Robotics and technologies for Rehabilitation and Sports Medicine

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Head, Bioengineering Rehabilitation Lab
IEEE RAS Technical Committee on Rehabilitation and Assistive Robotics
Outline of the presentation

• BioRobotics and Bionics convergence
• Rehabilitation and Assistive Robotics
  • Upper limb robot-assisted therapy
  • Gait robot-assisted therapy
  • Precision orthopaedic surgery - Precision orthopaedic rehab
  • RISE robotic wheelchair
• Biomechanics for Sports Medicine
• Lessons, new scenarios and challenges
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  • Sports biomechanics
• Lessons, new scenarios and challenges
Robotics in healthcare

No longer science fiction, robotics has emerged as a leading alternative for many healthcare applications.

Dr. Daniel Kraft - "What's next in healthcare?"

Daniel Kraft is a physician-scientist, inventor and innovator. He is chair of the Medicine track for Singularity University and Executive Director for FutureMed, a program which explores convergent, exponentially developing technologies and their potential in biomedicine and healthcare.
Founded in 2011, the Scuola Superiore Sant’Anna - Auxilium Vitae Rehabilitation Centre (100 beds) joint research laboratory is composed by bioengineers, medical doctors and therapists.

**Clinical facility**
- **Cardio-respiratory Dept:** 42 beds + 8 beds for assisted ventilation, monitoring and weaning
- **Neurological Rehabilitation Unit:** 35 beds
- **Severe Traumatic Brain Injury Rehabilitation Unit:** 15 beds

**Research activities**
- Design, development and validation of **robotic systems for** neurological rehabilitation (stroke, brain injury)
- **Tele-rehabilitation applications** (continuity of care from hospital to home/residential setting) for neurological and cardio-respiratory rehabilitation
- **E-health solution** for pulmonary rehabilitation (telemonitoring of physiological and respiratory parameters for ventilator-dependent patients)
Rehabilitation Bioengineering Laboratory

Robotic systems for upper limb motor therapy, technologies for e-health and sports biomechanics

- n=450+ chronic and subacute post-stroke patients treated using robotic systems for upper limb rehabilitation (50+ at Versilia Hospital, 400+ at Auxilium Vitae Volterra): 2nd largest sample size worldwide
- Design and development of innovative robotic systems for upper limb rehabilitation
- Analysis of patient-ventilator interaction: development of software routine for automatic identification of respiratory asynchronies and assessment of patient effort (diaphragmatic EMG)
- Pulmonary telerehabilitation: low-cost and portable interactive videogames for home-based training
- Ventilatory response to exercise of n=90 elite soccer players


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  • RISE robotic wheelchair
• Sports biomechanics
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Robotic devices for robot-assisted upper limb rehabilitation

**Proximal segments**
- MIME
- InMotion 2.0
- REHAROB
- MIT-MANUS
- NeReBot
- ReoGo

**Distal segments**
- Bi-Manu-Track
- Reha-Digit
- Reha-Slide
- AMADEO
- Supinator Extender
- RiceWrist-S
- InMotion WRIST
- GLOREHA
Aims:
To assess the effects of electromechanical and robot-assisted arm training for improving arm function in people who have had a stroke.

Selection Criteria:
RCTs comparing electromechanical and robot-assisted arm training for recovery of arm function with other rehabilitation or placebo interventions, or no treatment, for people after stroke.
The MIT-MANUS

Patient’s visual feedback

- A visual performance display appears following **five series of repetitions**. Based on the patient performance, the program either increases or decreases the assistance provided to reach the targets.
- Display provides positive reinforcement to patient and encourages them to improve

PM1: Initiated Movement

PM2: Maximum Distance Along Target Axis

PM3: Active Power

PM4: Minimum jerk deviation (smoothness)

PM5: Distance from straight line (accuracy)
Robotic systems for upper limb motor therapy

Shoulder/elbow robot (InMotion 2.0)

Wrist robot (InMotion 3.0)
Robotic systems for upper limb motor therapy in stroke patients: Our experience with MIT-MANUS

Aim: to present the effectiveness of robot-mediated therapy on the paretic upper limb of an experimental group of 20 chronic stroke patients

Participants:
A group of 20 subjects, age range 33–69 (mean age 53.3, standard deviation (SD) 11.2).

Methods:
Robot-mediated therapy was delivered using the MIT-MANUS, a robot designed for clinical neurological application

- **Adaptive:** system recognize subject’s active movements even partially performed. It helps subject to terminate the initiated movement
- **Planar movements**
- Kinematical parameters at the end-effector

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Robotic systems for upper limb rehabilitation in stroke patients: our experience with MIT-MANUS

Table II. Outcome measures comparison at admission and discharge

<table>
<thead>
<tr>
<th>Evaluation</th>
<th>Admission</th>
<th></th>
<th>Discharge</th>
<th></th>
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<tr>
<td></td>
<td>Median</td>
<td>IQR</td>
<td>Median</td>
<td>IQR</td>
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<tr>
<td>MSS-SE</td>
<td>12,800</td>
<td>10,350–14,800</td>
<td>14,200</td>
<td>11,950–16,600</td>
<td>&lt;0.001</td>
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<tr>
<td>MAS shoulder</td>
<td>8,000</td>
<td>4,750–11,250</td>
<td>4,000</td>
<td>2,750–6,625</td>
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<td>MAS elbow</td>
<td>1,500</td>
<td>750–2,000</td>
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<td>ROM shoulder</td>
<td>440,000</td>
<td>408,750–566,250</td>
<td>550,000</td>
<td>477,500–647,500</td>
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<tr>
<td>ROM elbow</td>
<td>440,000</td>
<td>417,500–460,000</td>
<td>460,000</td>
<td>450,000–460,000</td>
<td>&lt;0.005</td>
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</tr>
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</table>

IQR: interquartile range; MAS: Modified Ashworth scale; MSS-SE: Motor Status Score – Shoulder-Elbow; ns: not significant; ROM: range of motion.

Robotic systems for **upper limb** rehabilitation in stroke patients: our experience with MIT-MANUS

Mean speed

Numbers of peak

SM

AM

FMA/ue

MI

**Aim:**
to compare motor recovery in subacute and chronic stroke patients through clinical assessment scales and a set of kinematic parameters recorded using a robotic system

**Subjects:**
- **N=25 subacute stroke** patients (25±7 days from acute event)
  - Mean age: 70.2 ± 9.4 (range: 44-82 years)
  - 16 M, 9 F
- **N=25 chronic stroke** patients (>1 year from acute event)
  - Mean age: 58.8 ±13.1 (range: 31-86 years)
  - 17 M, 8 F
- **N=20 healthy subjects**
  - Mean age: 38.0 ± 9.8 (range: 27-60 years)
  - 9 M, 11 F

Methods

Intervention:
5 sessions/week, 4 weeks
- Reaching exercises
- Each session:
  - 16 not assisted movements (*Training test*)
  - 16 not assisted movements (*Record*)
  - 3 series of 320 robot assisted movements (*Adaptive*)

Clinical outcome measures:
- Fugl-Meyer Assessment (FMA) Scale – upper extremity section (*max 66*)
- Motricity index (MI) - upper limb component (*max 100*)

