Overview: Latest Numbers

- Currently: 55 studies
  - 33 studies completed
  - 22 ongoing
  - 28 in North America
  - 27 in EMEA
  - 5 are multi-center
- Diagnoses: spinal cord injury (33), stroke (12), multiple sclerosis (3), cerebral palsy (1), and multiple diagnoses (4)
- Enrollment: total target = 1,200+ participants; 560 completed to date
- Publications: 5 SCI studies; 2 stroke study; 5 review articles on exoskeletons¹-⁵ and 1 book chapter⁶
- More trials and publications for 2017
Areas of Study: Mobility to Functional Outcomes to Mechanisms

- Feasibility, safety, progression of dosage, and user learning
- Cardiorespiratory effects on users
- Walking outcomes inside & outside of the device
- Muscle activity
- Amelioration of secondary complications
- Comparisons with other groups
- Augmentation of EksoGT training
- Neuroplasticity
Spinal Cord Injury: *Progression and Safety*

- 33 studies - 23 completed; 13 are ongoing; 16 in **North America** and 17 in **EMEA**

- Early studies: feasibility of EksoGT, progression in **dosage of walking** (n=86), **safety** (n=76), and **learning curve** (n=7)\(^2,7-14\)

- **PanEuro study**\(^7\) - 9 centers; variety of SCIs (n=52), training 3x/wk for 8 weeks
  - significant increases in “Up time”, “Walk time”, and number of steps in device

- **level of injury** had an effect on outcomes, while time since injury and severity of injury did not

- **skin irritation** noted as a safety issue
Spinal Cord Injury: Learning Curve

- Kozlowski et al.\textsuperscript{11} - variety of SCIs (n=7), training 1-2x/wk for 8-24 sessions, up to \textbf{2 hrs each session}
- 6 of 7 performed \textit{sit-to-stand} & \textit{stand-to-sit} with minimal assist in a median of \textbf{8 sessions} (range 5-11)
- All 6 performed this skill with CGA or supervision in a median of \textbf{18 sessions} (range 8-28)
- 6 of 7 \textit{walked} with minimal assist in a median of \textbf{8 sessions} (range 5-11)
- 5 of 7 walked with CGA or supervision in a median of \textbf{15 sessions} (range 8-22)
### Spinal Cord Injury: Cardiovascular and Effort Measures

Baunsgaard et al.\textsuperscript{15} - mostly chronic, more severe SCI (n=8)
- **Improved circulation** during walking through increased HR and CO, yet was perceived as *light effort* (2/10)
- Amount of work and perceived effort were similar to NI controls walking normally at a self-selected pace in Ekso

Stampacchia et al.\textsuperscript{16} – variety of SCI (n=8)
- Walking in Ekso was an average of 2.6 METs; comparable to NI controls walking normally at 2.0 mph

Faber et al.\textsuperscript{18} – variety of SCI (n=10)
- Increasing $\%$VO\textsubscript{2 max} and HR in the Ekso when reducing support; can “*induce high physical strain*”
- Proximal muscle groups show increased motor output on EMG compared to the distal muscles

### VO\textsubscript{2} in % of peak capacity (%VO\textsubscript{2}peak)

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<thead>
<tr>
<th></th>
<th>Peak</th>
<th>Sitting</th>
<th>Standing</th>
<th>Walking</th>
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<tbody>
<tr>
<td>SCI</td>
<td>10</td>
<td>0 (0-1)</td>
<td>1 (0-3)</td>
<td>2 (0-4)</td>
</tr>
<tr>
<td>CON</td>
<td>10</td>
<td>0 (0-1)</td>
<td>1 (0-2)</td>
<td>1 (0-2)</td>
</tr>
</tbody>
</table>

### RPE Scale (0-10)

- **Peak**: 10
- **Sitting**: 0 (0-1)
- **Standing**: 1 (0-3)
- **Walking**: 2 (0-4)
Spinal Cord Injury: *Lower Extremity Activity Walking in EksoGT*

Forrest et al.\(^ {17} \) - incomplete SCI example - greater proximal activity; **increased motor activity & organization** with decreased EksoGT support.
Spinal Cord Injury: *Trunk Activity Walking in EksoGT*

Alamro et al.\(^2\) (ICORD) - complete SCI (n=6 so far)

- **Trunk musculature activated** below the level of injury, adding to postural control of weight shifts in Ekso
- In NI participants, trunk activity in EksoGT is similar to walking overground

EMG data from the lower extremities (n=7)\(^2\)\(^0\) and trunk (n=6)\(^2\)\(^2\) showed:

\[ \text{↑ volitional activity} \rightarrow \text{↑ speeds in Ekso} \]
Incomplete Spinal Cord Injury: Gait Outcomes Outside of EksoGT

- Significant improvements in gait speed (10MWT, n=29)\textsuperscript{17,23,24}, walking distance (6MWT, n=31)\textsuperscript{23,24,25}, endurance (session minutes, n=20), and functional balance (TUG, n=4)\textsuperscript{24}.

