ELECTROMYOGRAPHY-BASED DIAGNOSTICS AND THERAPY OF CLINICALLY WEAK PATIENTS

Michał Mikulski

Promotor: dr hab. inż. Jarosław Śmieja

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CONTENTS

1 Introduction .......................................................................................................................... 3
   1.1 Motivation...................................................................................................................... 3
   1.2 Theses .......................................................................................................................... 4
   1.3 Outline ......................................................................................................................... 4
2 Basic terms and methods .................................................................................................... 4
   2.1 Manual Muscle testing (MMT) .................................................................................. 4
   2.2 Device assistive testing ............................................................................................. 5
   2.3 Neuroplasticity .......................................................................................................... 6
3 Proposed solution .............................................................................................................. 8
   3.1 Luna EMG Neurorehabilitation robot ....................................................................... 8
   3.2 Patient extensions ....................................................................................................... 9
   3.3 Stella.BIO neuromuscular exerciser ........................................................................ 12
4 Clinical evaluation ............................................................................................................ 13
   4.1 C4 spinal cord injury patient ..................................................................................... 13
   4.2 T11 spinal cord injury patient .................................................................................... 15
5 Other patients .................................................................................................................. 17
6 Conclusions ....................................................................................................................... 18
   6.1 Patents and patent applications ............................................................................... 23
   6.2 Published articles ..................................................................................................... 23
   6.3 Selected awards ......................................................................................................... 24
   6.4 Experience in leading R&D projects ....................................................................... 26
1 INTRODUCTION

1.1 MOTIVATION

The European Commission has revealed that 22% of European Union citizens suffer from long-term problems with muscles, bones or joints [1], with a set of neuromuscular issues to blame. The largest one is stroke, affecting 17 million people worldwide [2]. It is a leading cause of adult physical disability [3] [4], that is expected to grow by 34% annually [5]. Problems related to neurological issues have long-lasting effects, as 63% of survivors live with disability [6], and up to 59% of stroke patients in the UK report unmet clinical needs [7], mostly due to time pressures and clinical staff unavailability [8]. They get as low as 22 minutes per day of exercise therapy on weekdays [9], may experience no therapy on half of the days in the hospital [10] and about half of patients are not treated within the first 3 months [11]. Furthermore, 5% of adults in out-patient clinical setting experience a diagnostic error that corresponds to 10% of the total patient morbidity rate and 17% of treatment complications. [12].

The most common reason for the deficits in healthcare services is the lack of staff. It is predicted that there will be a shortage of up to 150 000 dentists, pharmacists and physiotherapists in the EU [13] and 41 000 physiotherapists in the USA [14] by 2020, resulting in an unmet healthcare demand of up to 13.5%.

The main problems this dissertation aims to tackle are presented in Fig. 1.1.

Fig 1.1 Identified problems within neurorehabilitation
1.2 Theses

This dissertation aims to validate two clinical and two technical theses, formulated as follows:

1. Surface electromyography (sEMG)-based devices may improve the objectivity of early innervation and muscular strength evaluations in comparison to standard manual scales.
2. Robotized EMG triggered exercises and EMG biofeedback exercises can be used for physiotherapy of clinically weak patients.
3. A single motor rehabilitation device with exchangeable extensions can be used for electromyography-based and force-controlled kinesiotherapy of most major joints.
4. Electromyography biofeedback devices can be successfully used for therapy of various neuromuscular disorders.

1.3 Outline

This dissertation describes in detail the intricacies of the nervous and muscular systems and its pathophysiology leading to clinical weakness in specific neuromuscular disorders, including stroke, spinal cord injuries, neurodegenerative, demyelinating and myodegenerative diseases. Analysis of existing manual diagnostic methodologies has been performed, with regard to muscular strength and innervation evaluation. Neuroplasticity and its diagnosis using electromyography is described as well. Afterwards, two novel electromyography-based devices are presented – Luna EMG neurorehabilitation robot and Stella.BIO neuromuscular exerciser, aimed at facilitation neuroplasticity to enhance nerve regeneration and muscle strengthening. Finally, the devices are evaluated clinically with four selected patients. Additionally, the dissertation contains description of using the devices by patients with other pathological conditions.

