History of New Technologies in Rehabilitation
Audience

Clinicians

Scientists

Engineers

Others

History of New Technology in Rehabilitation
Overview

History of New Technology in Rehabilitation

Part 1
Rehabilitation

Part 2

Technologies

Part 3

2014
New Technologies in Rehabilitation
1. History of Rehabilitation

2. History of Technologies

3. New Technologies in Rehabilitation
   3.1 Robot-Assisted Therapy
   3.2 Non-Actuator Devices
   3.3 Functional Electrical Stimulation
   3.4 Sensor Technology
   3.5 Virtual Reality
   3.6 Brain Stimulation
HISTORY OF REHABILITATION
Rehabilitation …

“…is the (re)integration of an individual with a disability into society. This can be done either by enhancing existing capabilities or by providing alternative means…”

Robinson 1993

~2000 years old

shoulder massage (relief)

present

practice of daily tasks
History of Rehabilitation

~ 460 - 370 BC
Hippocrates

~ 129 - 216
Galen of Pergamon
effect of hygiene

~ 1658 - 1742
Nicolas Andry de Bois-Regard
Orthopaedics

16th century
Ambroise Paré
limb prostheses

1747 - 1826
Joseph Clément Tissot
pioneer of physical therapy

Hydrotherapy

Massage

Middle Ages
Correct and regular movements, appropriate rest

Renaissance
Medical gymnastica

History of New Technology in Rehabilitation
History of Rehabilitation

1796
Gymnasticon machine for exercising the joints

1813
Pehr Henrik Ling
physical therapy

1835 - 1920
Gustav Zander
mechanotherapy

1894
Chartered Society of Physiotherapy

World War I
Vacuum tube peripheral stimulation

World War II
Howard A. Rusk
first rehabilitation units

1943
Karel & Berta Bobath
bobath concept

1948
Thomas DeLorme
progressive resistance training

1948
Cybex I
first isokinetics machine

1967
Rehabilitation

Compensation

- Walking aids
  - Crutches
  - Wheelchairs
  - Walkers

- Prostheses
  - Prosthetic toe
  - Iron Arm
Rehabilitation

Restoration

- Physiotherapy
  Increase mobility and function

- Occupational therapy
  Increase independence
Manual Arm Therapy

Target patient group
- Hemiplegic/tetraplegic patients
- Patients with cerebral palsy, traumatic brain injury and other neurological lesions
- Patients with orthopedic lesions or joint pain

Therapy goals
- Train activities of daily living (ADL)
- Reduce contractures by stretching joints
- Avoid secondary complications

➔ Improve arm function, patient well being and patient independence
Conventional Gait Therapy

For the therapist
- Not standardized (repeatable)
- Physically exhausting
- Ergonomically inconvenient (manual handling risk)

For the patient
- Limited in time
- Multiple therapists needed
- Gait pattern not optimal
HISTORY OF TECHNOLOGY
Technology ...

“...is the collection of tools, including machinery, modifications, arrangements and procedures used by humans.”

Wikipedia

~800'000 BC

Atlas, bipedal humanoid robot

2013
History of Technology

- **460 BC**
  - Aristotle

- **1350**
  - Automated Rooster

- **1552**
  - Automatic machine for shearing sheep (King Edward VI)

- **1738**
  - Digesting Duck (Jacques de Vaucanson)

- **1774**
  - Writer of Droz

- **1805**
  - Maillardet

- **1893**
  - Boilerplate

**History of New Technology in Rehabilitation**
History of Technology

1920
R.U.R. (Karel Capek)

1940
Westinghouse’s Electro

1942
«Runaround» (Isaac Asimov)

1954
UNIMATE

1973
WABOT-1

1979
Selective Compliant Articulated Robot Arm (SCARA)
Early Active Orthoses

Cobb’s «wind up» orthosis
(Cobb, 1935)

Pupin Institute «complete» exoskeleton
(Vukobratovic, 1990)

Wisconsin exoskeleton orthosis
(Seireg & Grundmann, 1981)
Powered Exoskeletons

«Yagn’s running aid» (Yagn, 1890)
«General Electric’s Hardiman» (Fick & Mackinson, 1971)
«Bleex» (Kazerooni & Steger, 2006)
«HAL», Hybrid Assistive Limb (Tsukuba University, JP)
NEW TECHNOLOGIES IN REHABILITATION
3.1 HISTORY OF ROBOTIC REHABILITATION
Upper Limbs
History of New Technology in Rehabilitation

