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Effects of Robot-assisted therapy on upper limb recovery after stroke: A Systematic Review

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Abstract

Background and Purpose—To present a systematic review of studies that investigates the effects of robot-assisted therapy on motor and functional recovery in patients with stroke.

Summary of Review—A database of articles published up to October 2006 was compiled using the following MEDLINE key words: cerebral vascular accident, cerebral vascular disorders, stroke, paresis, hemiplegia, upper extremity, arm and robot. References listed in relevant publications were also screened. Studies that satisfied the following selection criteria were included: (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; (4) The study was a randomised clinical trial (RCT). For each outcome measure, the estimated effect size (ES) and the summary effect size (SES) expressed in standard deviation units (SDU) were calculated for motor recovery and functional ability (ADL) using fixed and random effect models. Ten studies, involving 218 patients, were included in the synthesis. Their methodological quality ranged from 4 to 8 on a (maximum) 10 point scale. Meta-analysis showed a non-significant heterogeneous SES in terms of upper limb motor recovery. Sensitivity analysis of studies involving only shoulder-elbow robotics subsequently demonstrated a significant homogeneous SES for motor recovery of the upper paretic limb. No significant SES was observed for functional ability (ADL).

Conclusion—As a result of marked heterogeneity in studies between distal and proximal arm robotics, no overall significant effect in favour of robot-assisted therapy was found in the present meta-analysis. However, subsequent sensitivity analysis showed a significant improvement in upper limb motor function after stroke for upper arm robotics. No significant improvement was found in ADL function. However, the administered ADL scales in the reviewed studies fail to adequately reflect recovery of the paretic upper limb and valid instruments that measure outcome of dexterity of the paretic arm and hand are mostly absent in selected studies. Future research on the effects of robot-assisted therapy should therefore distinguish between upper and lower robotics arm training and concentrate on kinematical analysis to differentiate between genuine upper limb motor recovery and functional recovery due to compensation strategies by proximal control of the trunk and upper limb.

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Keywords

robotics; cerebrovascular accident; Activities of daily living; Upper limb; Rebiew; systematic

Introduction

Stroke is the leading cause of disability in the United States. 750.000 individuals are affected each year and the prevalence rate is among 200–300 patients per 100.000 inhabitants.[1] Although prospective epidemiological studies are lacking, findings of a number of longitudinal studies indicate that in 30% to 66% of hemiplegic stroke patients, the paretic arm remains without function when measured 6 months after stroke, whereas only 5% to 20% demonstrate complete functional recovery.[2]

The results of a systematic review involving 123 randomized clinical trials (RCTs) by van Peppen and colleagues demonstrated that there is strong evidence that intensity as well as task specificity are the main drivers in an effective treatment program after stroke. In addition, this training should be repetitive, functional, meaningful and challenging for a patient.[3,4]

However, the question as to how the effects of exercise therapy can be further enhanced in a clinical environment presents a challenge to answer. Therefore, there is a need to develop better ways to augment exercise training in a functional way. Using therapeutic adjuncts to facilitate clinical practice, such as robotics[5–11], is a new promising development. Robotics allows patients to train independently of a therapist and to improve upon their own functional level (i.e., robot-assisted therapy). In particular, there is strong evidence for robot-assisted therapy to increase treatment compliance by way of introducing incentives to the patient, such as games. In addition, by using computer assisted devices for regaining upper limb function, the robot can easily apply new constraints, in order to optimize the required movement pattern. Therefore, the complexity of a motor task to be learned can be controlled for more precisely with robotics than in conventional treatment approaches.

Although many devices have been designed to deliver arm therapy in individuals with stroke, five of these devices, the MIT-MANUS[5,6] (designed and built at the Massachusetts Institute of Technology), the ARM-GUIDE[7] (Assisted Rehabilitation and Measurement guide), the MIME[8,9] (Mirror-Image Motion Enabler), the InMotion[2] Shoulder-Elbow Robot[10] and the Bi-Manu-Track[11], were tested in at least one Randomized Clinical Trial (RCT). The MIT-MANUS is a robot that allows subjects to execute reaching movements in the horizontal plane. This two degrees of freedom (DoF) robot enables unrestricted movements of the shoulder and elbow joints[5]. The ARM-GUIDE is a trombone-like device and has four controlled DoF. A DC servo motor can assist in the movement of a subject's arm in the reaching direction along a linear track. Optical encoders record the position in the reach, elevation and yaw axes[7]. The MIME robot consists of a six DoF robot arm. The robot enables the bilateral practice of a three DoF shoulder-elbow movement, whereby the non-paretic arm guides the paretic arm[12]. The InMotion[2] Shoulder-Elbow Robot, which is the commercial version of MIT-MANUS (Interactive Motion Technologies, Inc, Cambridge, MA, USA), has two DoF and provides shoulder/elbow training in the horizontal plane with a supported forearm[10]. The Bi-Manu-Track is designed to specifically train distal arm movements by practicing bilateral elbow pro- and supination as well as wrist flexion and extension in a mirror or parallel fashion[11].