2 Basic Terms and Methods

2.1 Manual Muscle Testing (MMT)

Muscle strength evaluation is a key part of the medical diagnosis process, used to evaluate the central and peripheral nervous systems as well as muscles themselves. As any diagnostic test, it allows us to measure the current state of the patient’s health as well as track the effects of therapy or deterioration of a specific function (e.g. in neurodegenerative diseases). This dissertation evaluates manual testing scales commonly used for muscle strength and innervation.
evaluation are discussed. Results of using them for evaluation of tested patients is compared to data-driven device-based tests, using electromyography, dynamometric testing and robotic therapies.

The following standard tests have been evaluated and compared to the device assistive testing described in the subsequent section:

- Medical Research Council (MRC) Scale [15]
- Modified MRC Scale [16]
- Lovett’s Scale [17] [18]
- International Standards for Neurological Classification of Spinal Cord Injury [19]
- ASIA Impairment Scale (AIS) [19]
- Frankel Scale for spinal cord injury [20]
- Kendall Scale [21]

2.2 DEVICE ASSISTIVE TESTING

Apart from manual testing, a number of proposed device-assisted methodologies were used in clinical evaluation of muscle strength and innervation, especially:

- **Electromyography** (surface and intramuscular) – used to measure the activity of the whole muscle (multiple motor unit potential trains), usually with bipolar electrodes or the combination of thereof. The main parameters measured with sEMG (Fig. 2.1) are the time-force relationship, kinesiological, neurophysiological and psychophysiological properties of surface muscles and interfacing with external devices [22].

- **Dynamometric testing** – devices used for testing force and torque of patients, especially using **isokinetic exercises** - an exercise using dynamically changing resistance to facilitate constant speed of the exercise – eventually leading to maximal torque measurements in a specified joint [23],

While dynamometric testing is proven [23] to be more objective, it often is not suitable for severely weak muscles (especially during nerve regeneration and muscle reinnervation [24]), where movement with resistance cannot be performed [16]. Manual Muscle Testing, however, has its limitations when it comes to reliability and precision [25] [26] [27] [28]. During the course of this work, multiple MDs, physiotherapists and occupational therapists came forward with the limitations of patient assessment methods and the need for more objective ways to evaluate patient’s current health and progression, whether neurodegeneration or recovery.
Neuroplasticity comprises the adaptive (including maladaptive) changes within spared neuronal circuitries and thus reflects the reorganization of the nervous system after it has been injured [29], but plasticity occurs during the entire life span of an individual [30, 31]. Both the central and peripheral nervous systems are able to undergo neuroplasticity after an injury, however damaged axons within the CNS cannot regenerate to a significant extent (e.g. after a spinal cord injury), while the peripheral nervous system axons have superior abilities to regenerate, debated towards variations in myelin generation in both subsystems [32].

The available literature was analysed and evaluated for key characteristics needed to facilitate neuroplasticity and stimulate axonal recovery and sprouting, especially in acute central nervous system or peripheral nervous system damage. This dissertation focuses only on physical training and exercise part of neuroplasticity facilitation. Based on clinical data, a number of key properties of physical training activity necessary to evoke a pattern of muscle activation (similar to that found in individuals without injury of the nervous system ) should be taken into account to facilitate neuroplasticity, including [29]:

2.3 NEUROPLASTICITY
• **Training duration** - recovery rate is enhanced for patients after stroke with longer training times [33].

• **High intensity** - Greater intensity of leg rehabilitation improves functional recovery and health-related functional status, whereas greater intensity of arm rehabilitation results in improvements in dexterity [34, 35, 36].

• **Focus** – Improvement in functional recovery and dexterity depends on the focus on a specific function [33]. Patients that focus on specific limb and function – e.g. gait therapy with legs or arm dexterity - perform better in those tasks and build up those functionalities. On the other hand, it has been documented that facilitating movement in non-affected limbs may yield improvement in other affected limbs, e.g. arm movements contribute to bipedal gait, locomotor ability might be improved by involvement of the upper limbs in training [37, 38, 39, 40, 41].

• **Movement velocity** – clinical data suggests that Central Nervous System (CNS) recovery yields better results when the movement speed is adjusted dynamically during training to the patient’s maximal capacity, and reduced, if limitations occur [42].

