Evidence of Therapeutic Robots in Physiotherapy

Hospital Authority Convention 2014

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Prevalence of Gait & Upper Limb Problems in Stroke

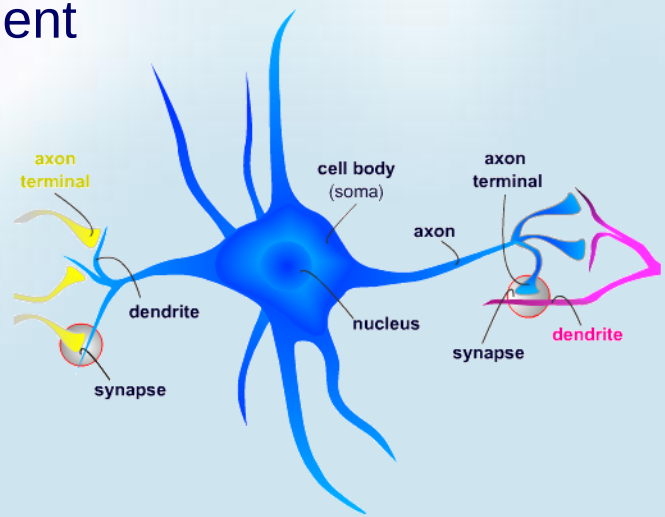
- Leading cause of long-term disability in adults (Urton et al., 2007)
- About 25,000 (7 million population) patients suffered from stroke each year in Hong Kong (HA Statistical Report 2010-11)
- > 80% with gait impairment during the course of disease (Duncan et al., 2005; Wevers et al., 2009)
- Estimated ~70% regained walking ability ± walking aids
- ~ 69% functional impairments in upper limb (Urton et al., 2007)
- Only ~ 5% of all patients regaining full use of their upper extremity following intensive rehabilitation (Merians et al., 2009)

Hypothesis of Neurorehabilitation--Brain Plasticity

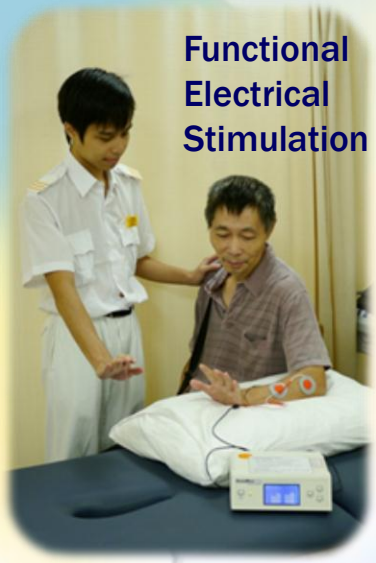
- **Plasticity** is the basic mechanism underlying improvement in functional outcome after stroke
- It refers to the potential for change within the nervous system embracing all re-organisational mechanisms including
  - ✧ Collateral axonal sprouting – new dendrite formation 開枝散葉
  - ✧ Formation of new synapses 加電製
  - ✧ Unmasking of previously inactive synapse 後備上位（叫醒冬眠）

(Koch et al., 2013)

- These new connections are activities dependent
- They adjust their activities in response to
  - ✧ Quality of activities 質量
  - ✧ Quantity of activities 數量



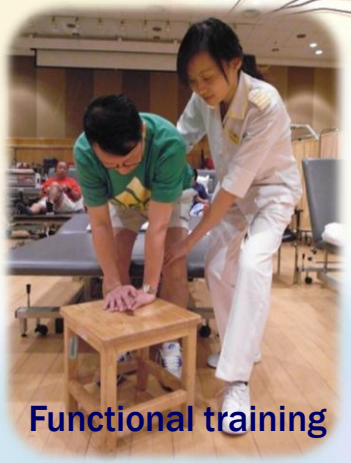
Common Physiotherapy Interventions in Neurological Rehabilitation


Functional Electrical Stimulation


Electroacupuncture


Manual therapy


Neuroprothesis


Functional training


Bobath Training


Facilitation ex


Tilt-table standing


Standing & balance training


Proprioceptive Neuromuscular Facilitation (PNF)

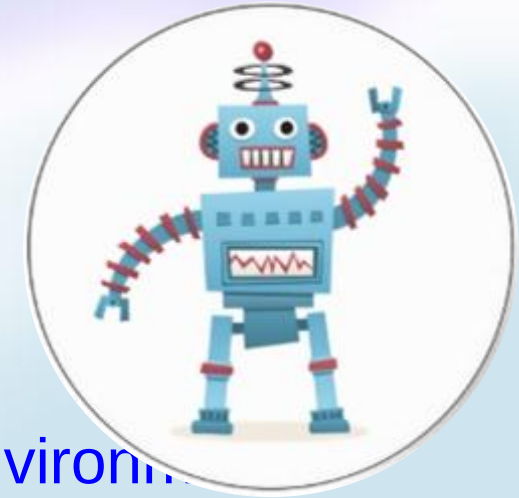
- Effective with literature support
- Training for moderate to severely disabled patients remained inadequate / outcome unpromising

Limitations of Conventional Physiotherapy Interventions

- Reason: difficulty in achieving enough therapeutic dosage
- **Higher intensities** of walking practice resulted in better outcomes for patients after stroke (Kwakkel 1999; Van Peppen 2004)
- Conventional gait training for patients with moderate to severe gait dysfunction usually requires **2 to 3** manual assistants
- Intensive manual handling required
- High demand of patient contact time
- **Constraints:**
  - ✧ **Physically exhausting** to patient & physiotherapists
  - ✧ Limiting training duration
  - ✧ Posing restraint on achieving the required effective therapeutic dosage
  - ✧ Jeopardizing clinical outcomes, leading to unsatisfactory results

