Evidence of Therapeutic Robots in Physiotherapy

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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)
• **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
  ✧ Formation of new synapses
  ✧ 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
  ✧ Quantity of activities
Common Physiotherapy Interventions in Neurological Rehabilitation

- Functional Electrical Stimulation
- Electroacupuncture
- Proprioceptive Neuromuscular Facilitation (PNF)
- Bobath Training
- Tilt-table standing
- Standing & balance training
- Manual therapy
- Neuroprosthesis
- Training for moderate to severely disabled patients remained inadequate / outcome unpromising

- Effective with literature support

*Further information provided in the text.*
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 environment
Commonly Used Therapeutic Robots

**Lower extremity**
- Gait Trainer
- Lokomat
- ReoAmbulator

**Upper Extremity**
- InMotion 2
- Armeo Spring
- Reo Go

Stand Tall Project: Sichuan
- QEH, KH, KWH, TMH, TPH, DKCH, HKSH
- HHH

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)
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)

<table>
<thead>
<tr>
<th>Author yrs</th>
<th>Study type</th>
<th>Disease type</th>
<th>Device/Intervention</th>
<th>Treatment Protocol</th>
<th>Results</th>
</tr>
</thead>
<tbody>
<tr>
<td>Husemann et al., 2007</td>
<td>RCT (2 arms)</td>
<td>Acute stroke</td>
<td>Lokomat vs conventional PT</td>
<td>30 min, 5×/wk ×4 wk</td>
<td>Lokomat group showed an advantage of robotic training over conventional PT in improvement of gait abnormality and body tissue composition</td>
</tr>
<tr>
<td>Mayr et al., 2007</td>
<td>RCT, Cross-over (2 arm)</td>
<td>Subacute stroke</td>
<td>Lokomat vs conventional PT</td>
<td>30 min, 5×/wk ×3 wk</td>
<td>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</td>
</tr>
<tr>
<td>Schwartz et al., 2009</td>
<td>RCT (2 arm)</td>
<td>Subacute stroke</td>
<td>Lokomat vs conventional PT</td>
<td>30 min, 3×/wk ×6 wk</td>
<td>Significantly greater no. of subjects trained with Lokomat reached independent walking compared with control group</td>
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</tbody>
</table>
## Robot-assisted Gait Training Research Findings (3)

### Exoskeleton-type device (e.g. Lokomat)

<table>
<thead>
<tr>
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</tr>
</thead>
<tbody>
<tr>
<td>Chang et al., 2012</td>
<td>RCT (2 arm)</td>
<td>Chronic stroke</td>
<td>Lokomat vs conventional PT</td>
<td>40 mins Lokomat+60 min PT x 10 days</td>
<td>Lokomat group showed advantage in increasing VO2 and lower limb strength</td>
<td></td>
</tr>
<tr>
<td>Hornby et al., 2008</td>
<td>RCT (2 arm)</td>
<td>Chronic stroke</td>
<td>Lokomat vs body weight supported manual gait training</td>
<td>30 mins Lokomat for 12 sessions</td>
<td>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.</td>
<td></td>
</tr>
<tr>
<td>Westlake &amp; Pattern, 2009</td>
<td>RCT (2 arm)</td>
<td>Chronic stroke</td>
<td>Lokomat vs manually-assisted body weight supported treadmill walking</td>
<td>30 min, 3×/wk × 4 wk</td>
<td>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</td>
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</tbody>
</table>
## Robot-assisted Gait Training Research Findings (4)

<table>
<thead>
<tr>
<th>Author, Year</th>
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</tr>
</thead>
<tbody>
<tr>
<td>Tong et al., 2006</td>
<td>RCT (3 arm)</td>
<td>Subacute stroke</td>
<td>(i) Gait trainer alone; (ii) gait trainer + FES; (iii) conventional</td>
<td>20 min, 5×/wk ×4 wk</td>
<td>Gait trainer with or without FES, had a faster gait, better mobility, and improvement in functional ambulation than participants who underwent conventional gait training</td>
</tr>
<tr>
<td>Pohl et al., 2007</td>
<td>RCT (2 arm)</td>
<td>Subacute stroke</td>
<td>Gait trainer vs. conventional</td>
<td>20 min, 5×/wk ×4 wk</td>
<td>Intensive locomotor training plus physiotherapy resulted in a significantly better gait ability and daily living competence in subacute stroke patients compared with physiotherapy alone</td>
</tr>
<tr>
<td>Peurala et al., 2009</td>
<td>RCT (3 arm)</td>
<td>Subacute stroke</td>
<td>(i) gait trainer gp; (ii) overground walking training gp; (iii) conventional treatment gp</td>
<td>20 min, 5×/wk ×3 wk</td>
<td>Exercise therapy with walking training improved gait function irrespective of the method used (gait trainer &amp; overground walking similar effect). Early intensive gait training resulted in better walking ability than did conventional treatment</td>
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## Robot-assisted Gait Training Research Findings (5)

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<tbody>
<tr>
<td>Morone et al., 2001</td>
<td>RCT (2 arm)</td>
<td>Subacute stroke</td>
<td>Gait trainer vs. conventional (high vs. low motor impairment gp)</td>
<td>20 min, 5×/wk ×4 wk</td>
<td>The low motor impairment gp with gait trainer showed significant improved in the FAC, rivermead motor impairment &amp; walking distance</td>
</tr>
<tr>
<td>Dias et al., 2007</td>
<td>RCT (2 arm)</td>
<td>Chronic stroke</td>
<td>Gait trainer vs. conventional</td>
<td>40 min, 5×/wk ×4 wk</td>
<td>Both gp shared similar improvement in all outcome measures but only gait trainer gp maintained functional gain after 3 months</td>
</tr>
<tr>
<td>Peurala et al., 2005</td>
<td>RCT (3 arm)</td>
<td>Chronic stroke</td>
<td>(i) gait trainer + FES (GTstim), (ii) gait trainer alone (GT), (iii) walking overground (WALK)</td>
<td>20 min, 5×/wk ×3 wk</td>
<td>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</td>
</tr>
</tbody>
</table>
Benefits & Feasibility Review
- Evidence of Robot-assisted Arm Training

