/0</td>
<td>0/90</td>
<td>21-62</td>
<td>F-M</td>
<td>Significant gains in F-M upper-limb coordination</td>
<td></td>
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<tr>
<td>Kahn 2006</td>
<td>?</td>
<td>3.5/3.2 mo</td>
<td>RT vs. task-matched amount of unassisted reaching</td>
<td>ARM Guide</td>
<td>61/0</td>
<td>0/61</td>
<td>55.6/55.9</td>
<td>Ch McM</td>
<td>Robotically assisting in reaching successfully improved arm movement ability</td>
<td></td>
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<tr>
<td>Lum 2006</td>
<td>?</td>
<td>8.4/5.0 wk</td>
<td>RT vs. conventional therapy</td>
<td>MIME</td>
<td>45/0</td>
<td>0/45</td>
<td>69.8/59.9</td>
<td>F-M</td>
<td>Robot-assisted treatment gains exceeded those expected from spontaneous recovery</td>
<td></td>
</tr>
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