Robotic Therapy Training

- Robot-assisted gait / arm training – fill in the service gap
- A beneficial "adjunct" modality to conventional physiotherapy treatment
- It provides
  - ✧ High-intensity
  - ✧ Repetitive (>1,000 repetition/session)
  - ✧ Task-specific
  - ✧ Interactive movement in stimulated environ



Commonly Used Therapeutic Robots

Lower extremity

QEH, KH, KWH, TMH, TPH, DKCH, HKSH

Stand Tall Project: Sichuan

Upper Extremity

Robot-assisted Gait Training System in Hong Kong Hospitals

The unique features:

Dynamic
Body Weight Support (BWS) system
(~2" physiological vertical displacement)

A motor-driven gait orthosis
robotic exo-skeleton guiding force
pre-programmed gait pattern

Robotic legs are **synchronized**
with the Treadmill to achieve
functional walking speed

~0.1 to 1.4 km/h in BWST versus **3.2 km/h** in Lokomat
(Normal **functional gait speed** for young city walker)

- Provide real time feedback
- Facilitate detail reporting of the patient's progress

(Hayward et al., 2010)

Benefits & Feasibility Review
- Strong Evidence of Robot-assisted Gait Training

"Electromechanical devices can be used to give non-ambulatory patients intensive practice of complex gait cycles."

Mehrholz J,Werner C, Kugler J, Pohl M. Electromechanical-assisted training for walking after stroke. ***Cochrane Database of Systematic Reviews*** 2007, Issue 4. Art. No.: CD006185. DOI: 10.1002/14651858.CD006185.pub2.

Stroke & Traumatic Brain Injury

Chin *et al.*, 2010;
Fisher *et al.*, 2011;
Hidler *et al.*, 2009;
Hornby *et al.*, 2008;
Husemann *et al.*, 2007;
Krewer *et al.*, 2006;
Lapitskaya *et al.*, 2011;
Mayr *et al.*, 2004, 2007;
Mehrholz *et al.*, 2007;
Schwartz *et al.*, 2009;
Westlake & Patten, 2009
Chisari *et al.*, 2014
Wu *et al.*, 2014
Uçar *et al.*, 2014

Spinal Cord Injury

Colombo *et al.*, 2000, 2001;
Field-Fote *et al.*, 2011;
Galen *et al.*, 2011;
Hornby *et al.*, 2005;
Lam *et al.*, 2008;
Winchester *et al.*, 2005;
Wirz *et al.*, 2005;
Manella *et al.*, 2010;
Mirbagheri *et al.*, 2005;
Nooijen 2010;
Schwartz *et al.*, 2011;
Sherman *et al.*, 2009
Hoekstra *et al.*, 2014
Varoqui *et al.*, 2014

Cerebral Palsy

Borggraefe *et al.*, 2008, 2010;
Brutsch *et al.*, 2010, 2011;
Druzbicki *et al.*, 2010;
Meyer-Heim *et al.*, 2007, 2009;
Patritti *et al.*, 2009, 2010;
Schmartz *et al.*, 2010;
Schuler *et al.*, 2011
Drużbicki *et al.*, 2013
Burdea *et al.*, 2013

Parkinson's Disease

Lo *et al.*, 2010; Barbe *et al.*, 2013
Ustinova *et al.*, 2010; Picelli *et al.*, 2013

Multiple Sclerosis

Beer *et al.*, 2008;
Lo and Triche, 2008;
Wier *et al.*, 2011

Robotic gait training is effective in regaining walking ability with sustained effect for patients with moderate to severe stroke at the subacute (Morone *et al.*, 2012; Schwartz *et al.*, 2009; Conesa *et al.*, 2012; Husemann *et al.*, 2007) & chronic stage (Hidler *et al.*, 2009; Westlake, 2009; Hornby *et al.*, 2008)

Clinical Use of Electromechanical Devices (Robotic) for Gait Rehabilitation After Stroke

Therapeutic benefits

- Improves functional walking ability (Hesse et al., 2001; Werner et al., 2002)
- Improves walking independence & mobility in the community (Hesse et al., Pohl et al., 2007) 1995)
- Improves muscle activation patterns (Hesse et al., 2001; Mayr et al., 2007)
- Improves gait speed (Mayr et al., 2007; Simons et al., 2009)
- Reduces muscle tone (Mayr et al., 2007)
- Improves joint range of motions (Simons et al., 2009)

Service enhancement

- Facilitate a much earlier rehabilitation
- Allow non-ambulatory patients intensive practice of complex gait cycles with a reduced effort for therapists
- Provide accurate & objective kinematics & kinetics measure
- Provide quantifiable and repeatable assistance that ensure consistency during the rehabilitation

Robot-assisted Gait Training Research Findings (1)

- **Cochrane review (Level 1 evidence)** ⇨ Robotic gait training after stroke
  Included 23 trials with 999 participants (Mehrholz et al., 2013)
- People who receive electromechanical-assisted gait training in combination with PT after stroke are more likely to achieve independent walking than people who receive gait training without these devices
- The ability to regain independent walking was not dependent on the type of device used, both Gait Trainer & Lokomat shares similar effectiveness on promoting independent walking after training
- People in the acute and subacute phase after stroke profit more than people in chronic phase post-stroke from this type of training
- People who are non-ambulatory at intervention onset can achieve greatest benefit from this type of training

- Electromechanical-assisted gait training (both Gait Trainer & Lokomat) combined with PT may improve recovery of independent walking in people after stroke
- Every fifth (1 in 5) dependency in walking ability after stroke could be avoidable if electromechanical-assisted devices are used

Robot-assisted Gait Training Research Findings (2)

Exoskeleton-type device (e.g. Lokomat)

