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## Disclosures:

Reha-Stim company, Berlin, Germany, holds the national patent on the mechanical arm trainer Reha-Slide; the company is owned by Dr. Beate Brandl-Hesse, the spouse of the author S.H. Dr. H. I. Krebs is a co-inventor of several MIT-held patents of rehabilitation robotics and he holds equity positions in Interactive Motion Technologies, Inc., the company that manufactures and distributes in the Western Hemisphere rehabilitation robotics technology under license to MIT and Reha-Stim. The study was sponsored by a grant of the Gesellschaft zur Förderung der Neurologischen Rehabilitation e.V., Berlin Germany. Reha-Stim company, Berlin, Germany, provided the devices used in the study.

0894-9115/08/8710-0779/0  
*American Journal of Physical  
Medicine & Rehabilitation*  
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DOI: 10.1097/PHM.0b013e318186b4bc

October 2008

Stroke

## ORIGINAL RESEARCH ARTICLE

# Mechanical Arm Trainer for the Treatment of the Severely Affected Arm After a Stroke

## A Single-Blinded Randomized Trial in Two Centers

### ABSTRACT

Hesse S, Werner C, Pohl M, Mehrholz J, Puzich U, Krebs HI: Mechanical arm trainer for the treatment of the severely affected arm after a stroke: a single-blinded randomized trial in two centers. *Am J Phys Med Rehabil* 2008;87:779–788.

**Objective:** To test whether training with a new mechanical arm trainer leads to better outcomes than electrical stimulation of the paretic wrist extensors in subacute stroke patients with severe upper limb paresis. Electrical stimulation is a standard and reimbursable form of therapy in Germany.

**Design:** Randomized controlled trial of 54 inpatients enrolled 4–8 wks from stroke onset, mean upper-extremity subsection of Fugl-Meyer assessment (0–66) at admission less than 18. In addition to standard care, all patients practiced 20–30 mins arm trainer or electrical stimulation every workday for 6 wks, totaling 30 sessions. Primary outcome was the Fugl-Meyer assessment, secondary outcomes were the Box and Block test, the Medical Research Council and the modified Ashworth scale, blindly assessed at enrollment, after 6 wks, and at 3-mo follow-up.

**Results:** Both groups were homogeneous at study onset. Shoulder pain occurred in two arm trainer patients. The primary Fugl-Meyer assessment outcome improved for both groups over time ( $P < 0.001$ ), but this improvement did not differ between groups. The initial (terminal) mean Fugl-Meyer assessment scores were  $8.8 \pm 4.8$  ( $19.2 \pm 14.5$ ) for the arm trainer and  $8.6 \pm 3.5$  ( $13.6 \pm 7.9$ ) for the electrical stimulation group. No patient could transport a block initially, but at completion significantly more arm trainer patients were able to transport at least three blocks (five vs. zero,  $P = 0.023$ ). No significant differences were observed between the groups on the secondary Box and Block outcome at follow-up (eight vs. four patients). All Box and Block responders had an initial Fugl-Meyer assessment  $\geq 10$ .

**Conclusions:** Arm trainer training did not lead to a superior primary outcome over electrical stimulation training. However, “good performers” on the secondary outcome seemed to benefit more from the arm trainer training.

**Key Words:** Stroke, Rehabilitation, Upper Limb Paresis, Upper Limb Exercise, Arm Trainer

RCT of a Mechanical Arm Trainer

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In the industrialized world, approximately 180 per 100,000 inhabitants suffer strokes each year, with 30% of survivors experiencing for 4 to 8 wks a severe flaccid upper limb paresis without volitional distal extensor activity.<sup>1</sup>

The prognosis for regaining functional hand activity 6 mos later is very poor, even for patients receiving the standard of care in Europe (Bobath therapy).<sup>2,3</sup> As a result, most patients fall short of the criteria for promising active training programs such as constraint-induced movement therapy.<sup>4</sup>

Shorter inpatient hospitalizations shift program emphasis toward compensatory techniques that facilitate functional abilities such as gait retraining and compensatory use of the nonaffected upper extremity, potentially resulting in little therapy intensity of the severely affected upper extremity. Recent data suggest that hasty compensation for impaired motor skills engenders a pattern of disuse that can mute the potential for future improvements in motor ability or function in the paretic limb.<sup>5</sup>

Rehabilitation is a labor-intensive process, relying on one-on-one therapy and evaluation procedures administered by a single clinician working with the patient. Labor-intensive procedures represent one of the primary application fields of robotics. A robotic therapist can act as a modern, effective, and novel tool that delivers a reproducible, intense task-specific training experience for the paretic arm; quantitatively monitors and adapts to patients' progress; and ensures consistency in planning a therapy program. Positive results from investigations involving robotic therapy systems have been widely reported, notably involving MIT-Manus,<sup>6</sup> MIME,<sup>7</sup> Bi-Manu-Track,<sup>8</sup> and the NeReBot.<sup>9</sup> These studies compared robotic *vs.* sham therapy (MIT-Manus, NeReBot) or electrical wrist stimulation (Bi-Manu-Track) in subacute or *vs.* Bobath therapy in chronic stroke patients. Other groups working with different robotic devices and protocols for the upper extremity (for review, see Kwakkel et al.<sup>10</sup>) have observed similar results.