In the past, several studies were unable to prove superiority of one type of conventional stroke regimen over another[13–16], but there is strong evidence that highly repetitive movement training can result in improved recovery[4,16]. Applying robot-assisted therapy enables patients to practice intensively with their upper paretic limb. The objective of the present systematic review is to determine the additional effects of robot-assisted therapy on motor recovery and functional outcome in comparison with conventional treatment forms.

Material and methods

Literature search

A computerized literature search was conducted in MEDLINE, CINAHL, EMBASE, Cochrane Controlled Trial Register, DARE, SciSearch, Doc-on-line and PEDro. Studies were collected up to October 2006. Used MeSH and keywords were: cerebral vascular accident, cerebral vascular disorders, stroke, paresis, hemiplegia, upper extremity, arm and robot* (i.e. all words that start with the term ‘robot’). Literature lists of narrative reviews were also evaluated for relevant publications. Only articles written in the English, German or Dutch language were included. Studies were included when: (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; (4) The study was a randomised clinical trial (RCT). Excluded were studies that compared the effects of two different types of robot-assisted therapy and studies of persons with chronic impairment due to stroke that compared discharge outcomes with pre-intervention stable scores (time since stroke onset > 6 months).

Definitions

Cerebral vascular Accident has been defined as ‘A sudden, non-convulsive loss of neurologic function due to an ischemic or hemorrhagic intracranial vascular event’ (PubMed [Medline], MeSH database, 2005). Robotics has been defined as: ‘The application of electronic, computerized control systems to mechanical devices designed to perform human functions’. Although formerly restricted to the industry, nowadays also certain human functions can be controlled by bionic (bioelectronic) devices, such as automated insulin pumps and other prostheses (PubMed [Medline], MeSH database, 2005). One independent reviewer (JH) selected articles based on title and abstract.

Methodological quality

The methodological quality of the studies was rated with the PEDro scale[17] and scored by two independent reviewers (JH and GK). Inter-rater reliability of individual items was tested with Cohen’s Kappa statistics. When no consensus between the 2 reviewers was reached, a third reviewer made the final decision. Reviewers were not blinded to author(s), institution(s), or journal. PEDro scores of 4 points or higher were classified as ‘high quality’, whereas studies with 3 points or lower were classified as ‘low quality’.

Quantitative analysis

The abstracted data (mean age, numbers of patients in the experimental and control group, mean difference in change scores on the measure scales of motor recovery and functional level and their standard deviations in experimental and control groups at baseline) were entered in Excel for Windows. The effect size g_i (Hedges’s g) for individual studies was established by calculating the difference between the means of the experimental and control groups divided by the average population SD_i. If necessary, means and SD_i were requested from the respective authors. Alternatively, Hedges’s g estimates were obtained from *t* values. The impact of sample size was determined by assigning a weighting factor (w_i) to each study, in such a way that larger effect-weights were given to studies with larger samples. Finally, g^u values of individual studies were averaged, resulting in a weighted SES, while the individual weights were combined to estimate the variance of the SES. The effect size g^u for individual studies was computed for the degree of motor recovery and functional performance. If a significant between-study variation (Q-statistic) was found (representing statistical heterogeneity) a random effects model was applied. Based on the classification of Cohen, effect sizes < 0.2 were classified as small, between 0.2 and 0.5 as medium, and > 0.5 as large. For all outcome variables, the critical value for rejection of H_0 hypothesis was set two-tailed at $p<0.05$.

Results

Appendix 2 shows the flow chart for the selection of studies. After searching the electronic databases 87 from 173 hits were considered to be relevant for further screening. However, from these 87 publications, after screening their abstracts forty-four relevant studies were selected. Ten of these articles were critical or narrative reviews[6,7,18–25], and 24 studies were non-controlled trials. Following the exclusion of (1) pre-experimental studies and (2) controlled studies that did not measure motor and/or functional recovery of the upper paretic limb, in total 22 studies were excluded[4,9,26–47]. Finally, ten studies were identified as being relevant[8,10,12,48–54]. Two studies referred to the same patient sample[49,54]. The study of Volpe et al[54] presented outcomes on motor recovery of the upper paretic limb (Fugl-Meyer Arm motor score; FMA), whereas the study of Fasoli et al.[49] reported on outcome of functional ability (Functional Independence Measure; FIM) in the same stroke population.

Table 1 shows the main characteristics of the ten eligible studies included in the present meta-analysis. The start of the therapy ranged from one week after stroke[48–50,53,54] to more than six months after stroke[6,8,10,51,52].

Methodological Quality

The results of the methodological quality score of the ten RCTs are presented in Appendix 1. Cohen's kappa for agreement was 0.82. The methodological quality varied from 4 points[51,52] to 8 points[49].

The groups of two studies were not comparable at baseline. In the study of Hesse et al[50], the Barthel Index was statistically significant higher in favour of the experimental group. The study of Kahn et al.[51] showed a statistical significant higher value for the Chedoke McMaster test in favour of the control group.