Kinematic parameters

- **Speed**
  \[
  \bar{v}_x = \frac{1}{N} \sum_{k=1}^{N} v_x[k] \quad \bar{v}_y = \frac{1}{N} \sum_{k=1}^{N} v_y[k] \quad v_{xy} = \sqrt{(v_x[k])^2 + (v_y[k])^2} \quad \bar{v}_{xy} = \frac{1}{N} \sum_{k=1}^{N} v_{xy}[k]
  \]

- **Smoothness**
  - Number of Speed Peaks (NSP)

- **Speed Metric**
  \[
  SM = \frac{v_{xy}}{v_{peak}}
  \]

- **Acceleration Metric**
  \[
  AM = \frac{a_{xy}}{a_{peak}}
  \]

- **Onset Movement Time**

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Results: clinical outcome measures

FMA

<table>
<thead>
<tr>
<th></th>
<th>Pretreatment</th>
<th>Posttreatment</th>
<th>Change</th>
<th>P</th>
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<tbody>
<tr>
<td>Chronic</td>
<td>20.92 ± 11.55</td>
<td>28.12 ± 13.11</td>
<td>7.20 ± 5.60</td>
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<tr>
<td>Subacute</td>
<td>26.28 ± 12.10</td>
<td>35.66 ± 12.34</td>
<td>9.50 ± 7.83</td>
<td>&lt;0.05</td>
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Motricity Index

<table>
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<th>Posttreatment</th>
<th>Change</th>
<th>P</th>
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<tr>
<td>Chronic</td>
<td>36.52 ± 22.83</td>
<td>44.20 ± 22.44</td>
<td>7.68 ± 6.23</td>
<td>NS</td>
</tr>
<tr>
<td>Subacute</td>
<td>40.42 ± 26.35</td>
<td>56.37 ± 26.25</td>
<td>15.95 ± 12.49</td>
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</table>

Kinematic parameters (subacute patients)

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<th>20 Sessions</th>
<th>30 Sessions</th>
<th>P</th>
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<tr>
<td>$v_{xy}$, m/sec</td>
<td>0.10 ± 0.03</td>
<td>0.09 ± 0.03</td>
<td>NS</td>
</tr>
<tr>
<td>NSP</td>
<td>4.81 ± 4.10</td>
<td>4.52 ± 2.82</td>
<td>NS</td>
</tr>
<tr>
<td>SM</td>
<td>0.49 ± 0.07</td>
<td>0.50 ± 0.07</td>
<td>NS</td>
</tr>
<tr>
<td>AM</td>
<td>0.43 ± 0.06</td>
<td>0.45 ± 0.09</td>
<td>NS</td>
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</table>

Results: kinematic parameters

Mean speed

Numbers of peak

Results: movement onset time and correlation among measures

Correlations

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<th>MI</th>
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<tbody>
<tr>
<td>AM</td>
<td>0.117&lt;sup&gt;c&lt;/sup&gt;</td>
<td>-0.236&lt;sup&gt;c&lt;/sup&gt;</td>
</tr>
<tr>
<td>NSP</td>
<td>-0.016&lt;sup&gt;c&lt;/sup&gt;</td>
<td>0.310&lt;sup&gt;c&lt;/sup&gt;</td>
</tr>
<tr>
<td>SM</td>
<td>0.123&lt;sup&gt;c&lt;/sup&gt;</td>
<td>-0.337&lt;sup&gt;c&lt;/sup&gt;</td>
</tr>
<tr>
<td>v&lt;sub&gt;xyr&lt;/sub&gt;, mean</td>
<td>0.069&lt;sup&gt;c&lt;/sup&gt;</td>
<td>-0.159&lt;sup&gt;c&lt;/sup&gt;</td>
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Chronic

<table>
<thead>
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<th>MI</th>
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<tr>
<td>AM</td>
<td>-0.217&lt;sup&gt;c&lt;/sup&gt;</td>
<td>-0.208&lt;sup&gt;c&lt;/sup&gt;</td>
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<tr>
<td>NSP</td>
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<td>0.043&lt;sup&gt;c&lt;/sup&gt;</td>
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<tr>
<td>SM</td>
<td>-0.208&lt;sup&gt;c&lt;/sup&gt;</td>
<td>-0.130&lt;sup&gt;c&lt;/sup&gt;</td>
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<tr>
<td>v&lt;sub&gt;xyr&lt;/sub&gt;, mean</td>
<td>-0.040&lt;sup&gt;c&lt;/sup&gt;</td>
<td>-0.078&lt;sup&gt;c&lt;/sup&gt;</td>
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</table>

Subacute

<sup>a</sup>Pearson correlation coefficient.
<sup>b</sup>Spearman rank correlation coefficient.
<sup>c</sup>P > 0.05.

Robotic systems for upper limb rehabilitation in stroke patients

Aim:
to present the results of an innovative functional assessment method for the upper limb in hemiparetic subjects, based on the integrated analysis of biomechanical data and electroencephalographic signals (EEG) recorded during reaching movements.

Robotic therapy can contribute to upper limb motor recovery: does it stimulate (and lead to activation of) cortex areas in the damaged hemisphere?

Biosemi Active Two system (16 channels)

Robotic systems for upper limb rehabilitation in stroke patients

Methods:
• N=6 subjects took part in the experiment: N=4 healthy subjects (aged 24-48) and N=2 chronic hemiparetic subjects (aged 59-61): P01 left hemiparesis, P02 right hemiparesis
• In each session, subjects received 60 minutes of robot-mediated therapy, 5 sessions per week, 4 weeks

Robotic systems for upper limb rehabilitation in stroke patients

Robotic systems for upper limb rehabilitation in stroke patients

EEG analysis: results

Predominant activation of controlateral cortex hemisphere in healthy subjects, whereas during the robotic therapy treatment, a gradual activation of ipsilateral hemisphere was observed in both hemiparetic subjects.

**Aim:**

is to propose a new methodology in order to evaluate the difference of recovery mechanisms in stroke subjects in subacute and chronic phase by using the trend, before and after the upper limb robot-aided training, of two biomechanical parameters, namely velocity and force.

**Participants:**

- **N=8 subacute** stroke subjects, age range 18–82 (mean age 63.0 ± 21.3) years. Time from the acute event: 25 ± 7 days.
- **N=17 chronic** stroke subjects, age range 33–66 (mean age: 51.9 ± 0.7) years. Time from the acute event: at least 1 year.

**Interventions:**

- Each subject was asked to perform goal-directed, planar reaching tasks, moving from the centre target to each of 8 peripheral targets.
- Five robot-aided sessions per week for 6 weeks.