• **Load receptor and proprioceptive input** – neuroplasticity and specific functional patterns are strengthened with corresponding load receptor input for affected limbs [43, 37], including proprioceptive inputs, mechanoreceptors and afferent joint related inputs, for example, during gait rehabilitation with leg extensor inputs, mechanoreceptors in the sole in locomotor EMG patterns [44, 45] are stimulated. This is specifically important with comparison of passive and active-assistive and active training methodologies with the patient. Active exercises stimulate proprioceptive and load receptors and therefore facilitate neuroplasticity.

• **Asymmetric exercises** – patients can benefit from asymmetric exercises, where limbs are treated with varied levels of speed, strength and intensity, depending on the severity of damage for each side, e.g. using split-belt treadmills [46].

• **Functional training** – with task-centric orientation of the brain, functional training directed towards task specific training yields good results for recovery of motor function and enhances neuroplasticity, data is based on animal studies [47, 48, 49, 50, 51] and has successfully been translated into humans,

• **Augmented feedback** [52, 53] and Virtual reality [54, 55].

While there are many parameters listed that affect neuroplasticity and can contribute to improvement of motor function, active participation of the patient contributes to significantly higher activation of the sensorimotor network during active than during passive motor control.
which led to the development of electromyography-based devices proposed, as the solution in this dissertation.

3 PROPOSED SOLUTION

Based on the identified problems, two electromyography-based devices have been proposed: Luna EMG neurorehabilitation robot and Stella.BIO neuromuscular exerciser.

3.1 LUNA EMG NEUROREHABILITATION ROBOT

Luna EMG is a rehabilitation robot specifically designed to support physiotherapy and occupational therapy of neurological patients suffering from clinical weakness (Fig. 3.2). It is intended as an all-in-one platform for complex diagnostics and personalized therapy for patients suffering from nerve or muscle damage. Luna EMG was specifically developed as an all-in-one solution to tackle the key problems regarding objective diagnosis, effective therapy for clinically weak patients and physiotherapy automation.

Fig 3.1 Luna EMG neurorehabilitation robot during an elbow flexion/extension exercises
3.2 PATIENT EXTENSIONS

To minimize the cost expenditure of individual clinics, Luna EMG was designed to allow the treatment of all most of the major joints and movements through a system of exchangeable patient extensions. This way all internal electronics, mechanical parts and drives remain in place, and only the extensions responsible for patient treatment change. Joints, whose movements are supported by the device are shown in Table 3.1:

<table>
<thead>
<tr>
<th>Joint \ Movement</th>
<th>Flexion/Extension</th>
<th>Abduction/Adduction</th>
<th>Rotation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shoulder</td>
<td>☒</td>
<td>☒</td>
<td>☒</td>
</tr>
<tr>
<td>Elbow</td>
<td>☒</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Wrist</td>
<td>☒</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hip</td>
<td>☒</td>
<td>☒</td>
<td></td>
</tr>
<tr>
<td>Knee</td>
<td>☒</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ankle</td>
<td>☒</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Tab 3.1 Available joint movements with Luna EMG extensions

Luna EMG has two sets of extensions:

- **Physiotherapy extensions** – 4 pcs - allowing the physiotherapy of large joints through isolated and functional movements, that can act as kinematically equivalent connections in isolated exercises for specific joints (e.g. for isolated elbow flexion / extension exercise, the upper limb universal extension acts as kinematically equivalent) to facilitate focused and asymmetrical neuroplasticity, as well as end point based (e.g. the steering wheel extensions for the closed loop of the upper kinematic chain or the universal lower limb extension for the single arm press) and the occupational therapy extensions, all designed to facilitate neuroplasticity through functional therapy,

- **Occupational therapy extensions** – 9pcs - dedicated to functional occupational therapy of the hand, including wrist deviation, wrist flexion, finger flexion and functional movements.