Author yrs	Study type	Disease type	Device/ Intervention	Treatment Protocol	Results
Husemann et al., 2007	RCT (2 arms)	Acute stroke	Lokomat vs conventional PT	30 min, 5×/wk ×4 wk Better	Lokomat group showed an advantage of robotic training over conventional PT in improvement of gait abnormality and body tissue composition
Mayr et al., 2007	RCT, Cross-over (2 arm)	Subacute stroke	Lokomat vs conventional PT	30 min, 5×/wk ×3 wk Better	EU-Walking Scale, Rivermead motor assessment scale, Medical research council scale, Ashworth scale demonstrated significantly more improvement during Lokomat training phase than during conventional PT phase
Schwartz et al., 2009	RCT (2 arm)	Subacute stroke	Lokomat vs conventional PT	30 min, 3×/wk ×6 wk Better	Significantly greater no. of subjects trained with Lokomat reached independent walking compared with control group

Robot-assisted Gait Training Research Findings (3)

Exoskeleton-type device (e.g. Lokomat)

Author yrs	Study type	Disease type	Device/ Intervention	Treatment Protocol	Results
Chang et al., 2012	RCT (2 arm)	Chronic stroke	Lokomat vs conventional PT	40 mins Lokomat+ 60 min PT x 10 days **Better**	Lokomat group showed advantage in increasing VO2 and lower limb strength
Hornby et al., 2008	RCT (2 arm)	Chronic stroke	Lokomat vs body weight supported manual gait training	30 mins Lokomat for 12 sessions **Better**	Improved in speed and single limb stance time on impaired leg at experimental group, however manual gait training showed more beneficial for those ambulatory patients.
Westlake & Pattern, 2009	RCT (2 arm)	Chronic stroke	Lokomat vs. manually-assisted body weight supported treadmill walking	30 min, 3×/wk × 4 wk **Better**	Within Lokomat group, self-selected walk speed, paretic step length ratio, Fugl-Meyer, Berg balance scale, and short physical performance battery improved. Within manual group, only BBS improved

Robot-assisted Gait Training Research Findings (4)

End-effector-type device (e.g. Gait Trainer)

Author yrs	Study type	Disease type	Device/ Intervention	Treatment Protocol	Results
Tong et al., 2006	RCT (3 arm)	Subacute stroke	(i) Gait trainer alone; (ii) gait trainer + FES; (iii) conventional	20 min, 5×/wk ×4 wk Better	Gait trainer with or without FES, had a faster gait, better mobility, and improvement in functional ambulation than participants who underwent conventional gait training
Pohl et al., 2007	RCT (2 arm)	Subacute stroke	Gait trainer vs. conventional	20 min, 5×/wk ×4 wk Better	Intensive locomotor training plus physiotherapy resulted in a significantly better gait ability and daily living competence in subacute stroke patients compared with physiotherapy alone
Peurala et al., 2009	RCT (3 arm)	Subacute stroke	(i) gait trainer gp; (ii) overground walking training gp; (iii) conventional treatment gp	20 min, 5×/wk ×3 wk No difference	Exercise therapy with walking training improved gait function irrespective of the method used (gait trainer & overground walking similar effect). Early intensive gait training resulted in better walking ability than did conventional treatment

Robot-assisted Gait Training Research Findings (5)

End-effector-type device (e.g. Gait Trainer)

Author yrs	Study type	Disease type	Device/ Intervention	Treatment Protocol	Results
Morone at al., 2001	RCT (2 arm)	Subacute stroke	Gait trainer vs. conventional (high vs. low motor impairment gp)	20 min, 5×/wk ×4 wk Better	The low motor impairment gp with gait trainer showed significant improved in the FAC, rivermead motor impairment & walking distance
Dias et al., 2007	RCT (2 arm)	Chronic stroke	Gait trainer vs. conventional	40 min, 5×/wk ×4 wk Better	Both gp shared similar improvement in all outcome measures but only gait trainer gp maintained functional gain after 3 months
Peurala et al., 2005	RCT (3 arm)	Chronic stroke	(i) gait trainer + FES (GTstim), (ii) gait trainer alone (GT), (iii) walking overground (WALK)	20 min, 5×/wk ×3 wk No difference	Both the body weight-supported training and walking exercise training programs resulted in faster gait after the intensive rehabilitation program. No statistical significant differences were found between the groups

Benefits & Feasibility Review
- Evidence of Robot-assisted Arm Training

Multiple Sclerosis

Bastiaens *et al.*, 2011
Carpinella *et al.*, 2012
Carpinella *et al.*, 2009
Vergaro *et al.*, 2010

Stroke

Brokaw *et al.*, 2011
Hu *et al.*, 2012
Kahn *et al.*, 2006
Kwakkel *et al.*, 2008
Lambercy *et al.*, 2011
Liao *et al.*, 2012
Lum *et al.*, 2006
Mehrholz *et al.*, 2008, 2012
Klamroth-Marganska *et al.*, 2014
Pignolo *et al.*, 2009
Reinkensmeyer *et al.*, 2007
Staubli *et al.*, 2009
Secoli *et al.*, 2011
Wu *et al.*, 2012

Spinal Cord Injury

Kadivar *et al.*, 2011
Zariffa *et al.*, 2012
Hochberg *et al.*, 2012
Jiang *et al.*, 2013

Cerebral Palsy

Krebs *et al.*, 2012
Holley *et al.*, 2013
Pathak & Johnson. 2012
Fasoli *et al.*, 2012

Patients who receive electromechanical and robot-assisted arm training after stroke are more likely to improve their arm function and general upper limb activities

Mehrholz J, Hädrich A, Platz T, Kugler J, Pohl M. Electromechanical and robot-assisted arm training for improving generic activities of daily living, arm function, and arm muscle strength after stroke. Cochrane Database Syst Rev. 2012 Jun 13;6:CD006876.