**Beginning of Robotic Rehabilitation**

- **1920** Movement therapy
  - Occupational arm training

- **1954** Unimate
  - First robotic arm

- **1975** Programmable Universal Manipulation Arm (PUMA)

- **1979** Selective Compliant Articulated Robot Arm (SCARA)

- **1991** MIT-Manus
  - First therapeutic arm robot
Upper Limbs Therapeutic Robots

History of New Technology in Rehabilitation

mid 1980's
First multi-axis concept
Khalili and Zomlefer

~1991
MIT-MANUS
Massachusetts Institute
of Technology

~1991
First tested system
Erlandson

~1997
mirror image movement enabler (MIME)
Stanford University

~2000
ARM Guide
Rehabilitation Institute of Chicago

~2003
Gentle/S
University of Reading

~2003
NeReBot
Padua University

~2003
Bi-Manu-Track
Klinik Berlin/Charité
University Hospital

~2005
ARMin
ETH Zurich
MIT-Manus (~1991)

Characteristics

- Newman Laboratory for Biomechanics and Human Rehabilitation
- Massachusetts Institute of Technology (MIT)
- 2-DoF end-effector type robot based on a selective compliance assembly robot arm (SCARA)
- Assists shoulder-and elbow movements in the horizontal plane
- First upper limb therapeutic robotic device Move, guide or perturb a patient’s limb
- Measure position, velocity and forces applied

MIT-Manus (Krebs et al. 2000)
Mirror Image Movement Enabler (Lum et al. 1999)

Characteristics

- Veterans Affairs Palo Alto Rehabilitation Research and Development (RR&D) Center
- 6-DoF end-effector type robot, 3-D space based on Puma 560 industrial robot manipulator
- For training unilateral or bilateral shoulder and elbow movements
- Passive mode, active-assisted mode, active-resisted mode, bimanual mode (movement mirroring to impaired limb)
- ARC-MIME
Characteristics

- Rehabilitation Institute of Chicago, University of California Irvine
- 3-DoF (1 active DoF)
- Arm reaching in 3-dimensions
- Assessments and therapy, exploring the effects of active assist therapy
  Real time visual feedback of the arm

Assisted Rehabilitation and Measurement Guide
(Reinkensmeyer et al. 2000)
Bi-Manu-Track (~2003)

Characteristics

Klinik Berlin/Charité University Hospital (Berlin)

1-DoF end-effector type robot

Distal arm movements, bilateral elbow pronation and supination and wrist flexion and extension

Provides bimanual practice, passive and active exercises against an adjustable resistance, no feedback

Bi-Manu-Track (Hesse et al. 2003)

Bi-Manu-Track

Characteristics

- Human Robot Interface Laboratory, Department of Cybernetics and School of Systems Engineering, University of Reading
- 6-DoF robot (3-DoF manipulator (Haptic-Master) + 3 DoF gimbal)
- Elbow pro- and supination and wrist flexion and extension
- Uses haptics and VR technology
- HapticMaster (component)

Gentle/S (Loureiro et al. 2003)
NeReBot (~2003)

Characteristics

Robotics Laboratory of the Department of Innovation in Mechanics and Management, University of Padua

3-DoF end-effector type, wire-based robot

For shoulder and elbow

Principle of hand-over-hand therapy
Robot learn movements of therapists and repeat those later on with patients.
Visual and auditory feedback

NEuro REhabilitation roBOT (Fanin et al. 2003)
ARMin (~2005)

Characteristics

- Sensory-motor-systems Lab, Swiss Federal Institute of Technology (ETH) Zurich

1st version: 4 DoF end-effector-based
2nd version: 6 DoF exoskeleton

- For shoulder and elbow
- Adjustable to arm length
- 3 training modes: mobilization, game training and ADL training.