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**Subacute stroke subjects characteristics**

<table>
<thead>
<tr>
<th>ID</th>
<th>Age</th>
<th>DH</th>
<th>AS</th>
<th>CM</th>
<th>FM Admission</th>
<th>FM Discharge</th>
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<tr>
<td>S01</td>
<td>44</td>
<td>R</td>
<td>R</td>
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<td>29.0</td>
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<tr>
<td>S02</td>
<td>70</td>
<td>R</td>
<td>R</td>
<td>2</td>
<td>19.0</td>
<td>47.0</td>
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<tr>
<td>S03</td>
<td>77</td>
<td>R</td>
<td>R</td>
<td>4</td>
<td>40.0</td>
<td>47.0</td>
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<tr>
<td>S04</td>
<td>18</td>
<td>R</td>
<td>R</td>
<td>2</td>
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<td>25.0</td>
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<tr>
<td>S05</td>
<td>82</td>
<td>R</td>
<td>L</td>
<td>2</td>
<td>21.0</td>
<td>41.0</td>
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<td>S06</td>
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<td>R</td>
<td>L</td>
<td>5</td>
<td>21.0</td>
<td>28.0</td>
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<tr>
<td>S07</td>
<td>72</td>
<td>R</td>
<td>L</td>
<td>4</td>
<td>36.0</td>
<td>49.0</td>
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<tr>
<td>S08</td>
<td>71</td>
<td>R</td>
<td>L</td>
<td>2</td>
<td>18.0</td>
<td>25.0</td>
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**Chronic stroke subjects characteristics**

<table>
<thead>
<tr>
<th>ID</th>
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<th>CM</th>
<th>MSS(SE) Admission</th>
<th>MSS(SE) Discharge</th>
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<tr>
<td>S09</td>
<td>61</td>
<td>R</td>
<td>R</td>
<td>3</td>
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<td>14.2</td>
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<td>S10</td>
<td>45</td>
<td>R</td>
<td>R</td>
<td>3</td>
<td>10.4</td>
<td>12.0</td>
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<tr>
<td>S11</td>
<td>53</td>
<td>R</td>
<td>R</td>
<td>3</td>
<td>14.9</td>
<td>17.8</td>
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<tr>
<td>S12</td>
<td>64</td>
<td>R</td>
<td>R</td>
<td>3</td>
<td>10.6</td>
<td>12.2</td>
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<tr>
<td>S13</td>
<td>57</td>
<td>R</td>
<td>R</td>
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<td>10.4</td>
<td>11.6</td>
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<tr>
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<td>R</td>
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<td>11.2</td>
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<td>L</td>
<td>3</td>
<td>13.8</td>
<td>16.2</td>
</tr>
</tbody>
</table>

**Clinical Outcome measures:**
- Motor Status Scale shoulder and elbow (MSS-SE) – chronic patients
- Fugl-Meyer (FM)-subacute

**Biomechanical Parameters:**
- Mean Forces
- Mean speed

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Robotic systems for **upper limb** rehabilitation in stroke patients: our experience with InMotion 2.0

Clinical outcome measures

<table>
<thead>
<tr>
<th></th>
<th>FM (subacute)</th>
<th>MSS-SE (chronic)</th>
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</thead>
<tbody>
<tr>
<td>PRE</td>
<td>23.75 ± 9.07</td>
<td>14.50 ± 7.02</td>
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<tr>
<td>POST</td>
<td>36.37 ± 10.62</td>
<td>16.56 ± 7.18</td>
</tr>
<tr>
<td><strong>Change</strong></td>
<td>12.62 ± 7.61</td>
<td>2.06 ± 1.12</td>
</tr>
<tr>
<td><strong>p</strong></td>
<td>&lt; 0.05</td>
<td>&lt; 0.001</td>
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</table>

Mean Force before and after the robotic-aided training in direction Nt

Mean Speed
Haptic device for upper limb rehabilitation in stroke patients: a pilot study

Aim:
to evaluate the effects of upper limb robot-assisted rehabilitation on motor recovery in stroke patients who underwent a treatment based on a haptic device.

Methods:
• N=23 subacute stroke patients (time from acute event: 14-35 days), mean age: 67.3 ± 11.7, 10 M, 13 F
• N=16 chronic stroke patients (time from acute event: 12-84 months), mean age: 66.9 ± 9.6, 10 M, 6 F
• N=13 healthy subjects, mean age: 43.9 ± 8.4, 8 M, 15 F

<table>
<thead>
<tr>
<th>ID</th>
<th>Age</th>
<th>Gender</th>
<th>Type of lesion</th>
<th>Time since acute event (day)</th>
<th>Number of sessions</th>
<th>Chedoke-McMaster Stroke Assessment</th>
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**Haptic device for upper limb rehabilitation in stroke patients: a pilot study**

**Methods:**
- The CE-marked MOTORE (Mobile robot for upper limb neurOrtho Rehabilitation, Humanware Srl, Pisa, Italy)/Armotion system was used in this study.

  - **10 batteries** (11.1 V)
  - **A 3-axes load cell** embedded in the handle is used to record patient-robot interaction forces
  - **3 omnidirectional wheels** (Konylak Coorporation Tranwheels) which are actuated by **three DC motors** positioned at 120 degrees and based on **the Killough’s kinematical model**
  - **an absolute localization** system based on odometry from motor encoders and an optical sensor based on **Anoto® technology**
  - **Bluetooth connection**
  - **Active, assist-as-needed** and **passive control modalities**

Different exercises characterized by (i) visual and haptic cues, (ii) graphical scenario and (iii) performance parameters.

Haptic device for upper limb rehabilitation in stroke patients: a pilot study

Clinical Assessment
• Modified Ashworth Scale (MAS)
• Fugl-Meyer Scale upper extremity section (FM/ue)
• Motricity Index (MI)
• Box and Block Test (B&B)
• Medical Research Council Scale (MRC)
• Modified Barthel Index (mBI)

Statistical analysis
The Wilcoxon signed rank test was used to compare differences between clinical outcome measures and kinematic parameters. Significance was set at p < 0.05

Kinematic parameters
• mean speed \[ v_{xy} = \frac{\sum_{i=1}^{5} \sqrt{v_{xi}^2 + v_{yi}^2}}{5} \]
• maximum speed;
• mean time;
• path length (total length: 768 mm);
• mean error, defined as the minimum distance between the ideal and the actual patient trajectory;
• jerk parameters \[ J = \sqrt{\frac{1}{2} \int_{t_{start}}^{t_{end}} \text{jerk}^2 (t) \text{d}t} \]
• mean force \[ F_{xy} = \frac{\sum_{i=1}^{5} \sqrt{F_{xi}^2 + F_{yi}^2}}{5} \]
• mean energy expenditure, representing the mean work carried out by the patient to executing the first five laps;
• active patient-robot interaction percentage, representing the percentage of elapsed time under the active modality.