Electromechanical & Robot-assisted Arm Training Research Findings (1)

- **Cochrane review** ⇨ Electromechanical & robot-assisted arm training after stroke (Mehrholz et al., 2012)
- Included 19 trials with 666 participants
- Patients who receive electromechanical & robot-assisted arm training after stroke are more likely to improve their generic activities of daily living; paretic arm function may also improve, but not arm muscle strength
- Improve activities of daily living in acute but not chronic phase after stroke
- The advantage of electromechanical and robotic devices, as compared with conventional therapies, may be an ↑ in repetition during arm training due to an ↑ of motivation to train & also the opportunity for independent exercise

- Electromechanical-assistive devices in rehabilitation settings may improve generic activities of daily living
- Arm function, but not arm muscle strength may improve

Electromechanical & Robot-assisted Arm Training Research Findings (2)

- Effects of robot-assisted therapy on stroke rehabilitation in upper limbs: systematic review and meta-analysis of the literature (Norouzi-Gheidari et al., 2012)
- 11 RCTs were selected for reviewed
- When the duration/intensity of conventional therapy is matched with that of the robot-assisted therapy, no difference exists between intensive conventional & robotic groups in terms of motor recover, activities of daily living, strength, & motor control
- Additional sessions of robotic therapy promote better motor recovery in the upper limb of patients with stroke when compared with standard conventional PT

- Use of robotics by itself does not translate into better therapy for people with stroke
- Robots deliver highly repetitive therapeutic tasks with minimum supervision of a therapist & these additional sessions of robotic therapy improve motor recovery of the hemiparetic arm of stroke patients

Electromechanical & Robot-assisted Arm Training Research Findings (3)

End-effector-type device (e.g. InMotion)

Author yrs	Study type	Disease type	Device/ Intervention	Treatment Protocol	Results
Lum et al., 2006	RCT (2 arm)	Subacute stroke	MINE vs. conventional	1 hr x 15 sessions in 4 weeks Better	Combined unilateral & bilateral robotic training had adv c/w conventional therapy, producing larger improvements on a motor impairment scale & measure of abn synergies
Fasoli et al., 2004	RCT (2 arm)	Subacute stroke	MIT-MANUS vs. conventional	1 hr x5/wk x5wk Better	Patients who received conventional therapy showed little improvement, whereas patients who received robot training plus conventional therapy continued to improve after inpatient discharge
Hesse et al., 2005	RCT (2 arm)	Subacute stroke	Bi-Manu-Track (arm trainer gp) vs. EMG-initiated electrical stimulation (ES gp)	30 min x3/wk x 6 wk Better	Arm trainer gp produced sup. improvement in UL motor control & power c/w ES gp in severely affected stroke pts. This may due to greater no. of repetitions & bilateral approach.

Electromechanical & Robot-assisted Arm Training Research Findings (4)

End-effector-type device (e.g. InMotion)

Author yrs	Study type	Disease type	Device/ Intervention	Treatment Protocol	Results
Masiero et al., 2007	RCT (2 arm)	Subacute stroke	NeReBot vs. control gp	4 hours a wk x 5 wk Better	Patients who received robotic therapy in addition to conventional therapy showed greater reductions in motor impairment and improvements in functional abilities
Volpe et al., 2000	RCT (2 arm)	Subacute stroke	MIT-MANUS vs. conventional	60 min x5/wk x 5 wk Better	Motor skills of the robotic gp improved sig. more than the control gp. Analysis showed that interactive robotic therapy sig. reduced motor impairment of the treated limbs, doubling the impairment reduction
Conroy et al., 2011	RCT (3 arm)	Chronic stroke	(i) InMotion 2 (planar robot); (ii) InMotion 2 (planar+vertical robot); (iii) conventional	60 min, 3×/wk ×6 wk No difference	All groups showed modest gains in the Fugl-Meyer arm fx from baseline to final with no significant btw gp differences. Most change occurred in the planar robot group

Electromechanical & Robot-assisted Arm Training Research Findings (5)

Exoskeleton-type device

Author yrs	Study type	Disease type	Device/ Intervention	Treatment Protocol	Results
Fazekas et al., 2007	RCT (2 arm)	Chronic stroke	REHAROB vs. conventional	30 min, for 20 consecutive days **Better**	Similar improvement in both gps generally. Modified Ashworth score of shoulder adductors & elbow flexors showed a statistically sig. change only in the robotic gp
Kahn et al., 2006	RCT (2 arm)	Chronic stroke	ARM-Guide vs. conventional	45 min x3/wk x 8 wk No difference	There were sig. improvements with training for ROM, velocity of supported reaching, straightness of unsupported reaching, & functional movement ability in both gps
Housman et al., 2009	RCT (2 arm)	Chronic stroke	T-WREX vs. conventional	30 min x5/wk x 8-9 wk No difference—Post-Rx **Better—6 mo FU**	Both gps sig. ⇧ upper limb motor control (Fugl-Meyer), AROM, & self-reported quality & amount of arm use. Robotic gp maintained a better gains on the Fugl-Meyer than controls at 6 months

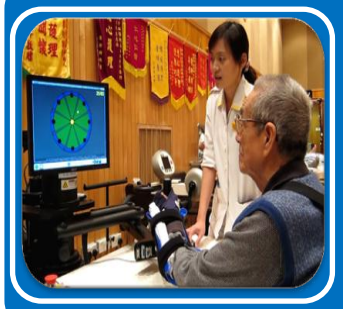
Local Experience Sharing of Robotic Service at KCC PT Departments

- Implementation of robotic training systems at PT department
  - As an "adjunct" to integrated physiotherapy neurorehabilitation
  - Robot-assisted gait training system – Lokomat
  - Quasi-robotic arm training system – Armeo Spring
  - Robot-assisted arm training system – InMotion 2
- Clientele
  - CVA (31%)
  - Spinal Cord Injury (21%)
  - Traumatic Brain Injury (15%)
  - Multiple Sclerosis (12%)
  - Others: e.g. Parkinsonism, Cerebellar Degeneration (21%)