Bonatti et al.\textsuperscript{23} - pre-post, sub-acute to early chronic incomplete paraplegia (n=20), 18 sessions

- Significant average gait speed increase from 0.26 m/s to 0.40 m/s
- Approximates the threshold for limited community walking for SCI (0.44 m/s)\textsuperscript{26}
- Nearly meets minimal clinically important difference (MCID) for slow walkers with SCI (0.15 m/s)\textsuperscript{26}
- Statistically significant improvements in WISCI-II, 10MWT, 6MWT, SCIM-mobility
Body Composition:

Forrest et al.\textsuperscript{17}: chronic SCI (n=8 so far), 5x/wk for 50 sessions in two exoskeletons

- Significant increase in **lean muscle volume**
- Significant decrease in **intramuscular fat**
- Potential for reversal of **muscle atrophy** and **fat infiltration** for chronic SCI
Spinal Cord Injury: Effects on Secondary Complications

- **Strength**: improved lower extremity strength (n=5+)^{17,21,28}
- **Bone**: improved bone density (n=6)^{27,28}
- **Bowel & Bladder**: improved bowel and bladder function (n=15)^{11,12,21,28}
- **Pain**: reduced pain (n=18)^{10,11,19,27,28} and pain medication use (n=2)^{11,28}
- **Spasticity**: reduced spasticity (n=32)^{9,11,12,21,29}

**Short Term Effects**: For pain and spasticity, some trained 1-3x/wk for 5-20 sessions, but about half had only one session.
Spinal Cord Injury: Quality of Life & Psychological Benefits

- **Sleep**: improved sleep, some due to decreased pain (n=5)\(^{10,11}\)
- **Mood**: improved mood & motivation with EksoGT training (n=19)\(^{21,25}\)
- **Self Image**: improved body perception (n=13)\(^{25}\)
- **Quality of life**: significantly improved QoL after 18 sessions (n=20)\(^{23}\)
- **Satisfaction**: satisfied with using EksoGT (n=35)\(^{11,16,23}\)

Stearns-Yodel et al.\(^{30}\) - interviews of veterans with SCI using Ekso (n=8 so far)

- Appreciation of upright interactions with others
- Reduced anxiety and anger
- Feelings of **control, accomplishment, and hope**
Participants with SCI have reported they were more positive and motivated about their recovery when using Ekso (n=4).
Stroke: Feasibility, Safety, and Progression

- 12 studies - 8 completed and 4 ongoing; 4 in North America and 8 in EMEA

- Several studies have shown the feasibility, safety, and positive progression in EksoGT in the acute and chronic stroke populations (n=127)\textsuperscript{31-33}
Stroke: **Dosage Comparison Between EksoGT vs Standard PT**

Nolan et al.\(^{31-32}\) - Inpatient stroke rehab (n=44) - average walking distance of EksoGT training sessions = 550-620 ft

- **150-200% increase in dosage** compared to 1) standard PT sessions in historical matched controls (n=15)\(^{31}\) or compared to 2) their own standard PT sessions (n=29)\(^{32}\) (both ~215ft)

- Most notable difference in dosage came at the first sessions: 443 ft in Ekso vs. 7 ft in standard PT\(^{32}\)
Stroke: *Gait Parameter Differences Outside vs EksoGT*

Nolan et al. (n=5 so far)\(^{32}\) & Angacian et al. (n=6)\(^{33}\) - more normal stepping via **improved gait parameters on both affected and unaffected sides** walking in EksoGT compared to gait training in standard PT.

**Spatial Changes:**
- Increased stride lengths (n=11)\(^{32,33}\)
- Decreased step width (n=5)\(^{32}\)
- Improved symmetry (n=5)\(^{32}\)

![Graph showing changes in step length, step width, and stride length](image-url)
Temporal Changes

- Increased single stance time (n=5)\(^{32}\)
- Increased swing time (n=5)\(^{32}\)
- Decreased double support stance time (n=6)\(^{32}\); increased double support stance time (n=5)\(^{33}\)
- Improved symmetry (n=5)\(^{32}\)

Nolan et al. (n=5)
Molteni et al.\textsuperscript{34} - EMG showed walking in EksoGT “can modulate the timing and intensity of the muscle activity” in both acute (n=25) and chronic (n=26) stroke groups. Proximal muscles showed significant difference.