# Haptic device for upper limb rehabilitation in stroke patients: a pilot study

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<tr>
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- **Mean speed**
- **Maximum speed**
- **Mean time**
- **Path length**

Haptic device for upper limb rehabilitation in stroke patients: a pilot study

Active patient-robot interaction percentage

Mean error

Normalized jerk

Mean force

Mean energy expenditure

Interemispheric competition

**Balanced cerebral emispheres** through callosum connections by *interemispheric mutual inhibition*

Cerebrovascular accident

Reduced inhibitory activity in the affected hemisphere due to:
- Lesion
- Abnormal transcallosum inhibition

(Schlaug et al., *Arch Neurol*. 2008)

**Large functional impact and correlation with motor recovery**

Explanation of increased excitability of non-affected hemisphere:
- Adaptation to lesion
- Determinant factor in pathophysiology of impairment

**New rehabilitation strategies**

Balance recovery
Combined robot-assisted wrist rehabilitation and transcranial Direct Current Stimulation (tDCS) in subacute stroke

**Study design:** RCT “sham controlled”

**Patients:** n=40 (age 18-79 yrs) stroke survivors with upper limb impairment (alfa<0.05; power=0.80)

**Treatment:** 5 sessions/week, 6 weeks

**Follow-up:** 6 months

**Study Group:** wrist robot + tDCS (anodal, 20 min, electrodes 35 cm², 2 mA, anodal electrode placed over the presumed hand area of lesioned hemisphere, and cathodal electrode above contralateral orbit)

**Control Group:** wrist robot + tDCS (sham)
**Inclusion criteria:** (i) persons affected by first supratentorial stroke, whose onset time is 25±7 days; (ii) upper limb hemiparesis; (iii) cognitive and speech abilities sufficient to understand instructions and to provide informed consent; (iv) absence of intense pain due to passive wrist mobilization assessed by VAS < 3 (range 0-10); (v) ability to provide written informed consent

**Exclusion criteria:** (i) previous epilepsy seizures, (ii) severe EEG abnormalities, (iii) previous neurosurgery interventions including metallic elements, (iv) anticonvulsant medications, (v) inability to keep sitting posture and (vi) other current severe medical problems

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<th>Subacute group (SG) (n=20)</th>
<th>p (two groups)</th>
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<td>11/9</td>
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Wrist robot-assisted rehabilitation and tDCS in subacute stroke patients

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<td>FM/se</td>
<td>20.40 ± 10.51</td>
<td>26.9 ± 9.39</td>
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<td>FM/ue</td>
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<td>&lt;0.001&lt;sup&gt;a&lt;/sup&gt;</td>
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<td>B&amp;B</td>
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<td>24.35 ± 16.37</td>
<td>0.002&lt;sup&gt;a&lt;/sup&gt;</td>
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<th>Post-Treatment</th>
<th>p</th>
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<td>6.74 ± 3.16</td>
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<td>&lt;0.001&lt;sup&gt;b&lt;/sup&gt;</td>
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<td>&lt;0.001&lt;sup&gt;a&lt;/sup&gt;</td>
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**Experimental Group (EG)**

**Control Group (CG)**

<sup>a</sup>: t-test, <sup>b</sup>: Mann-Whitney rank sum test

Wrist robot-assisted rehabilitation and tDCS in subacute stroke patients

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<td>EG (mean ± SD)</td>
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<td>3.65 ± 2.8</td>
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<tr>
<td>FM/se</td>
<td>21.37 ± 8.06</td>
<td>20.40 ± 10.51</td>
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<tr>
<td>FM/ue</td>
<td>34.11 ± 15.48</td>
<td>34.20 ± 18.35</td>
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<td>MAS/w</td>
<td>1.58 ± 2.34</td>
<td>1.1 ± 1.86</td>
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<tr>
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<td>B&amp;B</td>
<td>12.32 ±10.41</td>
<td>15.95 ± 12.10</td>
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</table>

\(a\): t-test, \(b\): Mann-Whitney rank sum test

Wrist robot-assisted rehabilitation and tDCS in subacute stroke patients

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<th>MI</th>
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<td>0.133</td>
<td>0.662*</td>
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</table>

Wrist robot-assisted rehabilitation and tDCS in subacute stroke patients

Wrist robot-assisted rehabilitation and tDCS in subacute stroke patients

Normalized jerk

![Graph a)](image1)

![Graph b)](image2)

![Graph c)](image3)

![Graph d)](image4)

Quantitative Index (QI)

![Graph a)](image5)

![Graph b)](image6)

![Graph c)](image7)

![Graph d)](image8)

Robot-assisted rehabilitation: novelty of results

- **Innovative assessment methods** based on (i) interaction forces (Mazzoleni et al., IEEE Trans Haptics 2013) and angular deviations from mean effort at the robot’s end-effector in chronic post-stroke patients (Mazzoleni et al., Applied Bionics and Biomechanics, 2011) and (ii) **kinematic parameters** in subacute post-stroke patients (Mazzoleni et al., Am J Phys Med Rehab 2013)

- Proof of **effectiveness of robot-assisted treatment** in chronic stroke patients (Posteraro et al., J Rehab Med 2009) using **proximal/distal approach** (Mazzoleni et al., Neurorehab 2013)
Motion tracking for quantitative and qualitative Assessment of Upper Limb Movements Following Acromioclavicular Joint Ligament Reconstruction: A pilot Study

Aim:
• to propose a quantitative and qualitative assessment of upper limb motor performance by means of a mechatronic device in patients who underwent a surgical procedure for ligament reconstruction following ACJ dislocation

Methods:
• Five patients (men, mean age: 40 ± 12 years, range: 20-51 years) with acute Rockwood type III and V ACJ dislocation
Motion Tracking for Quantitative and Qualitative Assessment of Upper Limb Movements Following Acromioclavicular Joint Ligament Reconstruction: A pilot Study

The ULTRA (Upper Limb TRAcker, Humanware Srl, Pisa, Italy) system, a passive end-effector mechatronic device was used in this study. It is an articulated mechanical structure formed by 7 rotoidal joints corresponding to 7 Degrees Of Freedom (DOFs) divided as follows: 2 DOFs in correspondence of the shoulder joint, 1 DOF in correspondence of the elbow joint and 4 DOFs in correspondence of the wrist joint.

Motion Tracking for Quantitative and Qualitative Assessment of Upper Limb Movements Following Acromioclavicular Joint Ligament Reconstruction: A pilot Study

Assessment:
• Constant-Murley Score (CMS)
• Final Mean Time (FMT)
• Mean Distance (MD)
• Speed Metric (SM)
• Final Mean Movement Deviation (FMMD)
• Number of Peaks in Speeds Profile (NSP)
• Normalized Reaching Speed (NRS)
• Normalized jerk

CMS: scale based on a 100-point scoring system that provides a global score based on weighted measures of physical impairments ROM and strength

The CMS is divided into four domains: pain (15 points), activities of daily living (20 points), strength (25 points) and range of motion (40 points): the higher the score, the higher the quality of the function

\[ MD = \frac{\sum_{k=1}^{y} |d_k|}{N} \]

\[ SM = \frac{v_{xy}}{v_{peak}} \]

\[ NRS = \frac{v_{y_{peak}}}{v_{y_{max}}} \]
Motion Tracking for Quantitative and Qualitative Assessment of Upper Limb Movements Following Acromioclavicular Joint Ligament Reconstruction: A pilot Study

Results

<table>
<thead>
<tr>
<th></th>
<th>IPA</th>
<th>AB</th>
<th>BC</th>
<th>CD</th>
<th>DE</th>
<th>EF</th>
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<td>NC</td>
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<tr>
<td>SM</td>
<td>NC</td>
<td>0.91</td>
<td>0.80</td>
<td>0.58</td>
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<tr>
<td>NRS</td>
<td>NC</td>
<td>0.35</td>
<td>0.93</td>
<td>0.71</td>
<td>0.69</td>
<td>0.80</td>
</tr>
<tr>
<td>Normalized Jerk</td>
<td>NC</td>
<td>0.37</td>
<td>0.36</td>
<td>0.89</td>
<td>0.06</td>
<td>0.49</td>
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Motion Tracking for Quantitative and Qualitative Assessment of Upper Limb Movements Following Acromioclavicular Joint Ligament Reconstruction: A pilot Study