3 Pilot Studies of Therapeutic Robotic Interventions at QEH

Effect of Robot-assisted Gait Training in Neurological Patients with Moderate to Severe Gait Dysfunction

- In period of Jan 2011 to April 2013
- 78 neurological patients (31% stroke, 21% SCI, 15%TBI, 12% MS)
- Significant improvement in functional independence, gait velocity, walking endurance, balance control & spasticity measures



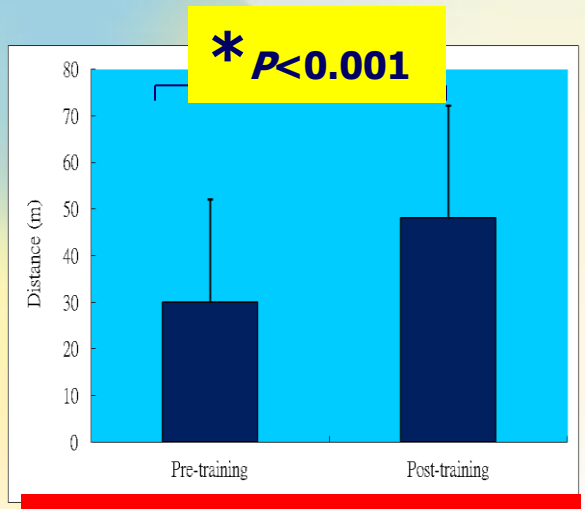
Effects of Robot-assisted Arm Training for Promoting Motor Recovery in Patients After Stroke

- In the period of April 2013 to October 2013
- 22 chronic Stroke patient recruited
- Significant improved the Fugl-Meyer Motor Assessment score, movement speed & smoothness, & shoulder strength

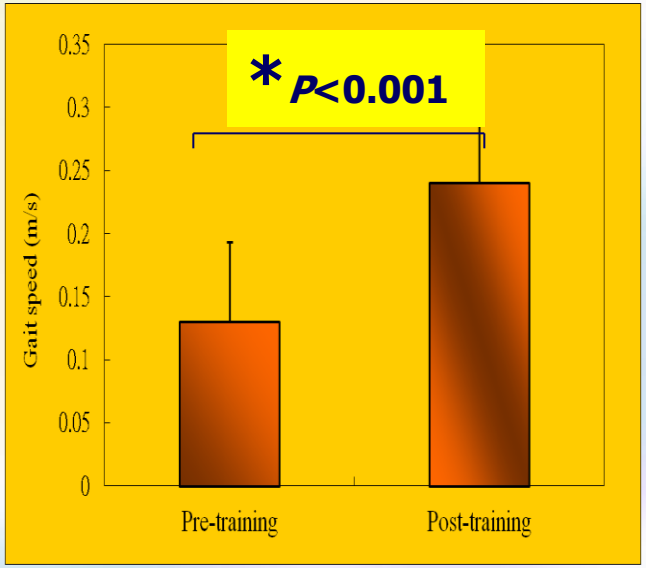
Robot Assisted Gait Training for Children with Cerebral Palsy after Botulinum toxin A – A Single Case Study

- A single-case study
- Pending result

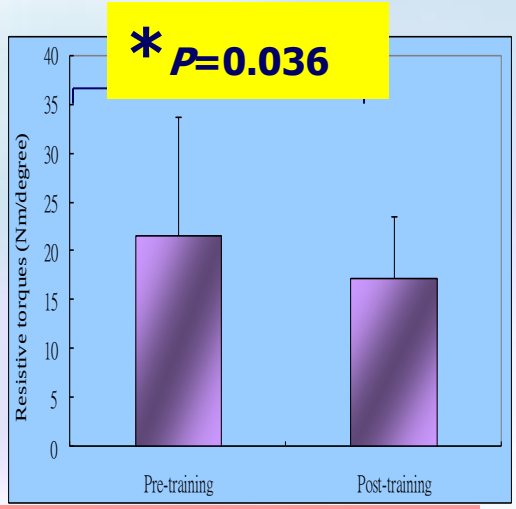
Effect of Robot-assisted Gait Training in Neurological Patients with Moderate to Severe Gait Dysfunction