Therapy robots are expensive, which may prevent their broader application, particularly within a comprehensive program for stroke rehabilitation that continues beyond the clinic into the home. Therefore, our group has designed a low-cost, passive mechanical arm trainer (AT) as a first step toward this comprehensive rehabilitation program. To that end we designed Reha-Slide, which allows unilateral or bilateral training of up to 3 *df* of the shoulder, elbow, and flexion or extension of the wrist.<sup>11</sup>

The device has some similarities to the BATRAC [bilateral arm training, auditory-cued], a 1-*df* custom-made mechanical AT introduced by Whitall and coworkers.

Auditory cued patients moved two unyoked T-grips of the BATRAC forward and backward in parallel or alternate fashion. Two positive studies included chronic patients who had the ability to move the affected limb in the shoulder and elbow joints against gravity.<sup>12,13</sup>

Reha-Slide also includes two handles but our target design was slightly different than the group developing the BATRAC. We wanted to allow patients to exercise both transport of the arm and hand posture. Furthermore, to afford training even to a plegic or very weak patient, the right and left handles were yoked so that, if necessary, patients could drive the affected arm with the nonaffected one. The handles can be moved forward or backward and sideways for shoulder-and-elbow training, and rotated for wrist flexion or extension training. Furthermore, the base plate can be inclined and passive resistance added via a graded brake to afford different levels of difficulty. Feedback of the handle's position is displayed on a computer screen, allowing patients to play a multitude of motivational games while providing feedback.

Here we intended to evaluate whether the mechanical AT leads to better outcome than the electrical stimulation (ES) of the paretic wrist extensors in subacute stroke patients with severe upper limb paresis. Patients received standard therapy and were randomly assigned to receive an additional 20 mins of either AT or ES training. The AT training involved bilateral movements aiming at repetitive practice of isolated and complex movements, with the nonparetic side driving the paretic side if needed. The ES group received neuromuscular ES of the paretic wrist extensors in accordance to the guidelines of the German Neurological Society, which recommends the ES treatment modality as a standard additional equipment-mediated therapy of the severely affected arm. Controlled studies and pooled analysis had shown its effectiveness in severely to moderately affected subacute patients.<sup>14-17</sup> Of notice, German insurance companies reimburse this modality including its home use.

## METHODS

### Design of the Study

The study was a single-blinded, randomized, controlled trial, conducted in two centers. Participating patients were randomly allocated to two groups, A and B. Over a 6-wk period, A-patients received 30 sessions of AT, and B-patients 30 sessions of ES in addition to their comprehensive rehabilitation programs. Patients were assessed before treatment (T-begin), after treatment (T-end), and at 3-mo follow-up (T-follow-up).

## Subjects

From March 2005 to August 2006, eligible subacute stroke patients of two rehabilitation centers were enrolled in the study. Inclusion criteria were

- First time supratentorial stroke,
- Stroke onset 4–8 wks before study enrollment,
- Enrolled in a comprehensive, inpatient rehabilitation program for 8–10 wks,
- At least wheelchair-mobilized and a Barthel Index of 20 (range, 0–100),
- Severe upper limb paresis with no or minimal volitional activity of the wrist and finger extensors, i.e., Medical Research Council (MRC) grade of 0 or 1 (range, 0–5),
- An initial upper limb Fugl-Meyer assessment (FM) of less than 18 (range, 0–66),<sup>18</sup>
- Inability to transport a single wooden 1 block of the Box and Block test,<sup>19</sup>
- Absent to moderate elbow, wrist, and finger spasticity,
- Capable of following basic instructions, and
- Written consent to participate in the study approved by the local ethical committee.

Patients were excluded from the study if they presented

- Shoulder pain insensitive to standard therapy,
- Swollen hand impairing finger joint mobility with no fist possible,
- Painful arthritis of the wrist or finger joints, and
- Forearm skin ulcers.