Motion Tracking for Quantitative and Qualitative Assessment of Upper Limb Movements Following Acromioclavicular Joint Ligament Reconstruction: A pilot Study

Motion Tracking for Quantitative and Qualitative Assessment of Upper Limb Movements Following Acromioclavicular Joint Ligament Reconstruction: A pilot Study

Motion Tracking for Quantitative and Qualitative Assessment of Upper Limb Movements Following Acromioclavicular Joint Ligament Reconstruction: A pilot Study

Biomechanical model of the musculoskeletal systems

The **biomechanical model** is applied to musculoskeletal rehabilitation to study:

- Kinematics properties of the human joint system.
- Mechanical and biological factors affecting the human skeletal system.
- Muscle responses to the external forces and perturbations.
Biomechanical model of the musculoskeletal systems

- Develop a model of the upper limb with acromioclavicular joint ligaments to:
  - Estimate motion kinematics of the shoulder movement with different types of Rockwood acromioclavicular dislocation
  - Evaluate the recovery of the patient after acromioclavicular ligaments surgery
- Direct application of musculoskeletal models to rehabilitation
Upper limb biomechanical model

- The model was developed by using OpenSim platform from the dynamic model of upper limb
- The trapezius muscle was added to control the moving, rotating, and stabilizing the scapula
- The acromioclavicular joint ligaments are modelled
The body landmarks to be recorded:
- Torso: acromion, clavicular, C7.
- Right upper arm: bicep front, elbow lateral, elbow medial.
- Right lower arm: wrist lateral, wrist medial and hand.

The subject performed a “hand to mouth” movement five times with a self-paced velocity.

The movements were recorded by a motion capture system (SMART-DT, BTS Bioengineering Corp., Milano, Italy).
Hand-to-mouth movement
Trajectories of DOFs angles during a representative trial
Contribution of muscles to elbow moment (BIClong: biceps brachii long head, BICshort: biceps brachii short head, BRD: brachioradialis)
Outline of the presentation

• BioRobotics and Bionics convergence
• Rehabilitation and Assistive Robotics
  • Upper limb robot-assisted therapy
  • Gait robot-assisted therapy
  • Precision orthopaedic surgery - Precision orthopaedic rehab
  • RISE robotic wheelchair
• Sports biomechanics
• Lessons, new scenarios and challenges
Robotic devices for robot-assisted lower limb rehabilitation: a quick evolution

**Timeline:**
- 1999: Volketswil, Switzerland, LokomatPro
- 2000: Auxerre, France, HERCULE
- 2003: Rex Bionics founded
- 2006: FDA approval is pending
- 2007: LokomatPro certified 2006
- 2008: AlterG
- 2010: Riga, Latvia, AGAINER SYSTEM
- 2010: Ankara, Turkey, ROBOGAIT
- 2010: Ottawa, Canada, PROWLER
- 2011: Moscow, Russia, EXOATLET
- 2013: Seoul, South Korea, PROWLER
- 2013: Toronto, Canada, ARKE
- 2014: Ottawa – Canada, MODO
- 2016: FDA certified

**Companies:**
- Rex Bionics
- AGAINER
- AXO Suits
- DSME
- ReWalk
- AlterG
- Bionik Laboratories
- ExoBionics
- Ekso
- Honda

**Events:**
- 1999: FDA approval is pending
- 2003: Rex Bionics founded
- 2006: LokomatPro certified
- 2007: AlterG
- 2010: Againer System, Robogait
- 2013: PROWLER
- 2014: EXOATLET
- 2016: FDA certified

**Countries:**
- Switzerland
- Latvia
- Turkey
- Canada
- Russia
- South Korea
- Canada

**Notes:**
- FDA approval expected in 2017
- CE Mark certified 2006
- FDA certified June 2014
- Observed in 2016

**Institutions:**
- Sant’Anna Institute of Technological Robotics
- Hocoma
Robot-assisted gait rehabilitation for Spinal Cord Injured (SCI) patients

Robot-assisted treadmill gait training

Robot-assisted overground gait training

FES-cycling

FES during walking
Robot-assisted rehabilitation for SCI patients: FES-cycling

Background

The loss of mobility following spinal cord injury (SCI) negatively affects the health status of life of patients. In addition other physical complications, such as muscular atrophy, muscular spasticity, reduction of cardio-respiratory capacity and pain, often occur as well.

The improvement of bone, muscular and joint trophism and the reduction of spastic hypertone represent relevant aims to be achieved during SCI rehabilitation.

The Functional Electrical Stimulation (FES) causes an electrically driven contraction, that differs from a physiological contraction in terms of action potential and in terms of number and type of recruited motor units, which progresses from large to small. (reference FES)

The benefits of FES were demonstrated since the 80s: improvements obtained in cardiovascular and respiratory functions (R. Martin et al. 2012), body composition, muscle mass, bone mass and quality of life.

Aim

to use FES to activate pedaling on cycle-ergometer and analyse the effects of this technique for a rehabilitation training in SCI persons


Robot-assisted rehabilitation for SCI patients: FES-cycling approach

Methods

Five subjects complete and incomplete spinal cord injured (SCI) subjects (mean age 43.0±11.8, four men and one woman) 20 sessions three times per week.

Clinical assessment

was carried out before starting the treatment (T0), at mid-treatment (T1), after 10 sessions, and at the end of the treatment (T2).

• ASIA,
• SCIM,
• Modified Ashworth Scale (MAS)
• 4-point Spasms Scale evaluati
• thigh circumference at 5 (A), 10 (B) and 15 (C) cm from the knee cap upper limit.
Robot-assisted rehabilitation for SCI patients: FES-cycling approach

Results: thigh circumference

Robot-assisted rehabilitation for SCI patients: preliminary results of FES-cycling approach and a novel Effectiveness Index proposal

Aims:
• to propose and validate a novel effectiveness index (EI) based on the mechanical power recorded during the FES-cycling training;
• to analyse the energy expenditure (EE) during the entire rehabilitation period in a group of complete SCI patients by using the power recorded during the rehabilitation session by using only the FES-cycling system.

Methods:
• 24 chronic complete SCI patients (20 men, mean age: 39.42 ± 11.26 , range: 22-66, n=14 ASIA A, n=10 ASIA B)
• N=20 sessions of FES-cycling training
• 8 healthy subjects for comparison purposes

Inclusion criteria
• age ≥ 18;
• motor complete spinal cord injury, both traumatic and not-traumatic.

Exclusions criteria
• severe joint limitations that prevent the use of FES-cycling;
• total denervation that prevents the use of FES-cycling.