ARMin (Nef et al. 2007)
3.1 HISTORY OF ROBOTIC REHABILITATION

Lower Limbs
Beginning of Robotic Rehabilitation

**Robotics**
- **1971**
  - Hardiman
  - First robotic exoskeleton

**Rehabilitation**
- **~1995**
  - Manual treadmill training

**1999**
- Lokomat
  - Early driven gait orthosis
Lower Limbs Therapeutic Robots

- ~1999 Lokomat (Hocoma)
- ~1999 Gait Trainer GT-1 (Reha Stim)
- ~2002 Reo/AutoAmbulator (Health South, Motorika)
- ~2008 Lopes (van Asseldonk et al.)
- ~2008 Haptic Walker (Hussein et al.)
Lower Limbs Therapeutic Robots

- **2009**
  - PowerKnee
  - Tibion PK 100 (Horst)

- **~2009**
  - ALEX
  - University of Delaware

- **~2010**
  - Anklebot
  - Khanna

- **~2010**
  - G-EO-System
  - Health South, Motorika
Lokomat (~1999)

**Characteristics**

- 4-DoF driven gait orthosis (exoskeleton) combined with treadmill and body-weight-support
- First driven gait orthosis with a treadmill
  - Adjustable force, body weight support and speed
- Balgrist University Hospital, Hocoma Volketswil

Lokomat (Colombo et al. 2000)
Gait Trainer (~ 1999)

Characteristics

- Based on a doubled crank and rocker gear system, end-effector type
- Simulation of stance and swing
  Control of the vertical and horizontal movements of the center of mass
- Gait Trainer GT I

Klinik Berlin/Charité University Hospital (Berlin)

Gait Trainer (Hesse et al. 2000)
Reo/AutoAmbulator (~2002)

Characteristics

- Cooperation with HealthSouth network of rehabilitation hospitals
- Robot arms move with 4-DoF (bilateral hip and knee flexion/extension), exoskeleton
- Assistance only in sagittal plane
- Reo/AutoAmbulator
Characteristics

- Department of Biomedical Engineering, University of Twente, Enschede

8-DoF lightweight exoskeleton

Translational movements of the pelvis are included along with extension-flexion and abduction-adduction
Haptic Walker

Characteristics

- Fraunhofer Institute IPK, Klinik Berlin/Charité University Hospital (Berlin)
- End-effector type (footplates)

*i* Permanent foot-machine contact, training not restricted to walking on even ground
3.2 NON-ACTUATOR DEVICES
Beginning of Non-Actuator Devices

Robotics
- 1991: MIT-Manus, First therapeutic arm robot
- 1997: MIME
- 2000: ARM Guide

Rehabilitation
- 1920: Movement therapy, Occupational arm training

Non-actuator devices

History of New Technology in Rehabilitation
History of Non-Actuator Devices

~ 2003
Gravity balanced orthosis

T-WREX
~ 2005

Freebal
~ 2007

T-WREX

Dampace
~ 2007

HandSOME
~ 2011

Gravity balanced orthosis

Freebal
~ 2007

ZeroG passive
~ 2010

HandSOME
~ 2011

T-WREX
~ 2005

Dampace
~ 2007

History of New Technology in Rehabilitation
Gravity balanced orthosis (~2003)

Characteristics

Robotics And Rehabilitation Lab, University of Delaware

Gravity balancing un-motorized orthosis (exoskeleton)

Full or partial gravity balance over the leg’s range of motion
Tunable to the geometry and inertia of individual subjects

GBO (Agrawal et al. 2007)
Training WREX (~2005)

Characteristics

- Department of Mechanical and Aerospace Engineering, University of California, Irvine
- 5 DoF backdrivable exoskeleton with arm weight counterbalancing using elastic bands
- Adaption of the WREX device for use in movement training of stroke patients
- Equipped with position sensors
- ArmeoSpring

Therapy/Training-Wilmington Robotic Exoskeleton (Sanchez et al. 2004)
Freebal (~2007)

Characteristics

- Department Biomechanical Engineering, University of Twente, Enschede
- Sling systems with ideal spring mechanisms
- Independent control of the compensation of the lower and upper arm
- Low movement impedance
- ArmeoBoom

Freebal (Stienen et al. 2007)
HandSOME (~2011)

Characteristics

- MedStar National Rehabilitation Hospital and Biomedical Engineering at The Catholic University of America, Washington DC
- Spring-powered assist of pinch-pad grasp
- Synchronized movement of fingers and thumb with adjustable assistance for hand opening
- ManovoSpring