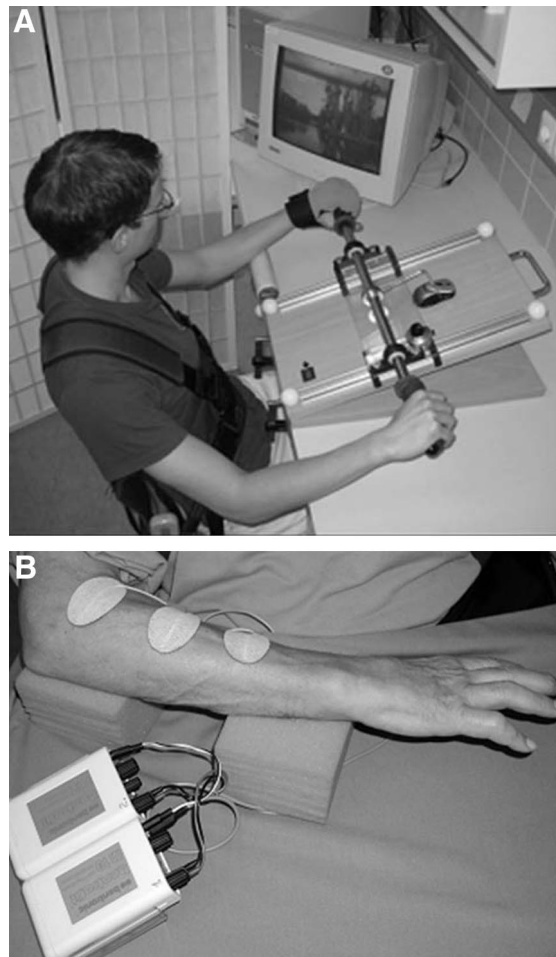
## Allocation

Fifty-four lots (A or B) had been prepared in two sealed envelopes, 27 for each centre. Immediately before the first session, the consenting patient drew a lot out of the envelope presented by a clinician not involved in the study.

Power calculation ( $\alpha = 0.05$ ,  $\beta = 0.8$ ) assumed that a clinically relevant difference between groups (effect-size = 1) should exceed one standard deviation (SD) of the FM (0–66) of the ES-group at the end of the intervention. In a separate prior study on the application of ES on a comparable population, we observed an FM mean of 14 (SD = 6.0) for the ES group at study completion. These led to 21 patients per group. Assuming an attrition rate of 20–30%, we decided to include 27 patients per group.

## Intervention

Patients practiced either with the mechanical AT (Reha-Slide, Reha-Stim, Berlin, Germany, AT-group, Fig. 1) or received an electrical muscle



**FIGURE 1** Mechanical arm trainer Reha-Slide (A) and EMG-triggered electrical stimulation of the paretic wrist extensors (B).

stimulation of their paretic wrist extensors (Bentofit M13, F12, Bentronic GmbH, München, Germany, ES-group), 20–30 mins net sessions, 5 days a week, for 6 wks (total of 30 sessions).

Here patients in the AT-group practiced bilateral movement. The mechanical trainer allows 3 *df*. Two handles are spaced by 0.75 m and connected by a rod and mounted on two sledges. The sledges are running on two parallel tracks mounted on a wooden board (50 × 30 × 2 cm). The patient can move the rod handles by 30 cm forward and backward (elbow extension or flexion), sideways in both directions by 15 cm (shoulder abduction or adduction), and fully rotate the rod (wrist extension or flexion). The handles are yoked, allowing during bilateral training the nonaffected arm to assist and drive the affected extremity as needed. The movements can be performed either in an isolated manner or in combination—for instance, drawing a square or a circle clockwise or counter-clockwise. Furthermore, the board can be inclined (0–25 degrees). Friction of forward and backward movement can be adjusted via a rubber brake (range,

5–80 N). An inductive sensor counts the number of repetitions and displays it to the patient. A wireless computer mouse is fixed at the connecting rod and thus the patient can control the cursor movement on any computer. The computer monitor is placed in front of the patient, who can exercise with a multitude of motivational games (e.g., shooting birds or following a labyrinth etc.). The level of difficulty and the training duration can be tailored to each patient's needs and a patient's performance is continuously monitored.

The patients sat at a height-adjustable table with their elbows bent 90 degrees; the paretic forearm was supported with a forearm sling from above. Each hand grasped a handle, a strap held the paretic hand in place, and a harness constrained the trunk movements. Within one session, each patient started to practice 100 isolated forward and backward movements with the board first in horizontal plane and then inclined, totaling 200 movements. Next the patients drew 100 circles clockwise and 100 circles counterclockwise with the board both horizontal and inclined, totaling 400 circles. A metronome helped to pace movements. Patients were instructed to attempt to assist the bilateral movement with the paretic arm and to extend the paretic elbows as much as possible without eliciting pain. A colored clamp was placed at the sledge to indicate the reaching distance and patients were instructed to draw circles so that each adducting arm would reach midline of the body. The forward-backward friction level was increased over the weeks of the training according to individual capabilities. The amount of inclination was set in such a way that the handles reached the shoulder level. At the end of each session, the patients played a computer game of their choice for another 5 mins.