Unpublished data
Robot-assisted rehabilitation for SCI patients: preliminary results of FES-cycling approach and a novel Effectiveness Index proposal

Assessment outcome measures:

- American Spinal Injury Association scale (ASIA)
- Spinal Cord Independence Measure Scale (SCIM)
- Penn Spasms Frequency Scale (PSFS)
- Modified Ashworth Scale (MAS)
- Numerical Rating Scale (NRS)
- Power generated
- Energy expenditure
- Efficiency Index

\[ EI(\%) = \left( \frac{P_{max}}{P_{final}} \right) \times 100 \]

20 FES-cycling training sessions
Robot-assisted rehabilitation for SCI patients: preliminary results of FES-cycling approach and a novel Effectiveness Index proposal

FES-cycling parameters:

(i) stimulation frequency $f=50$ Hz,
(ii) square biphasic alternated wave,
(iii) duration of pulse (pulse width) of 500 $\mu$s,
(iv) duty cycle (e.g., the ratio of the time when the stimulation wave is active and the time when it is inactive) of 50%.

The current amplitude represents the delivered stimulation intensity (FES-cycling range amplitude: 0-140 mA).

The target speed is the objective speed set by the therapist (range: 10-70 rpm) and it represents the speed to be reached during the session. In this study the target speed was set at 35 rpm.

The resistance level represents the resistance opposed by the FES-cycling motor. In this study this value was constant and equal to 5.00 Nm.
Robot-assisted rehabilitation for SCI patients: preliminary results of FES-cycling approach and a novel Effectiveness Index proposal

Data interpolation was performed using custom routines implemented under the Matlab environment (The MathWorks Inc., Natick, USA). Three different interpolation functions and different orders (n) were tested:

(i) polynomial (3 ≤ n ≤ 7),
(ii) sum of sine (3 ≤ n ≤ 5)
(iii) exponential functions as sum function of two terms.

Unpublished data
Robot-assisted rehabilitation for SCI patients: preliminary results of FES-cycling approach and a novel Effectiveness Index proposal

Results

\[ EI(\%) = \left( \frac{P_{\text{max}} - P_{\text{final}}}{P_{\text{max}}} \right) \times 100 \]
Robot-assisted rehabilitation for SCI patients: preliminary results of FES-cycling approach and a novel Effectiveness Index proposal

Results

Maximum Power

Final Power

Unpublished data
The aim of this study is to evaluate the effects of robot-assisted locomotor training on muscular recruitment in patients with gait disorders.

**Patients enrollment:**
- 7 subjects (5 M, 2 F, mean age 53.7±14.7, range 23-67)
- 3 SCI patients
- 4 Multiple Sclerosis (MS) patients
- 5 control subjects (4 M, 1 F, mean age 35.8 ± 17.6, range 18-57)

**EMG recording**
- rectus femoris (RF) and biceps femoris (BF) of both legs
- two treadmill speeds ($v_1 = 1.0$ km/h, $v_2 = 2.0$ km/h)
- two robot-interaction modalities (passive and active)

**EMG Data Analysis**
- Rectification
- Signal processing
- Signal filtering
- Signal normalization
- Integration
Robot-assisted treadmill gait rehabilitation for SCI patients: Surface EMG measurements and analysis

DGO active, $v_1$

DGO active, $v_2$

blue, patients pre-treatment; red, patients post-treatment; green: healthy subjects

<table>
<thead>
<tr>
<th></th>
<th>$v_1$ Stance</th>
<th>$v_1$ Swing</th>
<th>$v_2$ Stance</th>
<th>$v_2$ Swing</th>
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<tbody>
<tr>
<td>RF</td>
<td>55.55</td>
<td>58.49</td>
<td>71.51</td>
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<tr>
<td>BF</td>
<td>25.39</td>
<td>41.12</td>
<td>13.63</td>
<td>16.43</td>
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</table>

Robot-assisted overground gait rehabilitation for SCI patients: subjective experience

Aim
• to investigate the acceptability of overground robot-assisted walking and its effects on pain and spasticity

Methods
• 21 Spinal Cord Injury (SCI) patients (17 men, 4 women; mean age: 48.10±1.23)
• Single session using powered robotic exoskeleton (Ekso GT, Ekso Bionics, USA)

Assessment measures
• Pain and muscle spasticity assessed using Numerical Rating Scale (NRS-pain and NRS-spasticity). Muscle spasticity was also evaluated using Modified Ashworth Scale (MAS) and Penn Spasm Frequency Scale (PSFS)
• Positive and negative sensations were investigated using an apposite questionnaire
• PSFS, NRS-pain and NRS-spasticity scores were analysed using repeated measures ANOVA

Robot-assisted overground gait rehabilitation for SCI patients: subjective experience

Robot-assisted gait rehabilitation for SCI patients: driven gait orthosis vs overground powered exoskeleton

Hypothesis:
Is there any difference in terms of MET and VO₂ consumption between driven gait orthosis and overground exoskeleton training?

Methods:
• 8 SCI subjects, mean age: 45.38 ±15.26, mean time from pathology onset: 60.88 ± 103.41 months;
• Patients underwent a robot-assisted gait exercise using two different robotic systems: an overground robotic exoskeleton (Ekso GT, Ekso Bionics, USA) (modality 1) and a driven gait orthosis (Lokomat, Hocoma, Switzerland) (modality 2).
• Measurements were recorded during a single rehabilitation session
• A questionnaire (6 items, score ranging from 0 to 10) aims to investigate the subjective perception during the two robot-assisted gait exercises
Robot-assisted gait rehabilitation for SCI patients: driven gait orthosis vs overground powered exoskeleton

**Questionnaire**
- Fatigue (F)
- Muscle relaxation (R)
- Mental effort (Ef)
- Fear or Discomfort (D)
- Satisfaction (S)
- Emotion (E)

S. Mazzoleni, E. Battini, M. Dini, S. Corbianco, A. Gerini, G. Stampacchia. “Physical and cognitive effort during robotic exoskeleton assisted walking on treadmill and overground in SCI persons”, 17th National Congress of Italian Society of Movement Analysis in Clinical setting, 5-8 Ottobre 2016, Milano, Italy.
Outline of the presentation

• BioRobotics and Bionics convergence
• Rehabilitation and Assistive Robotics
  • Upper limb robot-assisted therapy
  • Gait robot-assisted therapy
  • **Precision orthopaedic surgery - Precision orthopaedic rehab**
  • RISE robotic wheelchair
• Sports biomechanics
• Lessons, new scenarios and challenges
A new research line: Precision Orthopaedic Surgery and Precision Orthopaedic Rehabilitation

- Clinical evaluation
- Multimodal sensor data acquisition (e.g., imaging) & processing
- Biomechanical model

Pre-operative planning → Surgical treatment → Intra-operative assessment

Post-operative assessment

Optimal Functional Recovery

Precision Orthopaedic Surgery – Precision Orthopaedic Rehabilitation (POS-POR)

REHABILITATION
- Home Rehabilitation
- Assessment & Planning
- Hospital Rehabilitation

Planning
From surgical intervention to rehabilitation

Musculoskeletal model

- $\Theta$: x-axis rotation
- $\Phi$: y-axis rotation
- $\psi$: z-axis rotation

$F_T = \sum_{i=1}^{N} F_i$: Reaction forces to external perturbations

Patient-robot dynamic interaction

Inpatient robot-assisted rehabilitation

Robot Force/Impedance control

Marker #1

Marker #2

Intramedullary nail

Post-operative check

$q, \dot{q}, \ddot{q}, F$

$M, K_d, K_p$

$F_q, \dot{F_q}, \ddot{F_q}$
Outline of the presentation

• BioRobotics and Bionics convergence

• Rehabilitation and Assistive Robotics
  • Upper limb robot-assisted therapy
  • Gait robot-assisted therapy
  • Precision orthopaedic surgery - Precision orthopaedic rehab
  • RISE robotic wheelchair