HandSOME (Brokaw et al. 2011)
3.3

HISTORY OF FUNCTIONAL ELECTRICAL STIMULATION
History of FES

- **~1961**
  - Electronic personal stimulator
  - Wladimir Theodore Liberson

- **~1982**
  - Parastep I

- **~1986**
  - Freehand System

- **~1989**
  - Bionic Glove

- **~1993**
  - Handmaster NMS-1

- **~1999**
  - Complex Motion

History of New Technology in Rehabilitation
Drop Foot Stimulator (~ 1961)

Liberson et al. 1961

Electrically stimulates the common peroneal nerve
Uses foot-switch to synchronize applied electrical stimulation to swing phase of gait

First functional electrical stimulator (FES)
Developed to prevent foot-drop in hemiplegic patients
Parastep I (≈ 1982)

Characteristics

Sigmedics Inc.

Noninvasive, microcomputer controlled functional neuromuscular stimulation (FNS) system

Enables independent, unbraced ambulation (i.e., standing and walking) by people with a spinal cord injury
Freehand System (~ 1986)

Characteristics

- NeuroControl Cleveland, USA
- Surgically implanted receiver/stimulator unit and electrodes with an external controller and power supply/microprocessor
- Neuroprosthesis intended to restore hand function in C5 and C6 level tetraplegics
- Stimulation of eight different muscles in order to produce a useful grip and key pinch
Bionic Glove (~ 1989)

**Characteristics**

- Prochazka et al., University of Alberta
- Three channels of electrical stimulation to stimulate finger flexors, extensors and thumb flexors.
  Control signal comes from a wrist position Tranducer mounted in the garment
- Enhance grasp in subjects that have voluntary control over the wrist
  Stimulates finger flexors and extensors
  Enhances strength of grasp

Bionic Glove
Handmaster NMS-1 (~ 1993)

**Characteristics**

- **Bioness** (formerly Neuromuscular Electrical Stimulation Systems Ltd.)
- Lightweight, ergonomical arm-hand orthosis with integrated FES and separate, wireless control unit.
- Reaching, grasping, opening and closing the hand
- Ness H200

Handmaster NMS-1 (Nathan 1993)
Complex Motion (~1999)

**Characteristics**

- University Hospital, Zurich
- Rehabilitation Engineering Group ETH Zurich
- Complex SA, Switzerland

Portable electrical stimulator with 4 stimulation channels and surface stimulation electrodes

- Able to generate arbitrary stimulation sequences which can also be controlled by external sensors
- Multiple stimulators can be combined to increase number of stimulation channels
3.4

HISTORY OF SENSOR TECHNOLOGY
History of Sensor Technology

- **1990**: Life Alert Classic
- **2002**: AMON
- **2005**: LiveNet
- **2007**: Stroke Rehabilitation Exerciser
- **2007**: Wellcore system
- **2011**: Valedo System

History of New Technology in Rehabilitation
Stroke Rehabilitation Exerciser (2007)

**Characteristics**

- **Philips Research, Netherlands**

A wireless inertial sensor system records the patient’s movements. Data is automatically analyzed for deviations from a personal movement target and patient and therapist are provided with adequate feedback.

- **i**

Coaches the patient through a sequence of neurological motor exercises, which are prescribed by the physiotherapist and uploaded to a patient unit.
Hocoma AG in collaboration with the team led by Prof. Dr. Jan Kool at Zurich University of Applied Sciences in Winterthur, Switzerland

Wireless sensors attached to the patient's skin transfer even the smallest movements of the trunk and pelvis into a motivating game-like environment.

Exercises were designed to train specific therapeutic goals such as stabilization, mobilization and movement awareness.
3.5 HISTORY OF VIRTUAL REALITY
Beginning of Virtual Reality

Virtual Reality

1958 Sensorama
1965 Sutherland's Ultimate Display
1975 Videoplace
1999 Virtual Teacher

Rehabilitation

1993 Virtual Therapy
Psychotherapeutic application
1997 Virtual Vietnam
Treatment of posttraumatic stress disorder

History of New Technology in Rehabilitation
**History of Virtual Reality**

- **~ 1996**
  - Vivid Group’s Mandala Gesture Extreme platform

- **~ 2000**
  - Computer Assisted Rehabilitation Environment (CAREN)

- **~ 2001**
  - Rutgers Ankle Reha Interface

- **~ 2007**
  - Rehabilitation Gaming System (RGS)