In the ES-group, patients sat at a height-adjustable table with their elbows bent 90 degrees and their forearms in pronation. Trains of 4–7 secs monophasic exponential pulses (75 Hz, 0.5 msec, 0–80 mA) were applied by two self-adhesive flexible electrodes (2.5 × 3 cm) targeting the extensores antebrachii superficialis. The location of the electrodes and the stimulation intensity were set to produce maximum selective wrist extension; the patient was instructed to attempt to assist the movement. A third flexible self-adhesive electrode, placed between the two stimulation electrodes, recorded the volitional muscular activity (EMG). Patients performed 60–80 wrist extensions per 20–30 mins session with an interstimulus interval between 8 and 15 secs. If the patient could volitionally activate the wrist extensor muscle during the study, EMG-triggered electrical muscle stimulation was employed. In this case, whenever the patient reached the preset EMG threshold, the external stimulation was triggered. The EMG activity

threshold required to trigger the ES was continuously adjusted near the patient's highest level.

In both centers, all patients were supervised by the same therapist in the same room. The therapists had participated in a prestudy workshop lasting 3 days, and had been working with the ES for at least 1 yr and with the AT for at least 4 mos on a regular basis before the study onset. The therapist assisted during set-up (2–3 mins for both AT and ES) and the patients practiced without close supervision.

All 54 patients participated in a comprehensive, inpatient rehabilitation program lasting 8–10 wks.<sup>20</sup> The weekly program included five 45-min sessions of physiotherapy and four 30-min sessions of occupational therapy based on the neurodevelopmental technique concepts. Restoration of stance, gait, and activities of daily living competence were the primary goals of the comprehensive rehabilitation program. Upper limb exercises comprised approximately 15% of physiotherapy and occupational therapy aiming at mobilization of the shoulder girdle, tone-inhibiting maneuvers, and the facilitation of motor functions. Speech, neuropsychologic, and hydrotherapies were administered according to individual needs.

## Outcome Variables

Primary outcome variable was the upper-extremity subsection of FM (0–66). The sensitive, reliable, and valid FM test included items related to movements of the shoulder, elbow, forearm, wrist, and hand (FM).<sup>18</sup>

Secondary outcome variables were the Box and Block test, which assesses upper limb disability,<sup>19</sup> the Medical Research Council (MRC), and the modified Ashworth scale. The Box and Block test is a simple, valid, and reliable disability test. It consists of two adjacent boxes of the same size, separated by a 15.2-cm high partition, with one of them filled with 150 blocks of 2.5 cm<sup>3</sup> each. The boxes stand close and centered in front of the sitting patient. Following instruction and a 15-sec trial period, the patient performs the test with his unaffected and then with his affected upper extremity. Within 60 secs the patient grasps as many individual blocks as possible, transports, and releases them across the partition with the finger crossing the partition. It is not necessary to neatly place them on the bottom of the box. The examiner determines whether individual block transport follows the rules. As stated in the inclusion criteria, none of the patients at admission was able to transfer any block with the affected hand. Responders were defined as those subjects who could transfer at least three blocks. Prestudy testing had revealed that some patients with high wrist and finger tone could, in some instances transfer one or two blocks. To guarantee consistency in test-retest, we required responders

to transfer three or more blocks. The MRC (0–5) evaluated the strength of the shoulder abductors, flexors, and extensors of the elbow, of the wrist, of the fingers, and of the thumb (total MRC-sum, 0–45). The modified Ashworth scale (0–5) assessed the muscle tone of the shoulder adductors, the flexors of the elbow, wrist, fingers, and the thumb (total AS-sum, 0–25).

Data were collected at study enrollment (T-begin), at the end of treatment (T-end), and 3 mos later (T-follow-up). The assessment of the Box and Block test and of the FM were videotaped with the patient sitting on a chair and a mirror placed at an angle of 45 degrees to his or her paretic shoulder. A single experienced therapist, blinded to group assignment, rated the videos. Muscle strength and tone were assessed by the training therapists.