Quantitative analysis

Motor recovery—Seven studies[8,10,12,48,50,53,54] used the F-M as outcome parameter, whereas the studies of Kahn et al.[51,52] evaluated outcome with the Chedoke McMaster. A total of 218 patients with stroke were involved. Five RCTs reported statistically significant effects for motor recovery in favour of the experimental group, whereas four RCTs did not find significant differences. On average, the experimental group received daily 48.3 minutes of Robot-assisted therapy (RT) and the control group 29.0 minutes of Control Therapy (CT). An overall statistically non-significant (0.65, 95%CI: −0.02 to 1.33; $Z = 1.90$, $P=0.06$) heterogeneous SES ($\chi^2 = 40.82$, $P<0.001$) was found in favour of the robot-assisted therapy. (Figure 1 and Table 2a). As shown in Table 2a and Figure 1, observed heterogeneity between studies was mainly due to study of Hesse and colleagues who reported a larger individual effect size for bilateral distal arm training when compared to the other studies. Subsequent sensitivity analysis without the study of Hesse et al showed a homogeneous SES ($\chi^2 = 4.35$, $P=0.60$) in favour of shoulder-elbow arm robotics (0.36 SDU [fixed]; 95%CI: 0.05 to 0.65, $Z = 2.32$, $P<0.026$).

ADL—Five studies[8,12,48,49,53] evaluated outcome with the FIM. A total of 139 patients with stroke were involved. None of the studies reported significant effects for ADL in favour of the experimental group. The study of [Burgar et al, 2000] is not shown due to the inability to calculate an individual effect size. On average, the experimental group received daily 50.3 minutes of RT and the control group 23.4 minutes of CT. A homogeneous non-significant SES was found (χ^2 =0.50, P> 0.05) for robot-assisted therapy (SES [fixed] 0.13 SDU; CI, −0.23 to 0.50, Z = 0.86, P>0.05) (Figure 2 and Table 2b).

Discussion

The present review, involving 218 patients, shows a positive trend toward robot-assisted therapy for the proximal upper limb when compared to conventional treatment modalities with regard to motor recovery when measured with the FM assessment scale (FMA) or the arm and hand impairment part of the Chedoke McMaster Stroke Assessment Scale (CMSA). The lack of overall significance for all included studies on motor recovery was the result of the application of a random effects model (REM). This REM calculates a summary effect size (SES) that is based on the within and between study variance. As a consequence, larger 95% confidence intervals of the SES are obtained than a fixed effects model would generate. However, a sensitivity analysis showed that observed heterogeneity was mainly caused by the study of Hesse and colleagues[19], who investigated the effects of Bi-Manu-Track robotic on distal elbow pro-supination and wrist flexion and extension activities in patients with stroke. By contrast, the other robots, such as MIT-manus and MIME robots, are designed to train proximal shoulder and elbow movements. This finding suggests that the observed effect size is dependent on proximal or distal arm robot training. Unfortunately, only three of the seven studies that measured FMA or CMSA score provided additional subscores for the proximal and distal arm components at baseline and at the end of the therapy. Two studies reported only the subscores of both components at the end of the therapy, whereas the other studies did not differentiate between these scores at all. Therefore, it remains uncertain whether the observed improved motor score is due to an improvement at the proximal shoulder-elbow level or at the distal hand-wrist level. In order to better understand what exactly patients learn by robotics when they improve in upper limb motor function, future studies should address this issue.[1] 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. These effects were based on studies of high methodological quality (PEDro score = 6 ± 1.25 (mean ± SD)).

No significant improvements were observed on outcome of ADL measured by the FIM scale. It is common knowledge that the FIM (like the Barthel Index; BI) does not measure dexterity of the upper paretic limb properly.[4] Therefore, scales that measure dexterity specifically, such as the Action Research Arm test, the Wolf Motor Function Test and Jebsen test or Nine-hole-peg test, are preferred. In addition, as was shown recently by Rohrer et al,[44], and Kahn and colleagues[51], future studies should also investigate kinematic changes to better understand the observed improvements in motor co-ordination.[4] For this later purpose, longitudinal conducted studies with repeated measurements are needed to understand how synergistic-dependent movement patterns improve in patients during robotic assisted therapies. In particular, changes that occur in adaptive compensatory movements of the trunk should be also investigated.[57] Moreover, it should be noted that measurements at a functional level can not differentiate between improvements at motor recovery level and improvements due to the use of alternative compensating strategies. Therefore, a better understanding of the relationship between the mechanisms of cortical reorganization and motor recovery is needed. In particular, understanding the bi-hemispheric plasticity after stroke will allow the development of new (robot-assisted) therapies to enhance learning-dependent neuroplasticity.[17] While an initial

[1]Of notice, one of us (Krebs) is running an NIH/NCMRR sponsored robot trial at the Burke Rehabilitation Hospital, White Plains, NY enrolling 200 persons with chronic impairment due to stroke to determine the influence of proximal and distal components of training and the preferred order of training (160 robot trained subjects and 40 controls).

small study by Lum and colleagues suggested that unilateral training is superior to bilateral training[53], larger studies investigating whether bilateral robotic assisted training, with or without auditory or visual cueing and feedback that promotes interhemispheric activation of the limbs should be subject to investigation. It may have an added value to only unilateral training, particularly to the more impaired patients. New developments in robotic innovations and capabilities are still to be expected and most likely will expand its applicability to other or more specific motor functions.