- **~ 2009**
  - Paediatric Interactive Therapy System

**History of New Technology in Rehabilitation**
Mandala Gesture Extreme platform (~ 1996)

**Characteristics**

- Platform together with a suite of interactive, game-type environments
- Invented by a technology group in Toronto, Canada
- Since ~1999 it has also begun to be adapted for use in rehabilitation

- Subjects are immersed in a full-body virtual world where they can interact with on-screen images and objects, designed to enhance the sense of “presence” for the subject

- GestureTek’s Interactive Rehabilitation and Exercise System (IREX®)

Mandala Gesture Extreme platform
Vivid Group

History of New Technology in Rehabilitation
In 1997, MOTEK had applied for a research grant to the European commission. This grant was received in 1998 and enabled the development of the 1st prototype.

Hydraulic 6 DOF motion base with ~700 kg payload, 2m diameter platform top with integrated dual force plates, 8 camera real-time motion capture system.

The 1st production grade CAREN system was sold to the University of Groningen in 2000.
Rutgers Ankle Reha Interface (~ 2001)

Characteristics

- Designed for home use and internet-based remote monitoring by therapists. Invented by Rutgers, State University of New Jersey.
- Allows patient to interact with motivating virtual environments and allows movement in all 3 degrees of freedom of the ankle.
Rehabilitation Gaming System (~ 2007)

**Characteristics**

SPECS research group, University Pompeu Fabra
Hospital of Vall d’Hebron, Spain

Hospital de la Esperança, Spain

Tracking of arm movements with a Kinect sensor mounted on top of the display
Two data gloves detect finger movements

Movement execution is combined with the observation of correlated actions performed by a virtual body

**History of New Technology in Rehabilitation**
Paediatric Interactive Therapy System (~ 2009)

PITS is an applicable VR-system which can be feasibly applied during the rehabilitation of children with upper limb motor dysfunctions. It was invented by Rehabilitation Centre, University Children’s Hospital Zurich.

Characteristics

- Consists of a pair of therapy-optimized data gloves with integrated movement tracking.
- YouGrabber.
3.6

HISTORY OF BRAIN STIMULATION
Beginning of Brain Stimulation

~ antiquity
- Electric torpedo fish headache treatment

~ 1809
- Central electrical stimulation Luigi Rolando (1773-1831)

~ 1896
- Magnetic stimulation Jacques-Arsène d’Arsonval

~ 1896
- First reliable transcranial magnetic brain stimulator Anthony Barker

~ late 18th century
- 'Animal electricity' Luigi Galvani

~ 1874
- Exposed dura stimulation Robert Bartholow

~ 1937
- Electroconvulsive therapy Cerletti and Bini
Sheffield Magnet (~1985)

Characteristics

- Barker et al., Sheffield University
- 54 uF Mylarfilm capacitor, 4000 V
- Magstim

Sheffield Magnet
International Industry Society In Advanced Rehabilitation Technology (IISART)

General Information
info@iisartonline.org
www.iisartonline.org
Image sources

Slide 2 – Audience
Background: http://www.iisd.ca/ymb/climate/wcc3/pix/1sept/DSC_6266%20full%20rooom.jpg

Slide 6 – Rehabilitation ...
Left image (massage): http://www.physio-pedia.com/images/7/74/Shoulder_massage.jpg

Slide 7 – History of Rehabilitation
2nd image (Hippocrates): http://www-tc.pbs.org/wgbh/nova/assets/img/hippocratic-oath-today/image-01-small.jpg
3rd image (massage): http://www.physio-pedia.com/images/7/74/Shoulder_massage.jpg
4th image (Galen): http://www.general-anaesthesia.com/images/galen.jpg
5th image (Paré): http://upload.wikimedia.org/wikipedia/commons/6/6a/Ambroise_Par%C3%A9.jpg
6th image (mech. hand): http://www.christianhubert.com/writings/Prothesi.jpg
7th image (Regard): http://upload.wikimedia.org/wikipedia/commons/c/cf/Possible_portrait_of_Nicolas_Andry.jpg
8th image (orthopaedics): http://www.cfdrm.fr/images/Andry_1741_L.jpg
9th image (Tissot): http://upload.wikimedia.org/wikipedia/de/3/3f/WP_Joseph_Cl%C3%A9ment_Tissot.jpg