### Statistical Analysis

An intention-to-treat analysis was performed. If a patient dropped out of the treatment, the assessment continued or, if not possible, the last available score was assumed throughout the study. The homogeneity of the groups before study onset

was tested with the help of a Mann-Whitney *U* test. For the primary variable, the FM, we calculated intrasubject differences from enrollment to training completion (T-end – T-begin) and from follow-up to training completion (T-follow-up – T-end). We used the nonparametric Wilcoxon test to evaluate the differences, and the nonparametric Mann-Whitney *U* test to assess differences between groups ( $P < 0.05$ ).

For the Box and Block test, responders were defined as patients who could transport at least three blocks within 1 min. Variations between groups were calculated with a one-sided Fisher's test ( $P < 0.05$ ). The other two secondary variables, muscle strength and tone sum scores, were handled as the primary variable. We used SPSS software (Chicago, IL) version 14.0 for the analysis.

### RESULTS

Of 895 screened stroke patients, 54 patients volunteered for the trial with 25 of the AT group and 27 of the ES group completing treatment. We were able to recall 47 patients to follow-up (Fig. 2).

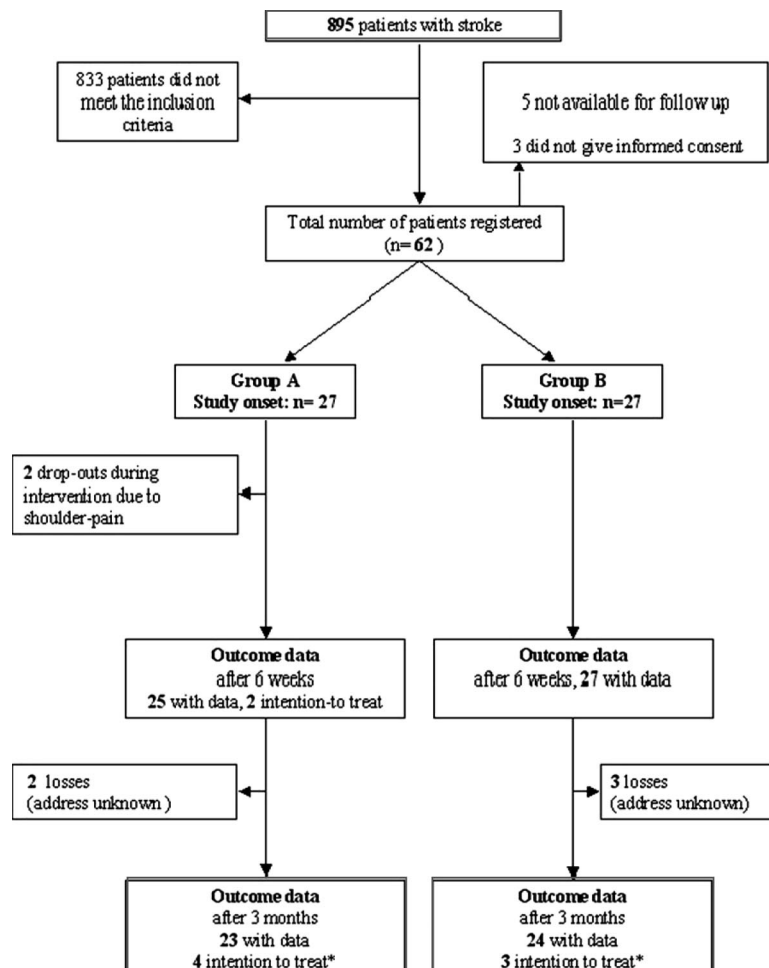


FIGURE 2 Flow diagram, \*last available data were used.

**TABLE 1** Clinical data and initial assessment scores in means and SD responders. Median and IR for both groups at study onset

	AT Group	ES Group	<i>P</i>
<i>N</i>	27	27	1.000
Diagnosis	10 = ischemic, 17 = hemorrhagic	13 = ischemic, 14 = hemorrhagic	0.787
Hemiparesis	16 = left, 11 = right	9 = left, 18 = right	0.058
Stroke interval, wks	4.6 (±1.0)	5.2 (±1.3)	0.277
Age, yrs	62.1 (±10.0) (range, 37–79)	65.2 (±11.7) (range, 41–79)	0.332
Sex	9 = ♀; 18 = ♂	8 = ♀; 19 = ♂	0.772
Neglect	9	7	0.555
Barthel index (0–100)	34.8 (±16.7)	35.8 (±17.1)	0.807
Ambulatory ( <i>n</i> )	4	3	0.391
Upper limb motor control	8.8 (±4.8)	8.6 (±3.5)	0.741
Fugl-Meyer motor score (0–66)	8 (5–11)	9 (6–11)	
Upper limb disability	0	0	1.000
Box and Block test ( <i>n</i> /min)			
Upper limb motor strength	5.6 (±4.4)	5.9 (±4.9)	0.901
MRC sum score (0–45)	5 (2–8)	4 (2–9)	
Upper limb muscle tone	1.9 (±2.4)	2.2 (±2.6)	0.596
Modified Ashworth sum score (0–25)	1 (0–4)	1 (2–8)	

Before study onset, both groups were comparable (Table 1).