Another important issue to elucidate is the impact of high intensity robot-assisted therapy on motor recovery after stroke. In studies with the MIT-MANUS robot, in addition to conventional therapy, patients received five hours per week of robot-assisted therapy, while the control group received only one hour of robot exposure.[48,49,54] The number of movements generated in robot-assisted therapy is far higher than in other forms of therapy, such as Electric Stimulation (ES)[50], free reaching[51] and NeuroDevelopmental Therapy (NDT).[8,12] It can be concluded that high intensity repetitive movements constitute an important contributor to the effectiveness of robot-assisted therapy. In fact studies that tried to match the intensity of robotic therapy to the number of movements generated by other forms of therapy failed to show a differential effect.[51,52] In other words, robotic therapy had no particular advantage at low utilization, but it also did not hinder or halt recovery.

To examine whether the effectiveness of robot-assisted therapy is due to the treatment modality or to the high intensity of training, dose-response trials are required. It is important to understand that robotic therapy simply utilizes robots as vehicles to deliver highly repetitive therapy. There is no reason to assume that robots will lead to better results than human delivered movement therapy if there is a match of all variables. In practice the high intensity of training in patients receiving robotics in either the clinic in a classroom format and also in their own home environment will likely justify cost-effectiveness studies in which the purchase of a robotic device and support with a single therapist supervising multiple patients as demonstrated by Daly and colleagues[10] is compared with the costs of intermittent, patient-tailored training by a therapist in a clinical setting. For the home environment, patients' performances can be monitored and data collected remotely using robotic therapy in conjunction with broadband telematics. This development has - among other benefits - the potential of saving travelling expenses to and from a health care facility and increasing of independent training time. To date, high quality studies investigating the efficiency of robotics in relation to usual care are lacking in the literature. Such trials should incorporate a critical and comprehensive economic and effectiveness evaluation of hospital and community care, patient and family resources and other resources e.g. home help visits, and involve a cost-effectiveness analysis rather than a cost-minimization, cost-benefit or cost-utility analysis. To our knowledge, the only such a study presently in progress is being supported and run by the Veterans Affairs in the US involving four of its rehabilitation hospitals (PI: Albert Lo, Yale University and VA West Haven; CSP 558; West Haven, CT; Baltimore, MD; Gainesville, FL; Seattle, WA).

Finally, most studies were based on a small sample size and were heavily underpowered to reject H0 hypothesis. In particular, because the stroke population is heterogeneous at impairment level and treatment effects are relatively small when compared to observed differences in patterns of recovery due to spontaneous recovery[55], stratification on the basis of prognostic baseline characteristics becomes necessary.[2] For example, assuming that a 6 points difference constitutes the minimal clinically important difference (MCID) on outcome of ARAT[56], at least 238 patients per arm are needed in a two arm RCT to maintain 80% statistical power in order to reject the H0 hypothesis. The large standard deviation of ARAT measurements, i.e. about 32 points at 26 weeks post stroke[2], is mainly responsible for this large sample size, In contrast, when selecting only stroke subjects displaying some dexterity on the ARAT (i.e., ARAT>9 points), a sample standard deviation of 12 points is observed and only

31 patients in each arm will be needed to show a MCID of 6 points. As is the case in CIMT[57], demonstrating a therapeutic effect is also a matter of appropriate selection of patients.[4] To that effect it is important to note that patients with some probability for return of upper limb function in the first 5 weeks post stroke[2] or those with some return of voluntary extension of wrist and fingers beyond the subacute stage after stroke are likely to be the most favorable candidates for robotic therapy because of the presence of some dexterity.[4] By the same token, we expect that patients in the middle range of the FM–arm score (i.e., about 22 to 44 of maximal 66 points) may benefit most from robotic therapy.