Examples of exercises supported by Luna EMG and its physiotherapy and occupational therapy extensions are presented in Figs. 3.2-3.15.
Fig 3.2 Luna EMG during shoulder flexion/extension exercise with the lower limb universal extension

Fig 3.3 Luna EMG during shoulder internal / external rotation exercise with the upper limb universal extension

Fig 3.4 Luna EMG during knee flexion / extension exercise – sitting with the lower limb universal extension

Fig 3.5 Luna EMG during knee flexion / extension exercise – prone lying with the lower limb universal extension

Fig 3.6 Luna EMG during hip flexion / extension exercise with the lower limb universal extension

Fig 3.7 Luna EMG during knee abduction / adduction exercise – side lying with the lower limb universal extension
Fig 3.8 Luna EMG during steering wheel – closed kinematic loop exercise with the steering wheel extension

Fig 3.9 Luna EMG during pouring water from a cup exercise with the steering wheel extension

Fig 3.10 Luna EMG during lateral bending exercise with the steering wheel extension

Fig 3.11 Luna EMG during elbow pronation/supination exercise with the elbow pronation/supination extension

Fig 3.12 Luna EMG during single arm row exercise with the lower limb universal extension

Fig 3.13 Luna EMG during single arm press exercise with the lower limb universal extension
3.3 **Stella.BIO Neuromuscular Exerciser**

*Stella.BIO* is an electromyography biofeedback device, a neuromuscular exerciser dedicated for home therapy to be used by the patient alone (business to customer – B2C – product). Stella.BIOs sole purpose is to scale up the amount of exercise done by clinically weak patients, allowing for telerehabilitation and remote supervision from the clinical staff, but without the need to be physically present in the clinic.
4 CLINICAL EVALUATION

To evaluate the validity of the proposed theses, four clinical case reports have been reported in the dissertation, two of which are summarized in the sections that follow. They involve of patients with clinical weakness resulting from acute spinal cord injuries and nerve damage. Furthermore, patients from other target groups of clinically weak patients were tested for being able to work with electromyography-based exercises, including EMG triggered and EMG biofeedback exercises.

4.1 C4 SPINAL CORD INJURY PATIENT

The following videos are available for this chapter

<table>
<thead>
<tr>
<th>Video 4.1</th>
<th>Biceps brachii muscular strength assessment of a C4 spinal cord injury patient</th>
</tr>
</thead>
<tbody>
<tr>
<td>Video 4.2</td>
<td>C4 spinal cord injury patient training on Luna EMG with EMG Trigger and Hold Exercises, triggered from his biceps brachii muscle</td>
</tr>
</tbody>
</table>

The case reports documents a man in his twenties, previously admitted to an in-patient occupational therapy spinal unit within the National Health Service (NHS) after a motorcycle accident resulting in a C4 spinal cord damage was presented for evaluation on a Luna EMG neurorehabilitation robot. The patient presented symptoms of clinical weakness in his upper and lower limbs as well as the abdomen and pelvic floor and was fitted with a wheelchair, catheter and was during an ongoing occupational therapy to facilitate recovery, mostly targeted at the upper limbs due to more muscular activity.

Initially, the patient’s peripheral nervous system and muscular strength were assessed manually, in the selected muscles of his upper limbs using an Medical Research Council MRC Scale presented in Table 4.2. No other scales or methods of evaluation of muscular strength or innervation through the peripheral or central nervous system have been used.

<table>
<thead>
<tr>
<th>Muscle</th>
<th>MRC Scale Left arm</th>
<th>MRC Scale Right arm</th>
</tr>
</thead>
<tbody>
<tr>
<td>Deltoid</td>
<td>1 / 2</td>
<td>4-</td>
</tr>
<tr>
<td>Biceps brachii</td>
<td>0 / 1</td>
<td>4-</td>
</tr>
<tr>
<td>Triceps brachii</td>
<td>0</td>
<td>4-</td>
</tr>
<tr>
<td>Brachioradialis</td>
<td>0</td>
<td>4-</td>
</tr>
<tr>
<td>Supinator</td>
<td>0</td>
<td>4-</td>
</tr>
<tr>
<td>Pronator teres</td>
<td>0</td>
<td>4-</td>
</tr>
</tbody>
</table>

Once in the clinic, the patient was diagnosed for innervation using surface electromyography (sEMG) with a Luna EMG robot in simplified conditions not unrelated to the
Medical Research Council Scale (MRC Scale) suggestions in [15] The specific muscles being evaluated were: Deltoid, Biceps brachii, Triceps brachii, Pronator teres. All muscles tested using surface electromyography presented distinct signs of muscle contraction (motor unit depolarisation detected through sEMG). Therefore the manual evaluation using MRC Scale for all sEMG tested muscles that resulted in “0 – No contraction” is a misdiagnosis as a result. In the biceps brachii the result of MRC scale was deemed inconclusive by the therapy staff. In that case the sEMG provided an objective way for evaluating innervation and existing muscle contraction. The trace of the whole innervation evaluation done on Luna EMG rehabilitation robot is presented in Table 4.3.