Each AT patient practiced a total of 18,000 movements, 6,000 forward or backward, point-to-point movements, and 12,000 circles. Two patients in the AT group reported shoulder pain and dropped out after day 8 and day 15 of the intervention.

Each ES patient practiced a total of 1800–2400 wrist extensions. Only 4 of 28 patients were able to trigger the stimulation (EMG) after 2–5 wks. Two patients reported a more swollen hand immediately

following the ES. No patient dropped out of this group.

In both groups, the FM improved significantly over time ( $P < 0.001$ ). There was no statistically significant primary outcome difference between the two groups (Table 2). We observed no difference during the intervention period from admission to discharge (T-begin – T-end), neither during the follow-up period (T-end – T-follow-up; see Fig. 3).

Although no patient could transport a block at enrollment, at study completion significantly more

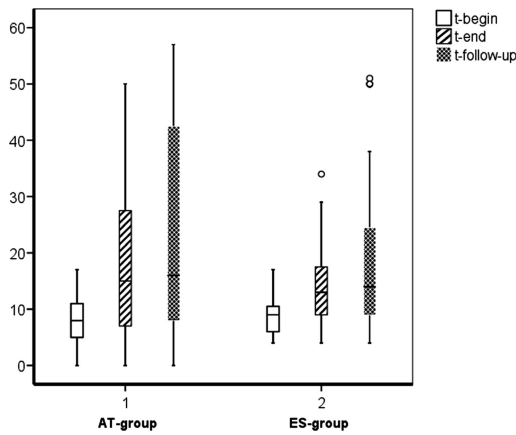
**TABLE 2** Mean (SD) and median (IR) scores, mean differences (SD), and approximate confidence intervals (CI) for the arm trainer (AT) and electrical stimulation (ES) group

Group	T <sub>begin</sub>		T <sub>end</sub>		NS	T <sub>follow-up</sub>		NS
	AT	ES	AT	ES		AT	ES	
Motor Fugl-Meyer Test (0–66)								
Mean (SD)	8.8 (±4.8)	8.6 (±3.5)	19.2 (±14.5)	13.6 (±7.9)		28.9 (±18.5)	18.4 (±14.3)	
Median (IQR)	8 (5–11)	9 (6–11)	15 (7–28)	13 (9–20)		16 (7–43)	14 (8–25)	
Box and Block test								
Responder	0	0	5	0	<sup>a</sup>	8	4	NS
Non-responder	27	27	22	27		19	23	
MRC sum score (0–45)								
Mean (SD)	5.6 (±4.4)	5.9 (±4.9)	14.0 (±10.6)	9.7 (±6.7)	NS	13.3 (±12.2)	13.4 (±10.4)	NS
Median (IQR)	5 (2–8)	4 (2–9)	13 (4–22)	9 (4–13)		10 (1–23)	14 (3–22)	
Total Ashworth score (0–25)								
Mean (SD)	1.9 (±2.4)	2.2 (±2.6)	4.7 (±5.9)	6.1 (±6.9)	NS	2.9 (±4.4)	6.4 (±5.8)	<sup>a</sup>
Median (IQR)	1 (0–4)	1 (2–8)	2 (0–7)	3 (4–13)		0 (0–3)	6 (1–23)	

Responder: ≥5 blocks at Box and Block test.

<sup>a</sup> Significant difference,  $P < 0.05$ , between groups.

IQR indicates interquartile range; NS, no significant difference.



**FIGURE 3** Box plot of the Fugl-Meyer Motor Score (FM, 0–66) of patients of the AT-group (left) and the ES-group (right) at T-begin, T-end, and T-follow-up. O indicates values larger than one and a half of the box.

patients of the AT group had become responders ( $P = 0.026$ ) with five patients transporting a mean of  $19.2 \pm 13.5$  blocks (Table 3). In the ES group, no patient could transport any block at study completion. At follow-up, eight patients of the AT and four patients of the ES group had become responders, although it did not reach a statistically significant difference between groups. They transported a mean of  $22.3 \pm 11.9$  wooden blocks (group AT) and  $10.0 \pm 5.9$  blocks (group ES; Table 3).

