

**Overview of wearable lower
extremity exoskeletons:
*Introduction, relative functional
uses and mobility skills achieved***

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- Grant funding for this research came from
 - VA RR&D #B9212C
- ReWalk Robotics, Inc. loaned us two units from 2011 to 2014
- Aetrex Worldwide Inc. – Donated orthopedic shoes for the Exoskeletal-Assisted Walking Program

Today's Presentation

- Review of walking speeds
- Brief history of exoskeletons
- Current available exoskeletons
- Population characteristics
- Mobility and functional capabilities

Walking Speeds in Humans

- **Establishing Pedestrian Walking Speeds.** Portland State University. Retrieved 2009-08-24.
- Browning, R. C., Baker, E. A., Herron, J. A. and Kram, R. (2006). **Effects of obesity and sex on the energetic cost and preferred speed of walking.** *Journal of Applied Physiology* 100 (2): 390–398
- Mohler, H., Pick, S. **3.1 mph (1.39 m/s)** "Visual flow influences gait transition speed and preferred walking speed". *Experimental Brain Research* 181 (2): 221–228.
- Levine, R. V. and Norenzayan, A. (1999). **The Pace of Life in 31 Countries.** *Journal of Cross-Cultural Psychology* 30 (2): 178–205.



Walking Speeds after Stroke/Hemiplegia

- Bohannon RW. **Walking after stroke: comfortable versus maximum safe speed.** *Int J Rehabil Res.* 1992;15:246–248.
- Turnbull GI, Charteris J, Wall JC. **A comparison of the range of walking speeds between normal and hemiplegic subjects.** *Scand J Rehabil Med.* 1995; 27:175–182.
- J. Siraghi, A. ... **0.40 to 1.8 mph** (0.20 to 0.80 m/s) ... **to increase gait speed in people with stroke: strategies adopted compared to healthy controls.** *Gait Posture.* 2009;29:355–359.
- Jonkers I, Delp S, Patten C. **Capacity to increase walking speed is limited by impaired hip and ankle power generation in lower functioning persons post-stroke.** *Gait Posture.* 2009;29:129–137.



Walking speeds in Incomplete-motor SCI during the first year of recovery

Van Hedel, H. J. A. (2009). **Gait speed in relation to categories of functional ambulation after spinal cord injury.** *Neurorehabilitation and Neural Repair*, 23(4), 343–50.

Supervised walker (minimum speed)

- $0.09 \pm 0.01\text{m/s}$

Indoor walker/outdoor wheelchair user

- 0.15 to 0.40 m/s

Outdoor walker

- $0.44 \pm 0.14\text{m/s}$

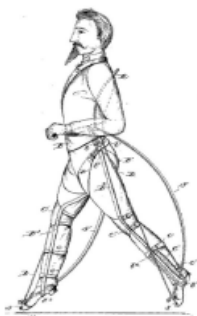


Summary Table of Walking Speeds

Population	m/s	mph	100m
RaceWalkers	2.50	5.6	0:40
Adults	1.39	3.1	1:12
Older Adults	1.32	2.95	1:20
Stroke / Hemiplegia	0.20-0.80	0.45-1.79	2:00-8:20
Incomplete SCI Outdoor Walkers ¹	0.44	1.0	3:45
COPD, CHF, Frail Elderly	0.44	1.0	3:45

¹Van Hedel, et.al (2009). Gait speed in relation to categories of functional ambulation after spinal cord injury. *Neurorehabilitation and Neural Repair*, 23(4), 343–50.

Early Robotic Exoskeletons



Yagn's Running Aid
(Yagn, 1890)



GE's Hardiman
(Fick & Mackinson, 1971)



BLEEX
(Kazerooni & Steger, 2006)

Lower Extremity Exoskeletons and Active Orthoses: Challenges and State-of-the-Art
Dollár, AM and H. Herr. *IEEE Transactions on Robotics*, 24(1), 144-158, 2008

Some of the newer Robotic Exoskeletons



Soft Exosuit

“Soft Exosuit” is attached with a network of fabric straps and uses cables to transmit forces to the joints

It works with the musculature to reduce injuries, improve stamina, and enhance balance even for those with weakened muscles



HULC, XOS2, HAL, and Soft Exosuit

.....are designed for humans that are not paralyzed

Walking Technologies for Persons with Paraplegia

Leg Bracing Devices



Knee Ankle Foot Orthosis (KAFO)



Reciprocating Gait Orthosis (RGO)

Functional Electrical Stimulation (FES)



Walking Technologies for Persons with Paraplegia
Body Weight Supported Treadmill Training (BWSTT)
Manual or Robotic