• Sports biomechanics

• Lessons, new scenarios and challenges
Robotic system for verticalisation and mobility of severely impaired persons (2013-2019)

Robotic wheelchair RISE

Innovative features:
• improved frontal access
• automatic verticalisation
• gluteal-perineal mechanical design for easy toilet access
• mobility (upright and sitting posture)

Clinical validation (end: July 2019) at CRM INAIL Volterra (n=10 persons affected by low-thoracic Spinal Cord Injury)

Patent: “Dispositivo robotico per la verticalizzazione e la mobilità di persone con gravi disabilità” (priority n. 102016000050120)
Mechanical design

Starting position

T stand-up = 30 sec

System for feet adjustable

3 interfacce regolabili:
- Thigh interface
- Frontal interface
- Tibial support

Actuator A (1350 N)
Actuator B (2450 N)

Thigh interface
Frontal interface
Tibial support

lumbar support
Control design

User standard interface

Wired connection

Main board
BeagleBone Black

Controllo sollevamento
Attuatori lineari LINAK

Driver for motor

Motors

User innovative interface

Wireless connection
Innovative powered wheelchair: Robotic Innovation for Standing and Enabling

1/1/2013 Start

Phase I: Analysis of the state of the art

Phase II: Design of the device

Phase III: Rehabilitation

Phase IV: Technical validation, Certification for electromagnetic compatibility and electrical safety

Phase V: Clinical validation

16/5/2016 Patent application (priority number: 102016000050120)

31/12/2018 End

Commercialization (2019/2020)

Anthropometric user characteristics

Weight, min-max. (kg): 52-110
Height, min-max. (cm): 160-200

Device dimensions

Total length (cm): 101
Total width (cm): 70
Total depth (cm): 56

Technical specifications

Maximum speed (km/h): 5
Turning radius (°): 360
Temperature exercise (min-max) (°C): -20 - 40
Driving wheel: 2x, d = 320 mm
Forward caster wheel: 2x, d = 100 mm
Backside caster wheel: 2x, d = 120 mm

Electric system

Lifters motors (W): 4x 55.20
Mobile base motors (W): 2x 350

Batteries: 2x 12 V, 40 Ah, LiFePO₄
Outline of the presentation

• BioRobotics and Bionics convergence
• Rehabilitation and Assistive Robotics
  • Upper limb robot-assisted therapy
  • Gait robot-assisted therapy
  • Precision orthopaedic surgery - Precision orthopaedic rehab
  • RISE robotic wheelchair
• Sports biomechanics
• Lessons, new scenarios and challenges
Sports bioengineering and performance biomechanics

Ventilatory response to exercise of elite soccer players

N=90 professional soccer players from Italian Major League (serie A)

Procedures:
• Lung functions test
• Electrocardiography
• Exercise test
• Gas measurement

4 groups based on role:
• Forwards (F)
• Central midfielders (CM)
• Central defenders (CD)
• Wide players (WP)

Quantitative assessment of professional boxers performances

Ankle injuries prevention in parachutists (Brigata “Folgore”)
**Ventilatory response to exercise of elite soccer players**

**Aim:** To evaluate the role of ventilatory parameters in maximal exercise performance in elite soccer players

**Methods**
- N=90 professional soccer players from Italian Major League (serie A)
- 4 groups based on role:
  - Forwards (F)
  - Central midfielders (CM)
  - Central defenders (CD)
  - Wide players (WP)
- Period: September-December 2009-2012

**Procedures:**
- Lung functions test
- Electrocardiography
- Exercise test
- Gas measurement

**Results**
- MEV median = 18.65 km/h
- VE$_{peak}$ median = 153.06 L/min
- VE$_{peak}$ = 41.76 + (21.88*VO$_{2peak}$) r=0.619; p<0.001

---

Published online 2014
Ankle injuries prevention in parachutists (Brigata Paracadusti “Folgore”)

Ground Force Reaction during a jump

PLF tests were conducted indoor. The experimental setup involved collection of ground reaction forces, lower extremity kinematics data using a force platform system.
Foot and Ankle Anatomy

It is made up of:
- 28 bones (26 for the foot and 2 for the leg (Fibula and Tibia))
- 33 ligaments
- 12 muscles

and 4 joints:
- Subtalar (Talocalcaneal)
- Tibiotalar (Talocrural, ankle mortise)
- Tibiofibular (Inferior)
- Tranverse-Tarsal (Talocalcaneonavicular)

Brockett et al., ScienceDirect 2016
Sequence of pressure plots over the entire stance phase of walking
Equipment

4 IMU sensors
- RL = right leg
- LL = left leg
- RF = right foot
- LF = left foot

1 insole with FSR sensors
- FF = forefoot
- MF = midfoot
- RF = rearfoot

Equipment images:
- Shimmer IMU sensors
- Tekscan insole with FSR sensors

Leg and foot labels:
- RL = right leg
- LL = left leg
- RF = right foot
- LF = left foot
- FF = forefoot
- MF = midfoot
- RF = rearfoot
3 videocameras

H1 = 0,51 m
H2 = 0,71 m
H3 = 1,04 m
lp = landing point

F = Frontal view
L = Lateral view
P = Posterior view
Jump dynamics analysis
Angular speed (Dps = °/s) XYZ – H3
Range of motion – H3
Range of motion– H3

Possible slipping on the insole
Landing Performance Index (LPI):

Single jump (sj):

\[ LPI_{sj\_vel} = \frac{v_i}{\bar{v}} \]

\[ LPI_{sj\_dps} = \frac{X_i}{\bar{X}} + \frac{Y_i}{\bar{Y}} + \frac{Z_i}{\bar{Z}} \]

\[ LPI_{sj\_BWR} = \frac{BWR_{i\_(fore)}}{BWR_{\_max\_(fore)}} + \frac{BWR_{i\_(mid)}}{BWR_{\_max\_(mid)}} + \frac{BWR_{i\_(rear)}}{BWR_{\_max\_(rear)}} \]

Mean of jumps (m):

\[ LPI_{m\_vel} = \frac{\bar{v}}{v_{\_max}} \]

\[ LPI_{m\_dps} = \frac{\bar{X}}{X_{\_max}} + \frac{\bar{Y}}{Y_{\_max}} + \frac{\bar{Z}}{Z_{\_max}} \]

\[ LPI_{m\_BWR} = \frac{BWR_{\_max\_(fore)}}{BWR_{\_max\_(fore)}} + \frac{BWR_{\_max\_(mid)}}{BWR_{\_max\_(mid)}} + \frac{BWR_{\_max\_(rear)}}{BWR_{\_max\_(rear)}} \]
Subject #5 (20 years – 84 kg – 173 cm) correct jump – H3
Subject #1 (26 years – 100 kg – 176 cm), 1) Flat landing – H2
Subject # 4 (20 years – 72 kg – 175 cm), 2) Squat landing– H3
Subject # 7 (19 years– 75 kg – 173 cm), 3) Forward step landing– H1
Subject # 9 (24 years – 74 kg – 175 cm), 4) Push upward landing – H3
Sports bioengineering and performance biomechanics