Both groups improved their MRC-sum score significantly over time ( $P < 0.001$ ). There were no statistically significant differences between groups, neither during the intervention period nor during the follow-up period. The muscle tone (AS-sum) remained constant in the AT-group throughout the

study whereas it increased in the ES-group ( $P < 0.001$ ). Both groups differed at follow-up ( $P = 0.018$ ) (Table 2). The modified Ashworth scale changes in the ES-group at follow-up were due to an increase in both distal and proximal muscle tone.

## DISCUSSION

This randomized study compared the mechanical AT *vs.* the electrical wrist stimulation in severely affected subacute stroke patients. Although the interventions differed with respect to training focus, we selected the ES as the control group because it is the standard equipment-mediated therapy of the severely affected upper limb in Germany, recommended by the guidelines of the German Neurological Society and presently reimbursed by insurance carriers. Furthermore, there is some evidence suggesting that distal limb training might be beneficial also to proximal limb segments. For example, different studies showed that training the distal wrist leads to some improvement of proximal limb segments, whereas the converse is not supported.<sup>8,21,22</sup>

The groups were homogeneous at study onset, the treatment duration did not differ, and both groups received the same comprehensive standard of rehabilitation. Early in the study, two patients of the AT group dropped out because of shoulder pain. One possibility is that the board inclination required arm elevation beyond 90 degrees, which could have provoked the adverse effects.<sup>20</sup> We instructed therapists to properly position the patient and to limit the inclination preventing patients from moving the hands above shoulder level. Although the causal relationship was not fully determined, the problem did not reoccur.

**TABLE 3** Individual clinical data of the responders of the Box and Block test in both groups

Patient	Age	Sex	Side of Lesion	Box and Block (n)			Fugl-Meyer (0–66)		
				T <sub>begin</sub>	T <sub>end</sub>	T <sub>follow-up</sub>	T <sub>begin</sub>	T <sub>end</sub>	T <sub>follow-up</sub>
AT-responder at T <sub>end</sub>									
AT 2	68	♂	Left	0	14	20	17	43	53
AT 5	71	♀	Right	0	15	21	7	37	46
AT 11	68	♀	Right	0	5	12	13	45	41
AT 22	59	♂	Right	0	41	45	16	41	50
AT 25	49	♂	Left	0	21	30	14	50	60
Additional AT-responder at T <sub>follow-up</sub>									
AT 7	58	♀	Left	0	0	27	11	28	42
AT 8	78	♀	Right	0	0	7	8	27	43
AT 16	63	♂	Left	0	0	16	11	17	44
ES-responder at T <sub>follow-up</sub>									
ES 8	41	♀	Left	0	0	9	12	22	38
ES 9	40	♂	Left	0	0	14	10	29	50
ES 21	73	♂	Right	0	0	12	11	15	51
ES 27	54	♂	Left	0	0	15	17	34	50

The mean ( $\pm$ SD) initial (terminal) FM scores were  $8.8 \pm 4.8$  ( $19.2 \pm 14.5$ ) in the AT group and  $8.6 \pm 3.5$  ( $13.6 \pm 7.9$ ) in the ES group and were in line with epidemiologic studies. For example, in a large survey of severely affected patients, Duncan et al.<sup>23</sup> reported a mean ( $\pm$ SD) FM score of 9 ( $\pm 15$ ) 1 mo after stroke and of 13 ( $\pm 19$ ) 3 mos after stroke.

The changes of the primary FM scores and of the muscle power favored the AT group, but there was no statistically significant difference between groups, i.e., the mechanical AT was not superior to the ES on the impairment level despite a much higher repetition rate,<sup>21,24</sup> more degrees of freedom, and the bilateral approach.<sup>25,26</sup>

Contrary to the ES-mediated selective wrist extension, the AT exercise required a more proximal movement of the shoulder and elbow joints. However, recent data supports the view that focusing initial therapy on the more distal segments might lead to better outcomes. The rationale for such approach stems namely from the larger cortical representation of the distal segments and a presumed competition among proximal and distal segments for plastic brain territory. Muellbacher et al. for instance, deafferented the shoulder girdle by regional anesthesia during hand motor practice, which dramatically improved hand motor function including some activities of daily living in chronic stroke patients. The improvement was associated with an increase in transcranial, magnetic stimulation-evoked motor output to the practice hand muscles.<sup>27</sup> Further, Church et al. included 176 acute stroke patients in their RCT comparing the ES of the shoulder girdle *vs.* sham therapy. There was no difference in arm function at 3 mos between groups in terms of the primary outcome measure or the Action Research Arm Test. In fact, significant differences were observed in other arm function and grasping measurements at 3 mos in favor of the control group. Secondary analysis suggested that these differences were most marked in subjects with severe, initial upper limb weakness. The authors hypothesized that the proximal stimulation may have interfered with distal recovery.<sup>28</sup> Krebs et al.<sup>22</sup> showed that the initial treatment with their wrist manipulator, followed by the treatment with the shoulder-elbow MIT-Manus, yielded superior results in chronic patients as the reversed treatment order.