**Manual
BWSTT**



Lokomat

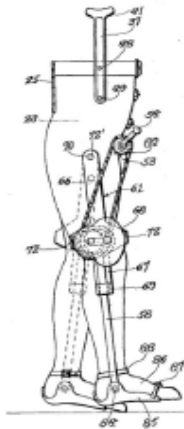


Walking Technologies for Persons with Paraplegia

- **Locomotor training has been shown to ameliorate some of the secondary medical consequences and show improvement in measures of quality of life.**
- **Studies that have used BWS treadmill training in motor complete SCI have shown improvements in**
 - cardiovascular regulation
 - muscle activation, which increases metabolic demand
 - improvements in subjective well-being
- **Yet, these benefits were lost once the walking program was discontinued.**

Powered Exoskeletons

Early Active orthoses for people with paralysis



G.L. Cobb's "Wind-Up" Orthosis (Cobb, 1935)



Wisconsin Exoskeleton Orthosis (Seireg & Grundmann, 1981)



Pump Institute "Complete Exoskeleton" (Vukobratovic, 1990)

Current Robotic/Exoskeletal Systems for Persons with Paralysis

Rehab Rex 2010

(REX Bionics, New Zealand)

Attains stability by means of size and weight, and movement by using a joystick; it's a robot that a person can step in and ride.



Current Robotic/Exoskeletal Systems for Persons with Paralysis

ReWalk 2010

(ReWalk Robotics, Inc., Israel)

Ekso 2011

(Ekso Bionics, Berkeley, CA)

Indego, 2013 (prototype)

(Parker Hannifin Corp., Cleveland, OH)

These three belong to the same category in the sense that the user crutches for stability and manipulation of center of gravity for triggering gait.



Mobility Functions - REX

- Joy stick manipulation for movement
 - Forward, backward, turning, side stepping, standing up and sitting down
- Knee and Hip flexion/extension
- Fully supports user allowing both hands free
- External footplates
- Limited stair climbing
- Accommodates statures of 4'8" to 6'4" and weight <220 lb.
- Injuries up to C4/5
- Fastest overground velocity
 - $\approx 0.15-0.20$ m/s



Mobility Functions - Ekso

- Tethered remote control for movement
 - Forward, turning, standing up and sitting down
- Crutches for balancing
- External foot plates
- Hip joint abduction for level surface transfers
- Computer in a backpack
- Multiple Walking modes:
 - FirstStep – Trainer initiates the step through a tethered remote.
 - ActiveStep – Step is initiated with instrumented crutches or walker.
 - ProStep – Step is initiated based change in body position over their feet.
 - ProStep Plus – User volitionally initiates the leg movement.
- Variable assistance
 - Bilateral Max Assist - performs total work load
 - Adaptive Assist – provides variable level of assistance to only what the user needs.
 - Fixed Assistance – provides a fixed percentage of assistance.
- Fastest reported 10mWT velocity = 0.38 m/s
- Fastest reported 6mWT velocity = 0.28 m/s



Mobility Functions - Indego

- Buttons on the Pelvic band and persons body position control movement
 - Forward, turning, standing up and sitting down
- Crutches for balancing
- Computer in pelvic band
- In-shoe footplates
- Software settings controlled with an App on a mobile device
- Modular system
 - Pelvic Band, Thigh segment, Shank Segment
 - All segments available in small medium and large
- Donned and doffed from current seated position
- Fits some wheelchairs (larger than the one normally prescribed)
- Stair mode potential
- Options for variable assist
 - Mobility Mode: provides total assistance
 - Therapy Mode: enables overground walking for potential to recover function
- Accommodates people from 5'1" - 6'4", and ≤ 250 lb.
- Weights – 26 lb.
- Fastest reported 10mWT = 0.54 m/s
- Fastest reported 6minWT velocity = 0.40 m/s



Mobility Functions - ReWalk

- Mode selector worn on wrist
- User's body position and weight shifting controls movement
 - Forward, turning, standing up and sitting down
- Crutches for balance
- In-shoe footplates
- Computer in backpack
- Adjustable gait parameter settings
 - Hip flexion, knee flexion, step time
 - Delay between steps
- 5mm adjustments (different limb lengths)
- 5'3" to 6'3" and ≤ 220 lb.
- Stair mode (Canada/Europe only)
- Fastest reported 10mWT and 6minWT velocities = 0.71 m/s
- FDA Class 2 (Institutional T4-L5; Home/Community T7-L5)



Summary of Exoskeletal Technology Publications to Date

- **Approximately 13 articles published to date with data from participants/users (2012-2015)**
 - 9 ReWalk (4 from the JJPVAMC)
 - 2 Ekso
 - 2 Indego
- **Population reported on:**
 - Motor complete and incomplete paralysis; all participants were wheelchair users for mobility
 - C4 to L1
 - Chronic SCI (<1.0 to 20.0 y)
 - 2 to 60 sessions

Future Considerations

- Lighter
- Packable
- Fit in wheelchairs
- Finding the balance between robot-driven and patient-driven devices
- Other