<table>
<thead>
<tr>
<th>Muscle</th>
<th>Minimal voluntary contraction</th>
<th>Maximal voluntary contraction</th>
<th>Muscle tone</th>
<th>SNR ratio above muscle tone</th>
</tr>
</thead>
<tbody>
<tr>
<td>Deltoid</td>
<td>2.18 µV</td>
<td>92.42 µV</td>
<td>3.03 ± 0.75 µV</td>
<td>Yes</td>
</tr>
<tr>
<td>Biceps brachii</td>
<td>0.72 µV</td>
<td>140.21 µV</td>
<td>1.64 ± 2.29 µV</td>
<td>Yes</td>
</tr>
<tr>
<td>Triceps brachii</td>
<td>0.56 µV</td>
<td>19.48 µV</td>
<td>0.79 ± 0.31 µV</td>
<td>Yes</td>
</tr>
<tr>
<td>Pronator teres</td>
<td>0.63 µV</td>
<td>18.51 µV</td>
<td>1.00 ± 0.29 µV</td>
<td>Yes</td>
</tr>
</tbody>
</table>

Tab 4.3 sEMG parameters of a C4 spinal cord injury patient

![Fig 4.1 Surface electromyography trace during innervation evaluation of a C4 spinal cord injury patient](image)

After diagnosis, the patient was treated using electromyography triggered exercises, further proving innervation, voluntary muscle contraction and good coordination. After more than 200 repetitions of active-assistive exercises for the damaged upper limb, a cross-correlation was
evaluated for muscular compensation due to upper motor neuron damage, which shown distinct signs of biceps brachii – triceps brachii cross-correlation and compensation (Fig. 4.2).

Fig 4.2 Normalised muscle compensation cross-correlation during calibration

4.2 T11 SPINAL CORD INJURY PATIENT

The following videos are available for this chapter

Video 4.3. Innervation diagnosis and EMG Triggered exercises with a T11 spinal cord injury patient on Luna EMG
https://www.youtube.com/watch?v=5J2MUtVBxOw

The case report documents woman in her twenties diagnosed with a complete T11 spinal cord injury. She was treated at an out-patient physiotherapy spinal unit in a private clinic in the
UK, among others on an Ekso Bionics Ekso GT exoskeleton. Until the point of evaluation, no electromyography based innervation studies have been performed. No contraction of the lower limb muscles could be visually or palpably confirmed. No manual peripheral nervous system evaluations have been performed or reported by the physiotherapists. The diagnosis of a complete spinal cord injury at T11 was based on an MRI imaging within the NHS. The patient did not respond to touch in her lower limbs, but reported an occasional tingling sensation.

Manual muscle assessment using MRC scale was conducted, confirming the same manual diagnosis as previously done in the clinical setting.

<table>
<thead>
<tr>
<th>Muscle</th>
<th>Left leg</th>
<th>Right leg</th>
</tr>
</thead>
<tbody>
<tr>
<td>Quadriceps femoris: Rectus femoris, Vastus lateralis, Vastus intermedius, Vastus medialis</td>
<td>0</td>
<td>None</td>
</tr>
<tr>
<td>Hamstring: Biceps femoris Semimembranosus Semitendinosus</td>
<td>0</td>
<td>None</td>
</tr>
<tr>
<td>Adductors: Adductor longus Adductor magnus Gracilis</td>
<td>0</td>
<td>Tingling</td>
</tr>
<tr>
<td>Calf: Gastrocnemius</td>
<td>0</td>
<td>None</td>
</tr>
<tr>
<td>Shin: Tibialis anterior</td>
<td>0</td>
<td>None</td>
</tr>
</tbody>
</table>

Tab 4.5 Lovett Scale manual peripheral nervous system evaluation of a T11 spinal cord injury patient’s lower limbs – selected muscles

With no evidence of contractility in all lower limb muscles, a surface electromyography evaluation was performed, using a Luna EMG neurorehabilitation robot (Table 4.5).