Slide 8 – History of Rehabilitation
1st image (gymnasticicon): http://upload.wikimedia.org/wikipedia/commons/4/42/Gymnasticicon.png
2nd image (Ling): http://upload.wikimedia.org/wikipedia/commons/8/8f/Pehr_Henrik_Ling.jpg
4th image (vacuum tube): http://c4.staticflickr.com/4/3345/3299295807_279a3db65b_z.jpg
5th image (Rusk): http://shs.umsystem.edu/historicmissourians/name/r/rusk/images/large/rusk_main_lg.jpg

History of New Technology in Rehabilitation
Image sources

Slide 8 – History of Rehabilitation
6th image (Cybex I):
http://www.isokinetics.net/images/stories/cybex1.jpg

Slide 9 – Rehabilitation
1st image (crutches):
http://ids.lib.harvard.edu/ids/view/20458087?width=3000&height=3000
2nd image (wheelchairs):
3rd image (walkers):
http://image.ec21.com/image/gentryway/oimg_GC04421974_CA04421975/Walking_Aid_Walker.jpg
4th image (prosthetic toe):
http://i.livescience.com/images/i/000/003/981/i02/070727_wood_toe_02.jpg?i295081730
5th image (iron hand):
http://news.bbcimg.co.uk/media/images/58793000/jpg/_58793348_1.jpg

Slide 10 – Rehabilitation
Images:
Presentation from Robert Riener

Slide 11 – Manual Arm Therapy
Slide:
Lecture slide from Robert Riener

Slide 12 – Conventional Gait Therapy
Slide:
Lecture slide from Robert Riener

Slide 14 – Technology...
Left image (handaxe):
http://humanorigins.si.edu/sites/default/files/images/portrait/3.3.4-30_handaxe_base_jdhd_p.jpg
Right image (atlas):
Slide 15 – History of Technology

Slide 16 – History of Technology
1st image (R.U.R.): Lecture from Rod Grupen, Foundations of robotics
2nd image (Capek): Lecture from Rod Grupen, Foundations of robotics
3rd image (electro): Lecture from Rod Grupen, Foundations of robotics
4th image (Asimov): Lecture from Rod Grupen, Foundations of robotics
7th image (SCARA): [http://www.robotics.org/userassets/riauploads/hm_hs-white.jpg](http://www.robotics.org/userassets/riauploads/hm_hs-white.jpg)

Slide 17 – Early Active Orthoses
1st image (wind up): From Dollar and Heer 2008. Lower extremity exoskeletons and active orthoses: challenges and state-of-the-art
2nd image (complete exo.): From Dollar and Heer 2008. Lower extremity exoskeletons and active orthoses: challenges and state-of-the-art
3rd image (Wisconsin exo.): From Dollar and Heer 2008. Lower extremity exoskeletons and active orthoses: challenges and state-of-the-art
Image sources

Slide 18 – Powered Exoskeletons
1st image (Yagn): From Dollar and Heer 2008, Lower extremity exoskeletons and active orthoses: challenges and state-of-the-art
2nd image (Hardiman): From Dollar and Heer 2008, Lower extremity exoskeletons and active orthoses: challenges and state-of-the-art
3rd image (Blexx): From Dollar and Heer 2008, Lower extremity exoskeletons and active orthoses: challenges and state-of-the-art

Slide 21 – Beginning of Robotic Rehabilitation
2nd image (PUMA): https://www.robotics.tu-berlin.de/typo3temp/pics/6/61d474341e.jpg
3rd image (SCARA): http://www.robotics.org/userassets/riauploads/hm_hs-white.jpg
4th image (mov. therapy): Lecture from Robert Riener
5th image (MIT-Manus): http://www.jneuroengrehab.com/content/figures/1743-0003-i-5-1.jpg

Slide 23 – Upper Limbs Therapeutic Robots
1st image (MIT-Manus): http://www.jneuroengrehab.com/content/figures/1743-0003-i-5-1.jpg
4th image (Gentle/S): http://www.gentle.rdg.ac.uk/103-0325.jpg
5th image (Bi-Manu-Track): http://stroke.ahajournals.org/content/43/10/2729/F1.large.jpg
6th image (NeReBot): http://cono-sciienza.fisica.unipd.it/pics/nerebot.jpg
7th image (ARMin): http://manokel.com/eng/img/eng_3a.jpg
Image sources