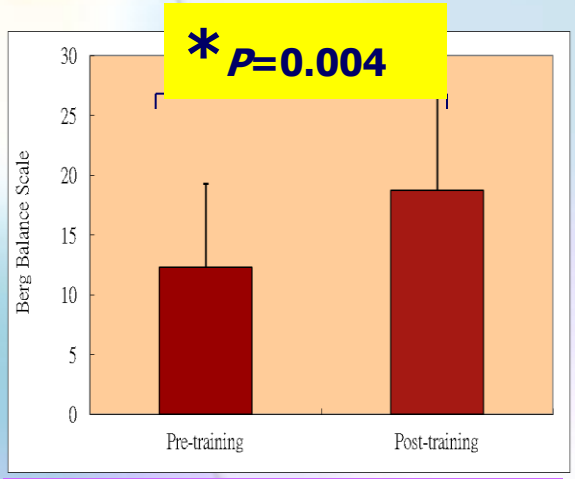
6-min Walk Test



10-meter Walk Test

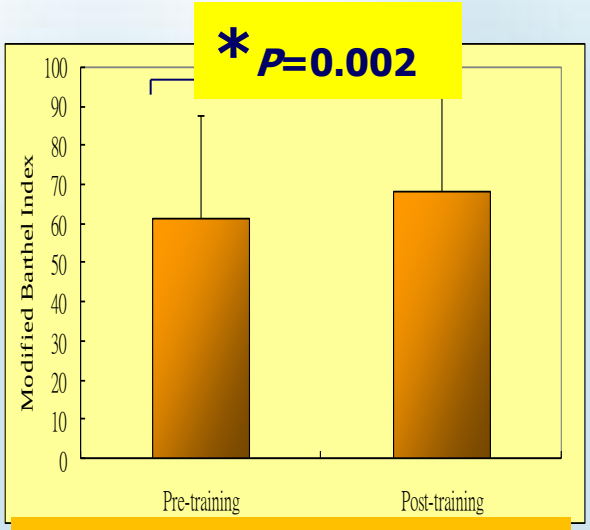


LL Resistive Torque



Berg Balance Scale

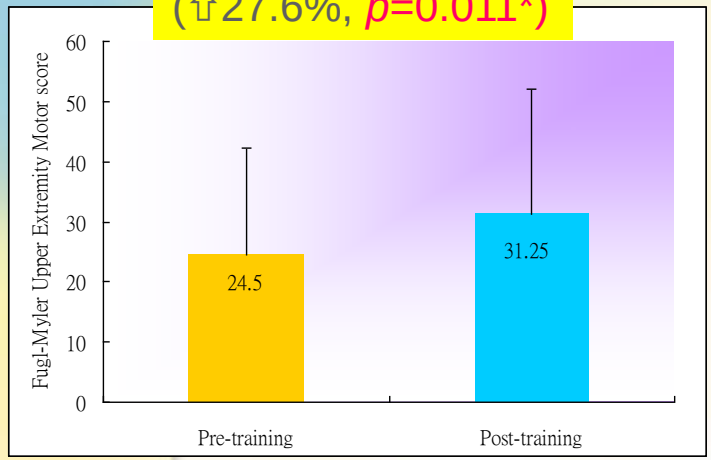
Significant Improvement in all domains



Modified Barthel Index

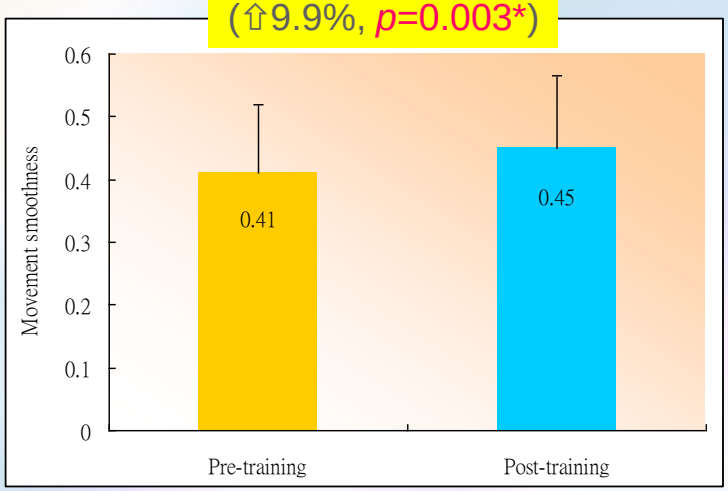
Robot-assisted Arm Training Promotes Motor Recovery in Patients with Chronic Stroke

(⇧27.6%, *p*=0.011*)

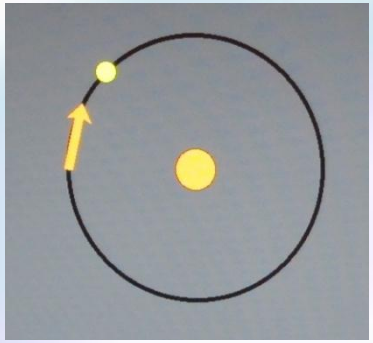


Fugl-Meyer Motor Assessment of Upper Extremity

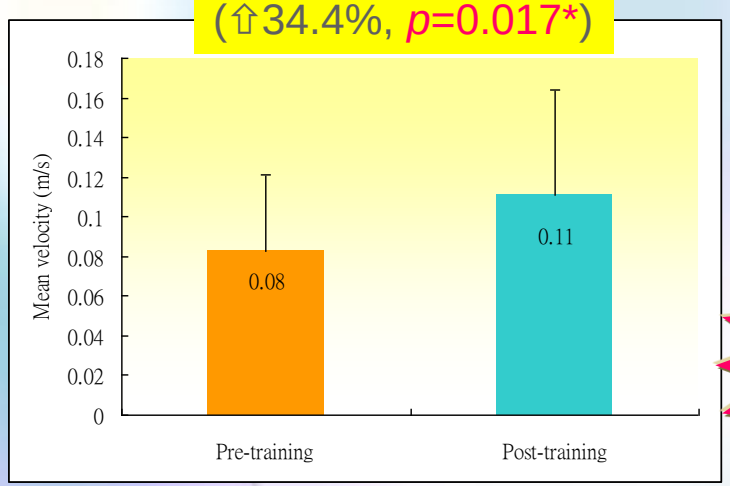
(⇧9.9%, *p*=0.003*)



Movement Smoothness



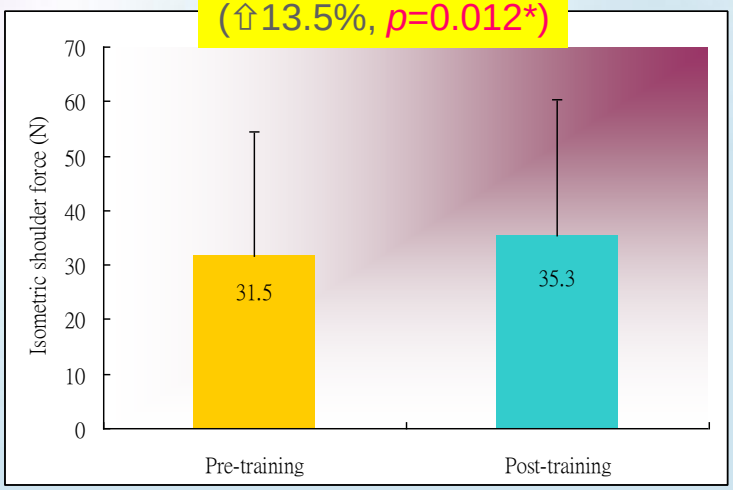
(⇧34.4%, *p*=0.017*)