The present review has a number of limitations. First, in this review we assumed that all studies used different patients, but because some studies were conducted at the same time and at the same place, we can not be certain that only unrelated study populations were used. Second, in the present study we pooled Fugl-Meyer arm motor scores[58] with the scores from the physical impairment inventory of the arm of the Chedoke-McMaster Stroke Assessment scale[59] in order to calculate one overall summary effect size for motor outcome of the upper paretic limb. The FMA includes 42 items to measure shoulder-elbow impairment and coordination and 24 items to measure the hand-wrist impairment.[58] On the other hand, the CSMA contains 2 dimensions related with motor control of arm and hand each measured on a 7 point scale.[59] In our opinion, pooling outcomes of both scales to generate one dimensionless SES is justified because both assessments are based on the six recovery stages of Brunnstrom. This suggests that both scales measure the same underlying construct (i.e., synergy-dependency of motor control). Third, we also pooled the robot-assisted interventions in order to obtain one overall effect size, even though different robots focussed on different parts of the upper limb function, different robot control strategies were employed (robots can be programmed to deliver different behaviours and as stated earlier we excluded comparison of different types of robot-assisted therapy), and some protocols focused on sub-acute phase of stroke recovery while other studies focused on the chronic phase. For the same reason we were unable to differentiate between the control interventions. Different types of control interventions, such as NDT and ES which have proven their effectiveness only at impairment level, made it difficult to interpret the effectiveness of robot-assisted therapy. These shortcomings emphasize the need for more high-quality RCTs. In the present review we did pool all motor outcomes of the upper limb, irrespective whether they were measured with the FMA or the Chedoke Assesment scale. We assumed that this was appropriate as both scales are based on the same motor stages of Brunnstrom.[59] Finally, only studies written in the English, German or Dutch language were included. We may have inadvertently missed relevant studies that were not published in scientific journals or in other languages.

In summary, the present systematic review confirms the potential for robotic assisted devices to elicit improvements in proximal upper limb function. However, improvements in terms of ADL could not be substantiated. Unfortunately, administered ADL scales such as FIM and BI do not reflect recovery of the paretic upper limb properly. Future research on the effects of robot-assisted therapy should focus on kinematic analysis[60] in order to differentiate between recovery by neural repair and recovery based on compensation strategies.[4,60] In addition, trials should use valid instruments that measure upper limb skills specifically, such as Action Research Arm Test (ARAT) or Wolf Motor Function Test (WFMT). Finally, the cost-effectiveness of robotics needs to be investigated. This latter is particularly important to be clarified because of the increasing pressure experienced by health care professionals in most countries to reduce health care costs. In addition, robotics may offer stroke patients an opportunity to train independently in an intensive functional fashion and at home. This becomes increasingly important at a time when a lack of time is reported to be the major barrier for therapists not to comply with evidenced based guidelines for stroke rehabilitation.[61, 62]

Acknowledgments

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Appendix

Appendix 1

Application of Methodological Criteria Investigating the Effects of Robot Therapy

Reference	1	2	3	4	5	6	7	8	9	10	11	Total Score	Co-intervention
Aisen, 1997	0	1	0	1	1	0	0	1	1	1	1	7	No
Burgar, 2000	0	1	0	1	0	0	1	1	0	1	1	6	No
Fasoli, 2004	1	1	0	1	1	0	1	1	1	1	1	8	Yes
Hesse, 2005	1	1	0	0	0	0	1	1	1	1	1	6	No
Kahn, 2000	0	1	0	0	0	0	0	0	1	1	1	4	No
Lum, 2002	0	1	0	1	0	0	1	1	0	1	1	6	No
Volpe, 2000	1	1	0	1	1	0	1	1	0	1	1	7	Yes
Daly, 2005	1	1	0	1	0	0	1	1	0	1	1	6	No
Kahn, 2006	1	1	0	0	0	0	1	0	0	1	1	4	No
Lum, 2006	1	1	0	1	0	0	1	1	0	1	1	6	No