<table>
<thead>
<tr>
<th>Muscle</th>
<th>Side</th>
<th>Minimal voluntary contraction</th>
<th>Maximal voluntary contraction</th>
<th>Muscle tone</th>
<th>SNR ratio above muscle tone</th>
</tr>
</thead>
<tbody>
<tr>
<td>Quadriceps femoris: Rectus femoris</td>
<td>Left</td>
<td>0.50 µV</td>
<td>15.87 µV</td>
<td>0.76 ± 0.19 µV</td>
<td>Yes</td>
</tr>
<tr>
<td>Adductors: Adductor longus Adductor magnus Gracilis</td>
<td>Left</td>
<td>0.40 µV</td>
<td>11.08 µV</td>
<td>0.61 ± 0.11 µV</td>
<td>Yes</td>
</tr>
<tr>
<td>Calf: Gastrocnemius</td>
<td>Left</td>
<td>0.53 µV</td>
<td>28.66 * µV</td>
<td>0.92 ± 0.28 µV</td>
<td>Inconclusive – likely artefacts</td>
</tr>
</tbody>
</table>
Shin:
Tibialis anterior

<table>
<thead>
<tr>
<th></th>
<th>Left</th>
<th>0.56 µV</th>
<th>11.22 * µV</th>
<th>0.97 ± 0.34 µV</th>
<th>Inconclusive – likely artefacts</th>
</tr>
</thead>
</table>

Tab 4.6 sEMG parameters of a T11 spinal cord injury patient

T11 spinal cord injury patient - left leg
Full training trace

Fig 4.3 T11 spinal cord injury patient – Full EMG evaluation trace

The patient not only was able to perform voluntary muscle contraction in 3 muscles previously diagnosed with no innervation, but was also able to perform active-assistive exercises with EMG trigger algorithms on Luna EMG.

5 OTHER PATIENTS

The following patients experiencing clinical weakness were tested to evaluate the validity of using electromyography-based diagnosis and therapy, apart from the case reports:

- Stroke,
- Spinal cord injuries,
- Post-surgical recovery
- Spinal muscular atrophy,
- Duchenne’s muscular dystrophy,
- Brachial palsy,
- Urinary incontinence.
6 CONCLUSIONS

The goal of the research presented this dissertation was to make a difference and propose new ways to solve major problems within rehabilitation medicine, physiotherapy, occupational therapy and neurology alike, that could bear real, quantifiable benefits to global healthcare and overcome the associated economic difficulties.

Two main issues this research was facing were:

- Difficulty in facilitating neuroplasticity and strengthening in severely clinically weak patients with no visible indications of muscle contractility,
- Finding implementable ways to significantly increase the supply of physiotherapy services due to shortage of medical staff in physiotherapy and occupational therapy.

Based on the research presented in this dissertation, two novel devices were proposed: Luna EMG neurorehabilitation robot and Stella.BIO neuromuscular exerciser. They were used to successfully validate four proposed theses stated in chapter 1.3 of the dissertation.

The problem of inconsistent grading systems, especially regarding manual evaluation of muscular strength and peripheral innervation has been described in detail in chapter 3.5 of the dissertation. In Chapters 5.2-5.6, four clinical case reports of misdiagnosed patients are presented. The diagnostic error in each case took place, due to the limitations regarding manual muscle testing. The patients have been re-evaluated using surface electromyography with Luna EMG and different treatment protocols were started, aimed at facilitating neuroplasticity, which were previously neglected due to misdiagnosis.

This device-based and data-centric approach to physical and neurological evaluation of clinically weak patients proves the proposed thesis 1 that surface electromyography-based devices can improve the objectivity of early innervation and muscular strength evaluations in comparison to standard manual scales.