Movement Speed

Significant Improvement in all domains

(⇧13.5%, *p*=0.012*)



Isometric Shoulder Force

Enhanced Interventional Physiotherapy Program

Robotics gait & upper limb training

- Fill in the service gap
  - ✧ Extending the rehabilitation window to the supra-acute phase & beyond the previously defined chronic plateau phase
  - ✧ Increasing the service scope in the management of patients with moderate to severe impairments/ disabilities
- Suit the local context in HA hospitals
  - ✧ High patient to therapist ratio (~ 30 patients per day)
  - ✧ Limited patient contact time

⇨ Early, intensive (high repetition) & task-specific treatment

⇨ Promote brain plasticity / recovery

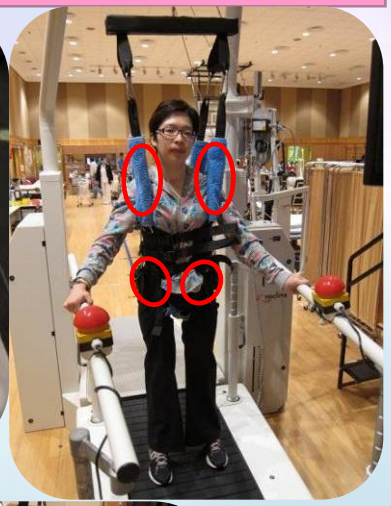
Key to Success

Implementation of Robot-assisted Training Programs at Physiotherapy Department of KCC

CQI Measures - Patient Safety & Focused Care (1)

- Local adaptation for product enhancement & patient safety

Protective padding for friction & pressure relief



Seating device – special harness to keep the trunk & shoulder in good alignment

Sports uniform during patient setup

CQI Measures - Patient Safety & Focused Care (2)

- Local adaptation for product enhancement & patient safety

Storage cabinet for various parts of the exoskeletons / harness
- ↑ efficiency & accuracy

Full length mirror at the front for visual feedback enhancement

CQI Measures – Health & Safety Issues: Guideline; Equipment Checking/ Maintenance / Repair scheduling

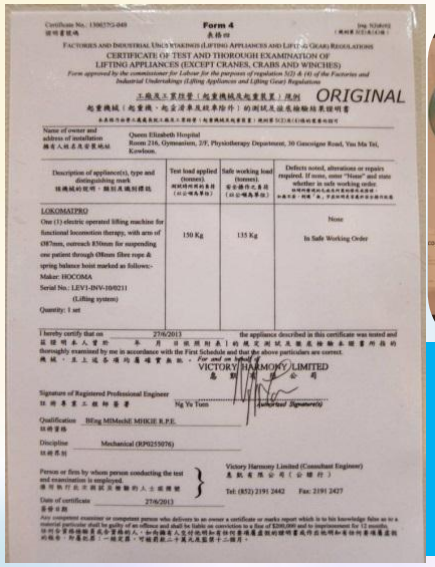
Kowloon Central Cluster
Hospital Authority
Queen Elizabeth Hospital

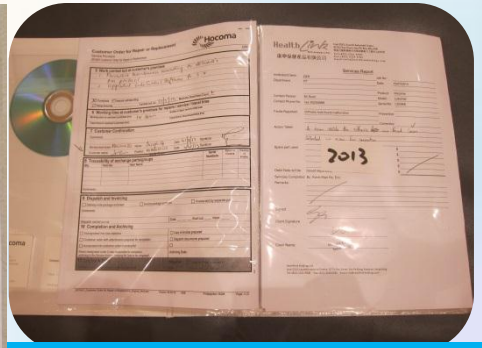
Physiotherapy Guideline for the Use of Robot-assisted Therapy (Robotic Therapy) in Patients with Neurological Conditions

Document No.	KCC/QEH/PHY/GUIDELINE/008		
Prepared By	Physiotherapy Department		
Type of Document	Physiotherapy Guideline		
First Issue Date	1 May 2011	**Version**	1st
Review Date	1 May 2012	**Effective Date**	1 June 2012
Next Review Date	1 June 2015		

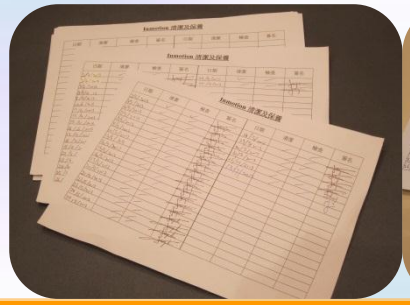
Guideline developed

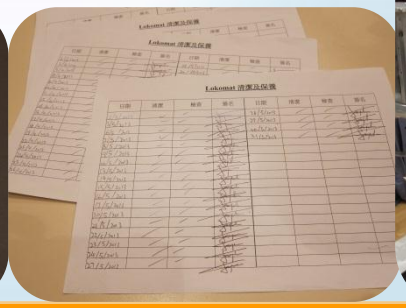
Guideline taken as reference for other hospitals in Robotic Gait Training