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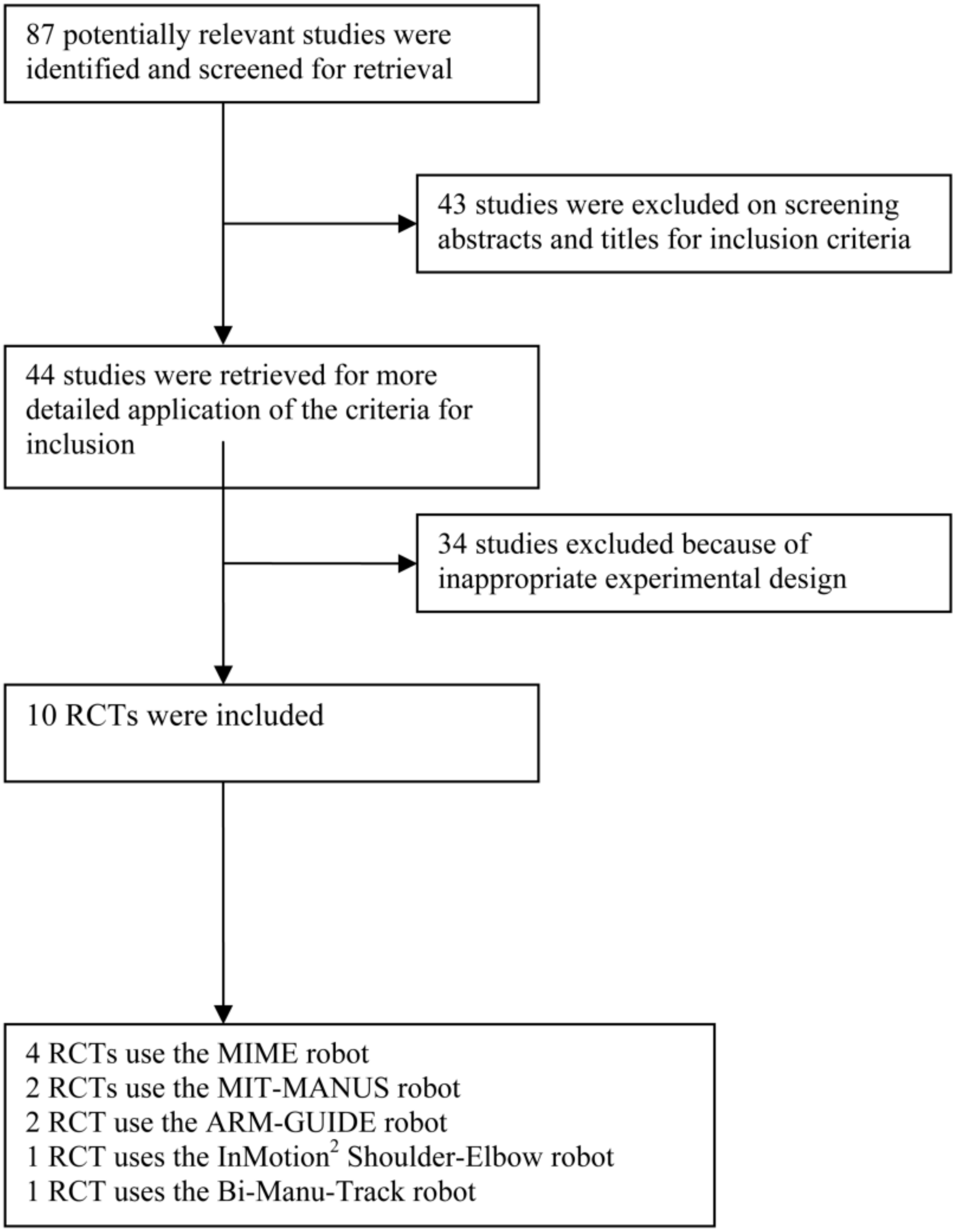
Appendix 2



Flow diagram

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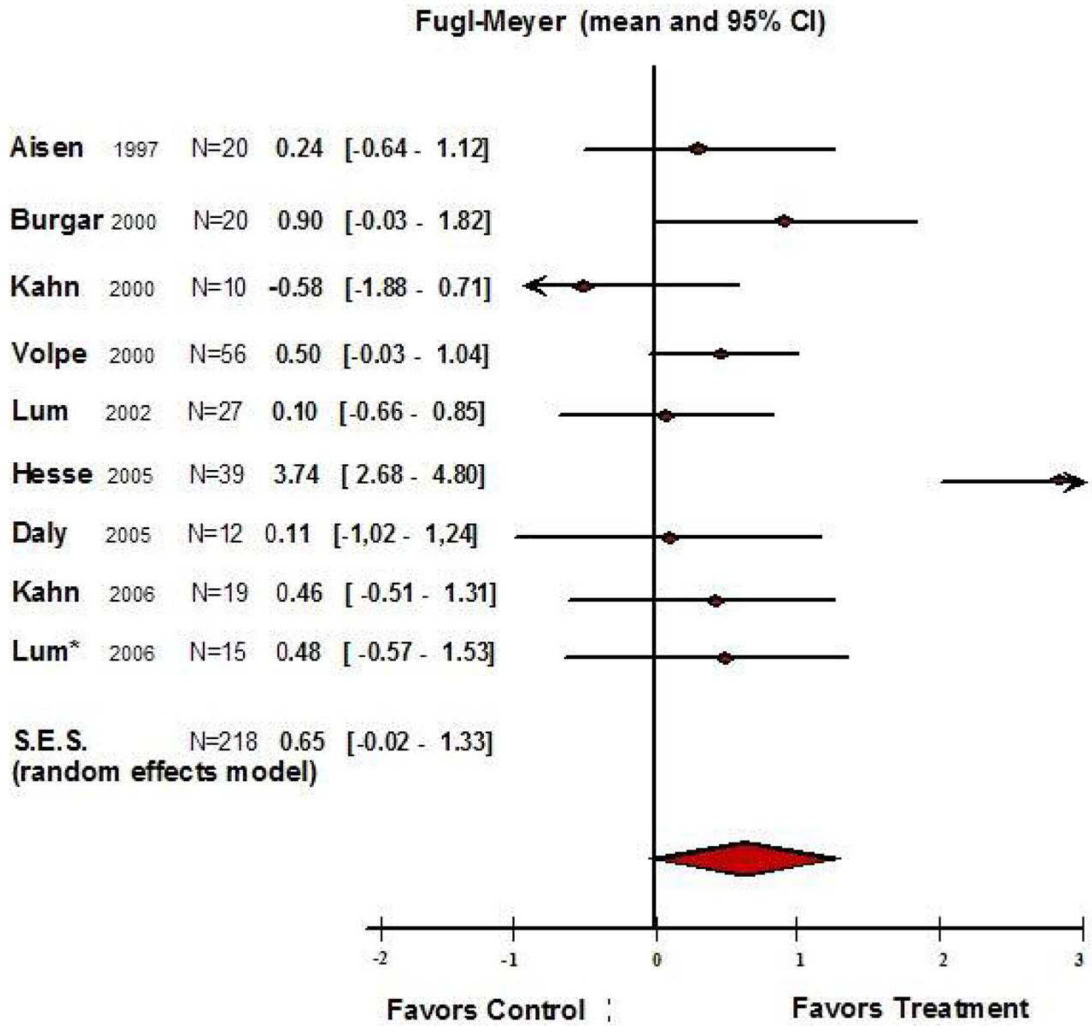