Slide 32 – Beginning of Robotic Rehabilitation
1st image (Hardiman): From Dollar and Heer 2008, Lower extremity exoskeletons and active orthoses: challenges and state-of-the-art
2nd image (man. training): Hocoma
3rd image (Lokomat): Hocoma

Slide 33 – Lower Limbs Therapeutic Robots
1st image (Lokomat): Hocoma
2nd image (Gait Trainer): http://www.reha-stim.de/cms/assets/images/GT-I-mit-Person
3rd image (ReoAmbulator): http://www.upsite.co.il/uploaded/images/1357_4e7015b7f7f343278c10f3f0d7dcd48.png
4th image (Lopes): http://www.utwente.nl/ctw/bw/RESEARCH/PROJECTS/LOPES/lopes-4.jpg
5th image (Haptic Walker): From Schmidt 2004, HapticWalker - A novel haptic device for walking simulation

Slide 34 – Lower Limbs Therapeutic Robots
1st image (PowerKnee): http://cdn.medgadget.com/img/balleq.jpg
2nd image (ALEX): http://roar.me.columbia.edu/projects/alex/figures/alex.png
3rd image (Anklebot): http://www.jneuroengrehab.com/content/figures/1743-0003-7-23-1.jpg
4th image (G-EO-System): http://img.medicalexpo.de/images_me/photo-mg/computerbasiertes-rehabilitationssystem-69821-3665809.jpg

Slide 41 – Beginning of Non-Actuator Devices
1st image (MIT-Manus): http://www.jneuroengrehab.com/content/figures/1743-0003-1-5-1.jpg
4th image (mov. therapy): Lecture from Robert Rienner
5th image (T-WREX): http://docs.exdat.com/data/46/45284/45284_html_m46c7b26d.jpg
Image sources

Slide 42 – History of Non-Actuator Devices
1st image (GBO): From Banala et al. 2004, A Gravity Balancing Leg Orthosis for Robotic Rehabilitation
2nd image (T-WREX): http://docs.exdat.com/data/46/45284/45284_html_m46c7b26d.jpg
3rd image (Freebal): http://www.utwente.nl/ctw/bw/research/projects/ar/ar-4.jpg
4th image (Dampace): From Prange et al. 2010, An explorative, cross-sectional study into abnormal muscular coupling during reach in chronic stroke patients
5th image (handSOME): http://cabrr.cua.edu/res/images/research/Handsomepic6.jpg

Slide 48 – History of FES
2nd image (Parastep I): http://www.musclepower.com/images/sitstand-l.jpg
4th image (Bionic Glove): http://t0.gstatic.com/images?q=tbn:ANd9GcRtfm8y5v3LuOIQ7cGN6gF2VitnkzBh5NBO0qL_uL3mY-chD3T
5th image (Handmaster): From Snoek et al. 2000, Use of the NESS Handmaster to restore handfunction in tetraplegia: clinical experiences in ten patients
6th image (Complex Mot.): http://control.ee.ethz.ch/~ncg/previous_projects/images/fes_tim_03.jpg

Slide 57 – History of Sensor Technology
1st image (life alert): http://protection.com/images/PhoneBG.png
2nd image (AMON): http://art-of-technology.ch/typo3temp/pics/AMON_d107c70ad0.jpg
3rd image (LiveNet): From Sung et al. 2005, Wearable Feedback Systems for Rehabilitation
6th image (Valedo): http://www.lucamed.de/files/6d3e138cb0.jpg
Image sources

Slide 73 – Beginning of Brain Stimulation
1st image (torpedo fish):  
http://upload.wikimedia.org/wikipedia/commons/d/df/Torpedo_torpedo_corsica2.jpg
2nd image (Luigi Galvani):  
http://upload.wikimedia.org/wikipedia/commons/3/39/Luigi_galvani.jpg
3rd image (Rolando):  
http://www.cerebromente.org.br/ni8/history/fatal_small.jpg
4th image (Bartholow):  
5th image (d’Arsonval):  
http://upload.wikimedia.org/wikipedia/commons/2/2d/Jacques-Ars%C3%A8ne_d%27Arsonval.jpg
6th image (electroconvul.):  
http://s.hswstatic.com/gif/electroconvulsive-therapy-1.jpg
7th image (Barker):  
http://www.magstim.com/img/imagecache/e/c/b/cache_ecbc4663b8c05a2dd477b86699ad67a0.jpg