**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

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

**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.

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**
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 recovery, 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
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<tbody>
<tr>
<td>Lum et al., 2006</td>
<td>RCT (2 arm)</td>
<td>Subacute stroke</td>
<td>MINE vs. conventional</td>
<td>1 hr x 15 sessions in 4 weeks</td>
<td>Combined unilateral &amp; bilateral robotic training had adv c/w conventional therapy, producing larger improvements on a motor impairment scale &amp; measure of abn synergies.</td>
<td></td>
</tr>
<tr>
<td>Fasoli et al., 2004</td>
<td>RCT (2 arm)</td>
<td>Subacute stroke</td>
<td>MIT-MANUS vs. conventional</td>
<td>1 hr x 5/wk x 5wk</td>
<td>Patients who received conventional therapy showed little improvement, whereas patients who received robot training plus conventional therapy continued to improve after inpatient discharge.</td>
<td></td>
</tr>
<tr>
<td>Hesse et al., 2005</td>
<td>RCT (2 arm)</td>
<td>Subacute stroke</td>
<td>Bi-Manu-Track (arm trainer gp) vs. EMG-initiated electrical stimulation (ES gp)</td>
<td>30 min x 3/wk x 6 wk</td>
<td>Arm trainer gp produced sup. improvement in UL motor control &amp; power c/w ES gp in severely affected stroke pts. This may due to greater no. of repetitions &amp; bilateral approach.</td>
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</tbody>
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### Electromechanical & Robot-assisted Arm Training Research Findings (4)

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</tr>
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<tbody>
<tr>
<td>Masiero et al., 2007</td>
<td>RCT (2 arm)</td>
<td>Subacute stroke</td>
<td>NeReBot vs. control gp</td>
<td>4 hours a wk x 5 wk</td>
<td>Patients who received robotic therapy in addition to conventional therapy showed greater reductions in motor impairment and improvements in functional abilities</td>
</tr>
<tr>
<td>Volpe et al., 2000</td>
<td>RCT (2 arm)</td>
<td>Subacute stroke</td>
<td>MIT-MANUS vs. conventional</td>
<td>60 min x 5/wk x 5 wk</td>
<td>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</td>
</tr>
<tr>
<td>Conroy et al., 2011</td>
<td>RCT (3 arm)</td>
<td>Chronic stroke</td>
<td>(i) InMotion 2 (planar robot); (ii) InMotion 2 (planar+vertical robot); (iii) conventional</td>
<td>60 min, 3 ×/wk ×6 wk</td>
<td>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</td>
</tr>
</tbody>
</table>

**End-effector-type device (e.g. InMotion)**
<table>
<thead>
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</thead>
<tbody>
<tr>
<td>Fazekas et al., 2007</td>
<td>RCT (2 arm)</td>
<td>Chronic stroke</td>
<td>REHAROB vs. conventional</td>
<td>30 min, for 20 consecutive days</td>
<td>Similar improvement in both gps generally. Modified Ashworth score of shoulder adductors &amp; elbow flexors showed a statistically sig. change only in the robotic gp</td>
</tr>
<tr>
<td>Kahn et al., 2006</td>
<td>RCT (2 arm)</td>
<td>Chronic stroke</td>
<td>ARM-Guide vs. conventional</td>
<td>45 min x3/wk x 8 wk</td>
<td>There were sig. improvements with training for ROM, velocity of supported reaching, straightness of unsupported reaching, &amp; functional movement ability in both gps</td>
</tr>
<tr>
<td>Housman et al., 2009</td>
<td>RCT (2 arm)</td>
<td>Chronic stroke</td>
<td>T-WREX vs. conventional</td>
<td>30 min x5/wk x 8-9 wk</td>
<td>Both gps sig. ↑ upper limb motor control (Fugl-Meyer), AROM, &amp; self-reported quality &amp; amount of arm use. Robotic gp maintained a better gains on the Fugl-Meyer than controls at 6 months</td>
</tr>
</tbody>
</table>

Exoskeleton-type device
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**: Significant Improvement in all domains
  - Pre-training vs. Post-training: *P* < 0.001
- **10-meter Walk Test**: Significant Improvement
  - Pre-training vs. Post-training: *P* = 0.036
- **Berg Balance Scale**: Significant Improvement
  - Pre-training vs. Post-training: *P* = 0.004
- **Modified Barthel Index**: Significant Improvement
  - Pre-training vs. Post-training: *P* = 0.002

*LL Resistive Torque*
Robot-assisted Arm Training Promotes Motor Recovery in Patients with Chronic Stroke

Fugl-Meyer Motor Assessment of Upper Extremity

Movement Speed

Movement Smoothness

Isometric Shoulder Force

Significant Improvement in all domains
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

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

- Protective padding for friction & pressure relief

- 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

Equipment checking: the yearly loading test/ monthly checking

Guideline developed
Guideline taken as reference for other hospitals in Robotic Gait Training

Daily equipment cleansing & operation check with signed documentation 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