Secondly, with the corrected diagnosis for the patients, described in chapters 5.2-5.6 of the dissertation, and with multiple other clinically weak patients presented in chapter 5.7, Luna EMG and Stella.BIO devices developed during this research were used for physiotherapy, which proves the proposed thesis 2 that robotized EMG triggered exercises and EMG biofeedback exercises, can be used for physiotherapy of clinically weak patients.
During the research leading to this dissertation, a wide range of needs regarding physiotherapy was observed, leading to the conclusion, that specific isolated and functional strengthening exercises that could benefit from automation. Taking into account the financial constraints in healthcare, Luna EMG was equipped with exchangeable extensions, detailed in chapter 4.2 of the dissertation. They were extensively tested on most of the major joints and documented in chapters 4.2.5-4.2.7. The vast majority of those extensions can be used with electromyography-based training and all of them can be used with force-controlled training, as described in case studies in chapter 5. That proves the proposed thesis 3: A single motor rehabilitation device with exchangeable extensions can be used for electromyography-based and force-controlled kinesiotherapy of most major joints.

Apart from the selected and documented case reports, this dissertation offers a wide set of other patients that were treated using electromyography-based techniques in chapter 5.7 of the dissertation, including electromyography biofeedback for clinical weakness and incontinence, which proves the proposed thesis 4: that Electromyography biofeedback devices can be successfully used for therapy of various neuromuscular disorders.

While this dissertation and the research behind it proves the clinical validity of electromyography-based devices, the transformation of physiotherapy healthcare services still remains ahead. The patient cases presented in this dissertation is but a fraction of the dozens misdiagnosis cases that were encountered between 2014 and 2017 in hospitals and clinics alike in the EU, Middle-East and Asia during the presented research and device development, where insufficient quantifiable, objective device-based methods of patient evaluation are used on a daily basis.

**BIBLIOGRAPHY**


PERSONAL ACHIEVEMENTS OF THE AUTHOR

6.1 PATENTS AND PATENT APPLICATIONS

- **Zgłoszenie patentowe europejskie EP14707215.1 z dn. 16.01.2014 „Rehabilitation device”**. Autor 100%. Zgłoszenie patentowe wdrożone w przemyśle – EGZOTech Sp. z o.o.
- **Zgłoszenie patentowe światowe PCT/IB2014/058339 z dn. 16.01.2014: „Rehabilitation device”**. Autor 100%. Zgłoszenie patentowe wdrożone w przemyśle – EGZOTech Sp. z o.o.
- **Zgłoszenie patentowe polskie P.406866 z dn. 16.01.2014: „Urządzenie do rehabilitacji”**. Autor 100%. Zgłoszenie patentowe wdrożone w przemyśle – EGZOTech Sp. z o.o.
- **Zgłoszenie patentowe polskie P.402465 z dn. 17.01.2013: „Urządzenie do rehabilitacji”**. Autor 100%. Zgłoszenie patentowe wdrożone w przemyśle – EGZOTech Sp. z o.o.
- **Patent polski nr 22365 z dn.16.02.2016 wg. wniosku P.391510 z dn. 15.06.2010: „Stanowisko do diagnostyki, monitorowania i leczenia zmian nowotworowych skóry kończyn, oraz sposób sterowania stanowiskiem”, wraz z: Ewą Piętką, Dominikiem Spińczykiem, Stanisławem Franielem. Autor 25%.

6.2 PUBLISHED ARTICLES

**BOOK CHAPTERS LISTED IN WEB OF SCIENCE**


CONFERENCE PROCEEDINGS LISTED IN WEB OF SCIENCE


6.3 SELECTED AWARDS


2015: Zwycięstwo w ogólnopolskim konkursie Think Big UPC Business dla firm o globalnych ambicjach organizowanym przez magazyn UPC Biznes.
2015: #6 miejsce w rankingu najbardziej kreatywnych w biznesie w 2014 organizowanym przez magazyn BRIEF.

2014: Laureat w kategorii innowacje medyczne w konkursie Soczewki Focusa z projektem pn. „egzoszkielekt do rehabilitacji”, organizowanym przez magazyn Focus.

2014: Nominacja do Nagrody Polskiej Rady Biznesu im. Jana Wejcherta w kategorii Wizja i Innowacja z ramienia Polskiej Agencji Rozwoju Przedsiębiorczości i Prezesa PARP.

2014: TOP3 startupów z Polski w Innov-a-thon Dubai, konkursie na najlepszy startup w Polsce, kwalifikacje krajowe do inkubatora i360accelerator w programie cześć Jarek Turn8, Dubai UAE.