Figure 1.
Meta-analysis of robot-assisted therapy trails on motor recovery

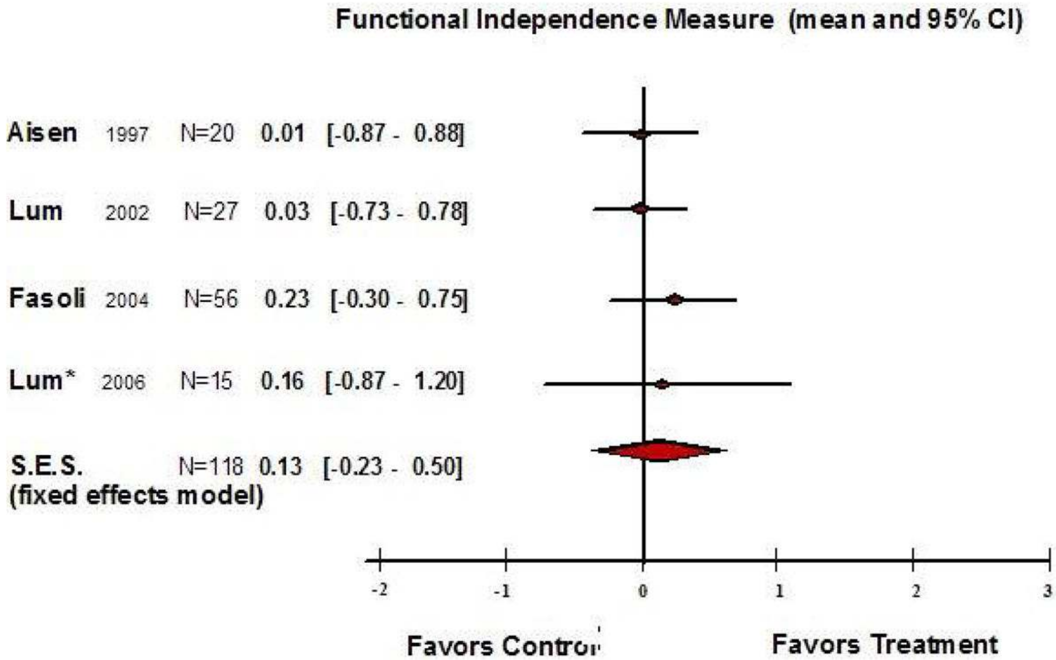

Figure 2.
Meta-analysis of robot-assisted therapy trails on ADL.

Table 1

Study characteristics

Reference	Stroke Type	Severity (F-M (U-L) at Baseline)	Start of RT/CT (E/C)*	Type of Intervention (E/C)	Intervention Categories	Daily (min) RT (E/C)#	Daily (min) CT (E/C)#	Mean Age (years) (E/C)*	Outcome	Authors Conclusion
Aisen, 1997	Hemorrhagic, ischemic	13.8/17.1	2.8/3.3 w	RT vs. Robot exposure (control)	MIT-MANUS	60/0	±0/10	58.5/63.3	F-M FIM	Significant difference in motor recovery (acute patients)
Burgar, 2000	All types	24.8/21.8	26.5/26.4 mo	RT vs. neurodevelopmental therapy	MIME	36/0	0/36	64.4/63.3	F-M FIM	Significant difference in motor recovery (chronic patients)
Kahn, 2000	?	?	>6 mo	RT vs. unassisted, unrestrained reaching exercises	ARM Guide	?	?	?	Ch McM	Repetitive movements seem to be the primary stimuli to recovery
Volpe, 2000	Hemorrhagic, ischemic	8.6/10.5	22.5/26.0 d	RT vs. Robot exposure (control)	MIT-MANUS	60/0	0/12	62/67	F-M	Improvement of the motor performance of the exercised shoulder and elbow
Fasoli, 2004	Hemorrhagic, ischemic	8.6/10.5	9/10 d	RT vs. Robot exposure (control)	MIT-MANUS	60/0	0/12	62/67	FIM	Intensive therapy leads to better recovery after stroke
Lum, 2002	All types	24.8/26.6	30.2/28.8 mo	RT vs. neurodevelopmental therapy	MIME	36/0	0/36	63.2/65.9	F-M FIM	Significant difference in motor recovery
Hesse, 2005	Ischemic (first stroke)	7.9/7.3	4–8 w§	RT vs. electrical stimulation	Bi-Manu-Track	20/0	0/20	65.4/64.0	F-M	Superior improvement in upper limb control and power
Daly, 2005	Hemorrhagic, ischemic	21/23	>12 mo	RT vs. functional neuromuscular stimulation and motor learning	InMotion2 Shoulder-Elbow Robot	90/0	0/90	21–62	F-M	Significant gains in F-M upper-limb coordination