Salvatore Cimmino, 54 yrs
Ponza-Ventotene 27 miles - 17 hrs swimming
Start: 11:00 pm Sept 18 2018, arrival: 3:00 pm Sept 19 2018
Ongoing research projects and collaborations

(2018-2020) **VERSUS - Virtual-Reality Enhanced Rehabilitation for Sustainable and Usable Services**, funded by Regione Toscana, within the framework POR-FESR 2014-2020, Bando n.2: progetti strategici di ricerca e sviluppo delle MPMI (budget: 211,229.00 €) - *Ranked 1st among 220+ research proposals in MEDTECH domain*

(2018-2020) **ARCONTE - Piattaforma multidisciplinare web-based integrata per la gestione delle procedure perioperatorie e delle pratiche medico chirurgiche**, funded by Regione Toscana, within the framework POR-FESR 2014-2020, Bando n.2: progetti strategici di ricerca e sviluppo delle MPMI (budget: 200,000.00 €)


(2017-2019) **ROBOVIR - Sviluppo e validazione di una piattaforma robotica per la riabilitazione motoria e il coordinamento visuomotorio degli arti superiori con scenari di realtà virtuale relativi ad attività di vita quotidiana**, funded by INAIL (Italian Workers Compensation Authority) (budget: 226,000.00 €), PI: Stefano Mazzoleni, Partners: Istituto Superiore Sanità, Politecnico di Bari, ASL Toscana Nord-Ovest

ROBOVIR - Sviluppo e validazione di una piattaforma robotica per la riabilitazione motoria e il coordinamento visuomotorio degli arti superiori con scenari di realtà virtuale relativi ad attività di vita quotidiana

ROBOVIR

Start: 29/06/2017  
Duration: 30 months  
End: 29/12/2019

Coordinator:
The BioRobotics Institute, Scuola Superiore Sant’Anna

Partner:
Istituto Superiore di Sanità
Politecnico di Bari
Azienda USL Toscana Nord Ovest

The project is funded by INAIL:
• Budget TOT di Partenariato: 384.000,00€
• Contributo concesso al partenariato: 226.000,00€
ROBOVIR - Sviluppo e validazione di una piattaforma robotica per la riabilitazione motoria e il coordinamento visuomotorio degli arti superiori con scenari di realtà virtuale relativi ad attività di vita quotidiana

Methods

The robotic platform consists of:
- end-effector characterized by 7 DoFs
- different sensors to analyse:
  - upper limb biomechanics
  - visuomotor coordination
  - role of tactile sensory

The robotic platform will be integrated with:
- virtual reality (VR) rehabilitation scenarios including ADLs
- adaptive control system

https://www.franka.de/panda
ROBOVIR - Sviluppo e validazione di una piattaforma robotica per la riabilitazione motoria e il coordinamento visuomotorio degli arti superiori con scenari di realtà virtuale relativi ad attività di vita quotidiana

Technical validation in progress
**ARCONTE** - Piattaforma multidisciplinare web-based integrata per la gestione delle procedure perioperatorie e delle pratiche medico chirurgiche

- **Start:** 15/03/2018
- **End:** 14/09/2019
- **Duration:** 18 months

**Coordinator:**
R.C.J. Soft S.r.l.

**Partner:**
MEHRIT S.r.l.
The BioRobotics Institute, Scuola Superiore Sant’Anna
Università degli Studi di Firenze
VICS S.r.l.

The project is **funded** by **Regione Toscana**:
- Total budget: 1.209.048,74€
- Funding: 604.524,38€

**Phase 1:**
Rehabilitation at hospital by means of ARCONTE platform

**INTERNET**

**INFORMATION**

**INTERVENTION**
VERSUS - Virtual-Reality Enhanced Rehabilitation for Sustainable and Usable Services

VERSUS

Start: 02/10/2017
End: 14/09/2019
Duration: 23 months

Coordinator:
SIGNO MOTUS S.r.l.

Partner:
VRMEDIA S.r.l.
MOV’IT S.r.l.
HORENTEK S.r.l.
DIELECTRIK S.r.l.
The BioRobotics Institute,
Scuola Superiore Sant’Anna
BTR
CPA WEB SOLUTIONS

The project is funded by Regione Toscana:
Budget TOT di Partenariato: 1.786.282,00€
Contributo concesso al partenariato: 893.141,00€

At hospital rehabilitation: subacute phase
At hospital rehabilitation: chronic phase
Outline of the presentation

• BioRobotics and Bionics convergence
• Rehabilitation and Assistive Robotics
  • Upper limb robot-assisted therapy
  • Gait robot-assisted therapy
  • Precision orthopaedic surgery - Precision orthopaedic rehab
  • RISE robotic wheelchair
• Sports biomechanics
• Lessons, new scenarios and challenges
Robotics and Bionics for improving quality of life of persons with disabilities
Integration and combination of technologies for improving functional outcome
Ethical issues and challenges

• A new alliance among researchers, stakeholders and institutions is needed to govern social, economic, cultural and anthropological changes associated to scientific and technological innovations in the field of biomedical applications (including micro- and nanosystems):
  • Personalised medicine
  • Regenerative medicine
  • Biomaterials
  • Nanomedicine
  • Gene editing

• Relevant ethical issues in biomedical technology:
  • Protecting human subjects in clinical trials
  • Affordability
  • Privacy and protection of personal data
  • Stem cells research
  • Bioterrorism
Open issues

- **Personalised rehabilitation** (duration, intensity, patient-robot interaction) and assistance
- **Precision rehabilitation** (kinematic/biomechanical metrics)
- **Integration among different technologies** (robotics, tDCS, FES,...)
- **Continuity of care** (from hospitalisation to home-based programmes) and patient empowerment
- **Combined design approach** (clinical and engineering): motions and emotions
- **Need of patients stratification** (severity, lesion site and volume, gender, age,...)
- **Education in PM&R** (Master programmes, PhD programmes, specialisation schools, master, professional education courses,...)
- **Privacy and protection of personal data** (data transmission)
Some conclusions...

- Technologies for rehabilitation, assistance and sports biomechanics (robots, wearable sensors): **movement quantitative and qualitative assessment** (kinematics, EMG, forces/pressures – upper limb/gait/posture)

- **Wearable sensors** as safe, valid and reliable tool for **non invasive functional assessment** of movements and activities of daily living

- Implementation of **viable healthcare services/solutions** (organisational, economic, clinical)

- **Integrated technologies for e-health services**: to cure by increasing appropriateness and patients safety, but even accessibility, equity and diagnosis/cure procedures speed
Bioengineering Rehabilitation Laboratory
The BioRobotics Institute, Scuola Superiore Sant’Anna

Stefano Mazzoleni, PhD, Assistant Professor

Vi Do Tran, PhD in Biorobotics

Elena Battini, Research Assistant
Thanks for your attention!