\textbf{Figure 4:} Percentage of Acute Patients with a correct activation timing. For each condition (standard and Ekso), the percentage of subjects with proximal and distal timing for the affected and non-affected side, are presented.
Stroke: Standing Midline Alignment

- Pre-Post EksoGT Training
  - Michalek et al.\textsuperscript{35} - improved midline alignment of standing center of pressure after 4 weeks of training (n=1)
EksoGT has been shown to increase **gait speed** (n=30)\(^{33,35,36}\) and **walking distance** (n=23)\(^{36}\) in people with acute and chronic stroke

Molteni et al.\(^{36}\) - sub-acute (n=12) and chronic (n=11) stroke, 3x/wk for 4 weeks

- **Gait Speed**: 10MWT
  - Sub-acute - significant ↑ of 0.10 m/s to 0.56 m/s
  - Chronic - significant ↑ of 0.05 m/s to 0.25 m/s
  - **Sub-acute group met “small meaningful change” MCID of 0.06 m/s** \(^{37}\)

- **Walking Distance**: 6MWT
  - Sub-acute - significant ↑ of 47 m to 205 m
  - Chronic - significant ↑ of 12.5 m to 92 m
  - **Sub-acute group met “small meaningful change” MCID of 20 m** \(^{37}\)
Molteni et al.\textsuperscript{36} - sub-acute (n=12) and chronic (n=11) stroke, 3x/wk for 4 weeks

- Significant ↑ in lower extremity strength (Motricity Index) and ambulatory function (FAC) for both groups

- Significant ↑ in trunk control (Trunk Control Test) & home/community ambulation (Walking Handicap Scale) for sub-acute group

- Neither group showed improvements in spasticity (Ashworth Scale), but there was no or minimal spasticity at baseline

- New walkers in both groups:
  - Sub-acute - 5 out of 12 walked OG at baseline, 9 at endpoint
  - Chronic - 4 out of 11 walked OG at baseline, 7 at endpoint
Stroke: *Ongoing Pilot Studies*

- Nolan and Kessler Research Group
  - Motion capture of kinematics, plus gait parameters outside and inside Ekso

- Jayaraman and RIC Research Group
  - Chronic, severe stroke vs standard PT
  - 10MWT for gait speed, 6MWT for endurance, Berg Balance Scale and Falls Efficacy Scales for balance
Nolan et al.\textsuperscript{31} - Inpatient rehab stroke (n=15) with average admission FIM score of about 27

- EksoGT group had significantly greater improvement in admission to discharge scores (27 points) compared to historical controls (22 points)
- No difference in place of discharge

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<thead>
<tr>
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<th>Admission FIM</th>
<th>Discharge FIM</th>
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<tbody>
<tr>
<td>RE</td>
<td>27</td>
<td>53.4</td>
</tr>
<tr>
<td>Control</td>
<td>26.93</td>
<td>48.53</td>
</tr>
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</table>

Average FIM scores on admission and discharge

Table 1
WISE Study - multi-center, randomized, controlled trial for chronic, motor incomplete spinal cord injury

- To determine effectiveness of an Ekso training protocol (3x/wk for 12 weeks) on gait, secondary complications, and PT burden
- Compared to active control (standard PT) and passive control
- Includes mid-point, end-point, and 3-month follow-up evaluations

Similar study in stroke starting this year comparing Ekso training with standard PT

Optimize its use in clinics by determining the most efficient dose and how to integrate it into therapy
Future Directions: Results of An Algorithm for EksoGT Training

- Clinic in Canada developed the Parkwood Program for Rehabilitation Innovations in Movement Enhancement (PRIME) algorithm\textsuperscript{39}
- Cornell et al. - subacute, incomplete SCI; OP PT 2x/wk at least 8 months (n=3)\textsuperscript{40}
- PTs stated they have seen “improved walking ability in patients previously thought to have plateaued”\textsuperscript{40}
Future Directions: *Combinational Therapy*

- Gad et al.[^1] - Transcutaneous spinal cord stimulation (tSCS); chronic, complete SCI (n=1); 5 sessions
  - evoked volitional lower extremity movement (supine on a mat), perspiration, and improved cardiovascular control
- Brain stimulation before or during Ekso training via transcranial direct current (tDCS) or magnetic field (TMS)
- EEG and EMG to show neuroplasticity in the brain and spinal cord
- Underlying mechanisms and patient characteristics that may determine responders and non-responders
Future Summary

- EksoGT is **safe and feasible** to use for gait training in SCI and stroke.

- Early evidence has demonstrated the possibility of walking long times in EksoGT with **low effort** while obtaining the physiological benefits of **improved circulation**. PT can also induce **high physical strain** during session by lowering the robotic assistance.

- Early evidence showing training **inside EksoGT** can improve gait speed, walking distance, balance, and motor activity and control while in the device (SCI and stroke), as well as gait parameters for a more normalized and symmetrical training pattern in the device (stroke).

- Early evidence of pre-post assessments **outside EksoGT** have shown **improvements in gait**: gait speed, walking distance, and balance (SCI and stroke), mobility independence (SCI), and midline alignment (stroke).

- Training effects in **EksoGT may lessen the effects of secondary complications**: may reduce spasticity and pain and may improve body composition, and bowel and bladder function (SCI), as well as may improve lower extremity strength and psychological well-being (SCI and stroke).
Thank You

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References – Cont.