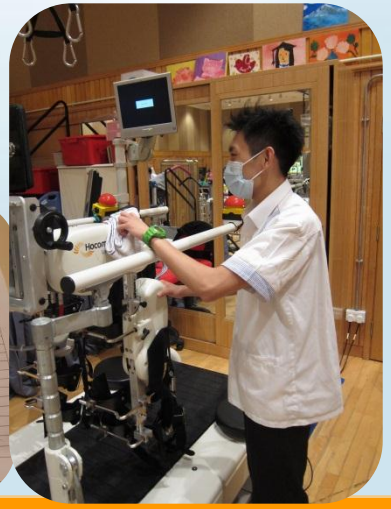

Form 4
FACTORIES AND INDUSTRIAL UNDERTAKINGS (LIFTING APPLIANCES AND LIFTING GEAR) REGULATIONS
CERTIFICATE OF TEST AND THOROUGH EXAMINATION OF LIFTING APPLIANCES (EXCEPT CRANES, CRABS AND WINCHES)
ORIGINAL
Name of owner and address of installation: Queen Elizabeth Hospital, Room 216, Gymnasium, 2/F, Physiotherapy Department, 30 Gascoigne Road, Yau Ma Tei, Kowloon.
Description of appliance(s), type and distinguishing mark: LOKOMATPRO
One (1) electric operated lifting machine for functional locomotion therapy, with arm of 08?mm, outreach 850mm for suspending one patient through 08mm fibre rope & spring balance hoist marked as follows:-
Make: HOCOMA
Serial No.: LEV1-INV-10/0211
(Lifting system)
Quantity: 1 set
Test load applied (tonnes): 150 Kg
Safe working load (tonnes): 135 Kg
Defects noted, alterations or repairs required. If none, enter "None" and state whether in safe working order: None
In Safe Working Order
I hereby certify that on 27/6/2013 the appliance described in this certificate was tested and thoroughly examined by me in accordance with the First Schedule and that the above particulars are correct.
For and on behalf of VICTORY HARMONY LIMITED
Signature of Registered Professional Engineer: Ng Yu Yuen
Qualification: BEng MIMechE MHKIE R.P.E.
Discipline: Mechanical (RP0255076)
Victory Harmony Limited (Consultant Engineer)
Tel: (852) 2191 2442 Fax: 2191 2427
Date of certificate: 27/6/2013



Equipment checking: the yearly loading test/ monthly checking

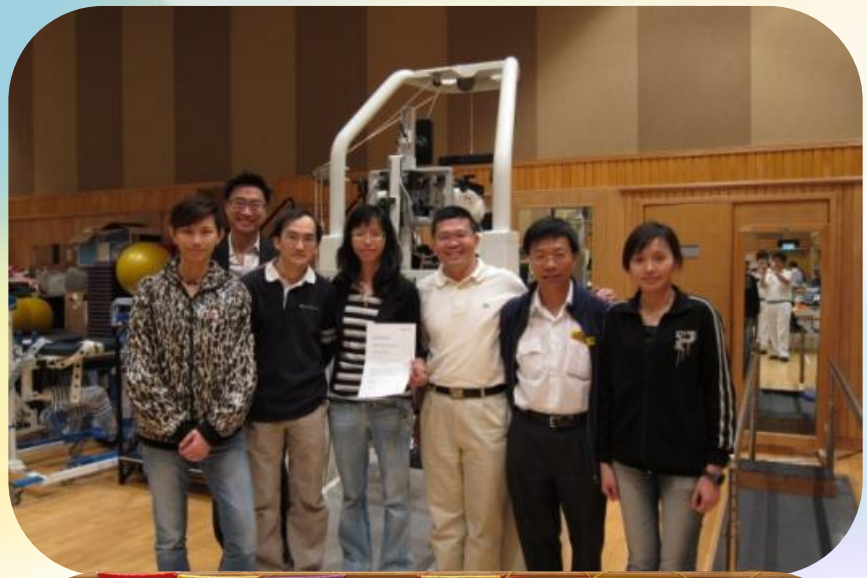


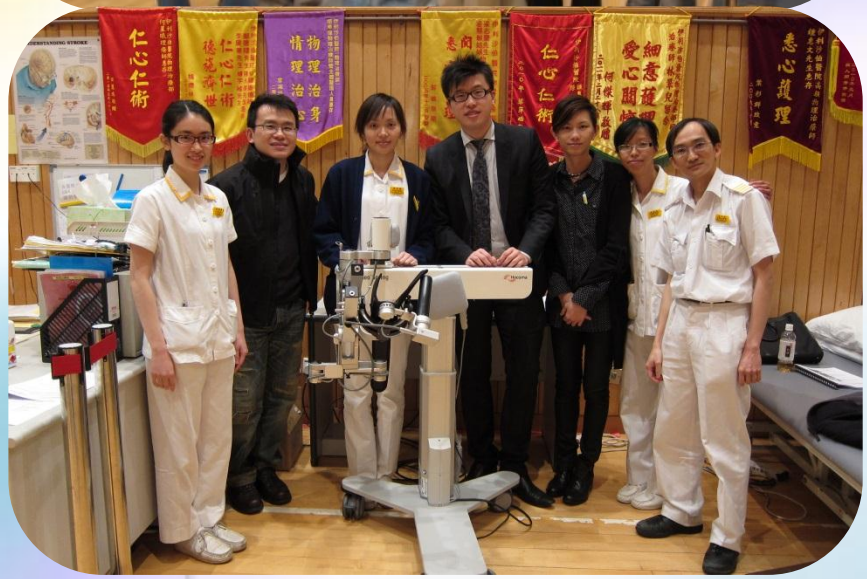




Daily equipment cleansing & operation check with signed documenation for record

CQI Measures – Training





Accreditation training for PT trainers

Structured training to PT staff

Take Home Messages

- Robot-assisted gait and arm training **combined with conventional physiotherapy training** enhance motor recovery in patients with moderate to severe neurological impairment
- Extend the horizon of stroke rehabilitation
- Act as an adjunct intervention
- To sustain the promising / encouraging results – documentation of clinical outcome; continuous quality improvement (CQI) measures are important


Thanks