Another aspect that separates both training approaches is the bilateral approach of the AT group *vs.* the unilateral approach of the ES group. Lum et al.<sup>29</sup> had reported that bilateral robotic training was not superior to unilateral robotic training in subacute stroke patients, and Dugue et al.<sup>30</sup> and Shimizu et al.<sup>31</sup> have shown that the activation of the nonlesioned hemisphere could

inhibit the lesioned hemisphere in chronic, moderately affected stroke patients. Clinically, it became apparent that some patients put a lot of effort in the movement of the nonparetic side as it had to drive the plegic side as well, which distracted the attention and gaze from the affected side.

Based on these two considerations, one may speculate that the presumed advantages of the unilateral distal approach of the ES could counterbalance the purported disadvantages of less frequent repetitions.

With respect to the secondary outcome measures, significantly more AT patients became able to transport at least three wooden blocks within 1 min at the end of the intervention (five subjects *vs.* zero). At follow-up, the number of responders did not statistically differ any more, although twice as many AT patients (eight *vs.* four) had reached the chosen criterion. This difference may be regarded statistically irrelevant given the number of 27 patients included in both groups. But one should keep in mind that stroke patients, whose FM score was less than eighteen 4 to 8 wks after stroke onset (see inclusion criteria), had less than a 5% chance to regain a meaningful hand activity 6 mos after stroke.<sup>10</sup>

The block transferring task with the patients sitting in front of the boxes required both transport of the arm and object manipulation. The AT patients had practiced more intensively the transport of the arm, whereas the ES patients had practiced more intensively object manipulation. For a severe stroke population performing the block transfer, transport of the arm might be perceived as preceding manipulation in importance. However, Bütefisch et al.<sup>21</sup> had shown that the repetitive practice of an isolated wrist extension resulted in a generalized improvement of upper limb functions in severely to moderately affected stroke patients. Therefore, additional studies are needed to clarify this aspect.

Further analysis demonstrated that almost all responders of both groups were "good rehabilitation candidates" with an initial FM  $\geq 10$  (Table 3). The site of lesion (cortical *vs.* subcortical) did not seem to distinguish them. Less severe patients may have been able to assist the bilateral complex movement with their paretic side, thereby profiting from the bilateral approach intending to facilitate the paretic side via intercallosal fibres.

Any comparison to robotic trainers must be done carefully. It is straightforward in the case of the Bi-Manu-Track study, as the inclusion or exclusion criteria, the primary outcome variable, treatment duration, and the ES in the control group were identical. In that study, patients in the motorized robotic group practiced a total 24,000 bilateral forearm pro-supinations and wrist flexion extensions in a mirror-like fashion, but the robotic

group achieved a statistically significant advantage in the FM result over the ES group. This difference again supports the concept to start the upper limb rehabilitation of severely affected patients distally. Also, we speculate that because patients had to overcome an adjustable initial isometric resistance to start the bilateral movement of the Bi-Manu-Track, they remained more engaged and enhanced volitional activity of the paretic side as compared with the exercise with the Reha-Slide.

Our study has several limitations. First, while we perceive the mechanical AT as a suitable home tool to extend therapy, we selected as our first experimental setting the subacute stroke rehabilitation ward to allow us a more controlled study. Second, motor power and muscle tone were not blindly assessed. Third, the study did not assess the actual use of the paretic arm among the responders. Finally, there were 11 patients in the experimental group *vs.* of 18 right hemiparetic patients in the control group. That fact might be important in view of McCombe Waller and Whittall results describing training response advantage for patients with left hemispheric lesions after completing 6 wks of bilateral arm training with the BATRAC.<sup>32</sup>

## CONCLUSION

Despite a much higher number of movements, the newly introduced mechanical AT did not lead to superior results on the motor impairment level in severe subacute stroke when compared with ES of the paretic wrist extensors. Both treatment options were equally effective. The proximal instead of a distal approach and the risk of distracting attention from the paretic side with the bilateral practice may explain the unexpected result. However, the secondary Box and Block test suggested that the mechanical AT led to better outcomes as significantly more patients (5 *vs.* 0) were able to transport at least three blocks at the end of the intervention. The responders were “good candidates,” *i.e.*, having an initial FM score  $\geq 10$ . Future studies may assess the value of this class of mechanical trainer as part of a set of affordable devices to extend therapy beyond rehabilitation hospitals and outpatient clinic to the home.

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