2013: Zwycięstwo w ogólnopolskim konkursie do Blackbox Summer Connect Silicon Valley Immersion Program, organizowanym przez Google for Entrepreneurs i Blackbox.vc z EGZOTech Sp. z o.o., jako TOP8 startup na świecie i TOP1 w Polsce.

2013: Zwycięstwo w ogólnopolskim konkursie „Do IT with Poland na 5 najlepszych startupów technologicznych w Polsce za EGZOTech Sp. z o.o., organizowanym przez Google for Entrepreneurs Kraków, Konsulat USA w Krakowie, Polish American Chamber of Commerce, oraz 4th Wave Consulting.

2013: I miejsce w uczelnianym konkursie Mój Pomysł na Biznes za przedsiębiorstwo EGZOTech, organizowanym przez Politechnikę Śląską.

2012: Nagroda I stopnia w ogólnopolskim konkursie na najlepszą pracę dyplomową o profilu mechanicznym Prezesa SIMP, nagroda II stopnia Prezesa Urzędu Dozoru Technicznego i Puchar Minister Nauki i Szkolnictwa Wyższego, z okazji XII edycji konkursu Prezesa Stowarzyszenia Inżynierów i Techników Mechaników Polskich.

2012: Wyróżnienie w ogólnopolskim konkursie Polski Produkt Przyszłości w kategorii wyrób przyszłości w fazie przedwdrożeniowej, organizowanym przez Polską Agencję Rozwoju Przedsiębiorczości.


2012: Brązowy medal na XV Moskiewskim Salonie Wynalazków i Innowacyjnych Technologii Archimedes 2012 w Moskwie.

2012: **Złoty medal** w konkursie Friendly Competition z okazji tygodnia inżynierii, organizowanym przez Fluor S.A.

2011: **Nagroda w konkursie Brussels Eureka** na Światowych Targach Wynalazczości, Badań Naukowych i Nowych Technik BRUSSELS INNOVA, Bruksela.

2011: **Złoty medal dla Młodych Wynalazców** na Światowych Targach Wynalazczości, Badań Naukowych i Nowych Technik BRUSSELS INNOVA, Bruksela.


2011: **Główna nagroda** w II edycji ogólnopolskiego konkursu Akademicki Mistrz Innowacyjności organizowanego przez Polską Agencję Rozwoju Przedsiębiorczości.

2011: **Laureat VII edycji ogólnopolskiego programu Ventures**, organizowanego przez Fundację na rzecz Nauki Polskiej, z projektem **Rehabilitacyjnego Egzoszkieletu Kóźczyn Dolnych**.

2010: Zwycięstwo w ogólnopolskim konkursie stypendialnym TME Transfer Multisort Elektronik sp. z o.o. dla najlepszego projektu pracy magisterskiej, za „Prototyp biomedycznego ramienia robotycznego sterowanego elektromiogramem”.

2005: **Wyróżnienie w konkursie na projekt multimedialny** w kategorii „strona internetowa”, organizowanym przez Instytut Fizyki, Uniwersytetu Śląskiego w Katowicach z okazji Roku Fizyki.

### 6.4 EXPERIENCE IN LEADING R&D PROJECTS

POIR.01.01.01-00-2077/15 – „Opracowanie innowacyjnych metod automatycznej diagnostyki i rehabilitacji z wykorzystaniem robotów i pomiarów bioelektrycznych” – **autor wniosku, kierownik projektu**. Dofinansowany w wysokości 8 770 878,62 PLN przez Narodowe Centrum Badań i Rozwoju.

POIG.03.01.00-00-012/08-18 – „Inicjowanie działalności innowacyjnej w ramach Jagiellońskiego Parku i Inkubatora Technologii” – **beneficjent, kierownik subprojektu** w projekcie „EGZOTech”. Dofinansowany w wysokości 838 814,00 PLN przez JCI Venture Sp. z o.o., rozliczony.

VENTURES/2011-7/8 – „Rehabilitacyjny egzoszkielet kończyn dolnych” – **autor wniosku, kierownik projektu**. Dofinansowany w wysokości 171 500,00 PLN przez Fundację na Rzecz Nauki Polskiej, rozliczony.