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Reference	Stroke Type	Severity (F-M (U-L) at Baseline)	Start of RT/ CT (E/C)*	Type of Intervention (E/C)	Intervention Categories	Daily (min) RT (E/C)#	Daily (min) CT (E/C)#	Mean Age (years) (E/C)*	Outcome	Authors Conclusion
Kahn, 2006	?	3.5/3.2	75.8/103.1 mo	RT vs. task-matched amount of unassisted reaching	ARM Guide	61/0	0/61	55.6/55.9	Ch McM	Robotically assisting in reaching successfully improved arm movement ability
Lum, 2006	?	8.4/5.0	10.0/10.6 w	RT vs. conventional therapy	MIME	45/0	0/45	69.8/59.9	F-M, FIM	Robot-assisted treatment gains exceeded those expected from spontaneous recovery

F-M (U-L) indicates Fugl-Meyer (upper-limb); RT, robot-assisted therapy; CT, control therapy; E/C, experimental group vs. control group; d, day; w, week; mo, month; FIM, Functional Independence Measure; Ch McM, Chedoke McMaster.

* Only median figures given;

Average of calculated minutes for every working day during intervention

§ Average age of experimental and control group together

Table 2

Table 2a. Summary Effect Sizes for motor recovery at the end of the intervention (N=218)

Reference	Outcome	Intervention time	N_E/N_C	SD_E/SD_C	ΔE−ΔC	ES g^u	95%-CI
Aisen, 1997	Fugl-Meyer (U-L)	6–7 w	10/10	15.1/16.4	14.1–10.1	0.24	−0.64–1.12
Burgar, 2000	Fugl-Meyer (U-L)	2 mo	10/10	16.5/17.9	16.0#	0.90	−0.03–1.82
Kahn, 2000	Chedoke-McMaster	8 w	6/4	1.7/1.5	0.2–0.8	−0.49	−1.60–0.95
Volpe, 2000	Fugl-Meyer (U-L)	>5 w	30/26	2.5/1.0	7.0–5.0	1.01	0.45–1.57
Lum, 2002	Fugl-Meyer (U-L)	2 mo	13/14	16.2/17.6	4.7–3.1	0.10	−0.66–0.85
Hesse, 2005	Fugl-Meyer (U-L)	6 w	19/20	3.4/3.3	16.7–3.1	3.98	2.86–5.08
Daly, 2005	Fugl-Meyer (U-L)	12 w	6/6	7.0/4.7	8.2–9.5	0.11	−1.02–1.24
Kahn, 2006	Chedoke-McMaster	8 w	10/9	0.9/1.0	−3.3–−2.9	0.46	−0.51–1.31
Lum, 2006*	Fugl-Meyer (U-L)	4 w	9/6	3.2/4.0	4.3/2.5	0.48	−0.57–1.53
F-M SES			**113/105**			**0.65**	**−0.02–1.33**

Table 2b. Summary Effect Sizes for ADL at the end of the intervention (N=139)

Reference	Outcome	Intervention time	N_E/N_C	SD_E/SD_C	ΔE−ΔC	ES g^u	95%-CI
Aisen, 1997	FIM	6–7 w	10/10	8.5/14.0	25.7–25.6	0.01	−0.87–0.88
Burgar, 2000	FIM	2 mo	11/10	6.3/9.8	?	?	?
Lum, 2002	FIM	2 mo	13/14	7.6/7.9	0.2–0.0	0.03	−0.73–0.78
Fasoli, 2004	FIM	6–7 w	30/26	4.4/6.1	10.3–8.7	0.30	−0.23–0.83
Lum, 2006*	FIM	4 wk	9/6	4.0/3.4	3.7–3.2	0.16	−0.87–1.20
FIM SES			73/66			0.13	−0.23–0.50

Fugl-Meyer (U-L) indicates Fugl-Meyer (upper-limb); N, number of patients; SD, standard deviation; E, experimental group; C, control group; ES g^u, effect size (Hedges' g); CI, confidence Interval; w, week; mo, month; SES, summary effect size.

* proximal and unilateral

\# calculated from p-value

FIM indicates Functional Independence Measure; N, number of patients; SD, standard deviation; E, experimental group; C, control group; ES g^u, effect size (Hedges' g); CI, confidence Interval; w, week; mo, month; SES, summary effect size; *, unilateral.