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GAIT FACILITATION PROGRAM USING A HORIZONTAL BICYCLE BUILT AND DESIGNED TO MONITOR KINETIC CHAIN PARAMETERS – CASE STUDY

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Abstract

Introduction Pedaling therapy is defined as a plan of physical activity prescribed to facilitate rehabilitation from immobilizing diseases and any conditions that disrupt the movement and activity of daily life or maintain well-being through neuro-reeducation, gait training, and therapeutic activities.

Material and method. It was addressed in a case study of a 40 years female patient who presented with a physiotherapy indication for gait rehabilitation from the specialist physician after immobilization in plasterboard for four weeks, the post-fracture status of the lateral malleolus of the left lower limb fibula. A personalized cycling program was applied for five weeks, period March-April 2022 using a pedaling system designed and built with plantar pressure sensors attached to the pedals to monitor outputs. There was performed gait analysis, joint and muscular testing using goniometry, Borg Cycling Scale for the perception of effort and rehabilitation zone correlations, and Visual Analog Scale (VAS) for pain. The patient's risk chart is based on the bioimpedance parameters for determining the body composition using Zepp Analyzer. Heart rate reserve, as well as heart rate training, was calculated according to Karvonen's formula supervised with Smartwatch Huawei Watch GT 2 during the cycling rehabilitation program. The sensor signals attached to the pedals are converted to analog values for both feet and the force in Newton is measured according to the values transmitted.

Results and Conclusions Rehabilitation treatment consisted of applying to the therapeutic program according to the rehabilitation phases for 5 weeks maintaining a perceptual level of 4/10 Borg (maintaining the resistance zone 2) with progressive intensity from level 3 to 5. After the rehabilitation program, average analog values between the two members were 219/240 - left / right respectively 0.89 / 0.98 N showing an insignificant force difference of 0.09 N in absolute value. The final evaluation of the joint balance by goniometry enhances exceeding the values of the functional-coefficient. Muscle balance registered an optimal value of 5/5 for the left foot. The pulse corresponding to the target range not exceeded 130. The kinetic chain deficit has improved, the muscle testing indicating a range of motion of 53 degrees in the ankle left joint versus 11 degrees after immobilization. Remission of edema after phase I (first week) proved an anti-inflammatory effect. Left foot support on the ground became possible without pain (VAS = 0). The application of the proposed pedaling program using the built horizontal device led to the achievement of the objectives regarding the facilitation of the ambulance, the system is reliable and technically functional.

Keywords: Pedaling therapy, rehabilitation phases, analog values, plantar pressure sensors, gait analysis, goniometry, Borg Cycling Scale.

Introduction

Pedaling therapy is defined as a plan of physical activity prescribed to facilitate rehabilitation from immobilizing diseases and any conditions that disrupt the movement and activity of daily life or maintain well-being through neuro-reeducation, gait training, and therapeutic activities. It is planned systemic execution including movements, postures, or activities designed to allow patients to improve neuro-motor function, reduce the risk of associated comorbidities, remedy or prevent deficiencies, and optimize overall health and well-being. Cycling is classified as a low-impact activity. (Kisner et al., 2018)

During the normal walking cycle, the ankle goes through a 32° to 35° range of motion. Approximately 7 ° dorsiflexion occurs at the end of the middle as the heel

begins to rise and 25° plantar flexion occurs at the end of the position (toe). (Kisner et al., 2018; Olneyat et al., 2011)

A range of motion ranging from 20° plantar flexion to 10° dorsiflexion is required for normal walking above the surface. It is necessary to perform a 20° dorsiflexion to go down the stairs. Dorsiflexion of the ankle while pedaling can be adjusted by approaching or moving away from the pedal body. A lower vertical seat height requires more dorsiflexion. (Kisner et al., 2018; Magee, 2014; Perry, 2010)

Gait is cyclic and is characterized by the synchronization of the foot contact with the ground, having two basic components: the support phase - the duration of the foot contact with the ground and the balance phase - the period in which the foot is in the air for advancement. The support (stance) phase has four sub-phases: initial contact, load response, middle support, terminal support, and pre-balance. The balance (swing) phase has three functional sub-phases: the initial balance, the middle balance, and the terminal balance. (Braddom, 2015)

The paper aims to certify the pedaling program type choice and the efficacy of using a horizontal bicycle built and designed to monitor kinetic chain parameters.

Material and method.

The benefits of using an improved physical therapy system that involves pedaling are multiple. It involves the safe use of the device, normalization of cardiac parameters, maintaining the viability of myo-arthro-kinetic structures, shortening rehabilitation time, motivating for independent mobilization, improving cognitive function and survival rates, and preventing and reducing physical weakness and physical impairment. (Shibata, 2010; Nickels et al., 2017; Kho, 2015; Kho, 2016; Fossat et al., 2018) The design of the horizontal bicycle took into account the reliability of the device, inter-pedal distance - optimally expressed by self-selected Q factor, patient position, mode of action, and force distribution in the controlled kinetic chain. Q factor in cycling is directly correlated with the width of the step during walking. Self-selected Q factor has the potential to reduce the risk of knee injury and provide increased efficiency while pedaling. (Thorsen, 2018; Paquette et al., 2014; Disley et al., 2014; Disley et al., 2014) Pressure sensors can be used to determine kinetic, biomechanical, and postural alignment chain imbalances, to determine the

effectiveness of orthoses, the risk of pressure injury in diabetes, and for postoperative recovery. Plantar pressure is measured using sensors attached to the pedals. The sensor signals are converted to analog values for both feet. The FSR (Force Sensing Resistor) is connected to a 10Kohm resistor and the sensor is read on analog pins 0 and 1 for each leg. The approximate force in Newton is then measured according to the values transmitted by FSR.

A 40-year-old patient, with no known pathological history, presented with a physiotherapy indication from the specialist after immobilization in plasterboard for four weeks, the post-fracture status of the lateral malleolus of the left lower limb fibula. Informed consent and ethics approval (no. 32/20.10.2021) has been provided from the own practice cabinet. The fracture was classified as closed, fracture without displacement, with a spiroid path, at the level of the healthy bone, with no reduction needed. The cause was trauma from falling from a height of one meter. It was recommended Aspenter for 45 days (one tablet daily) for the antiplatelet effect, preventing thrombus formation due to immobilization. Diagnosis based on the clinic (edema, bruising, pain, impaired function) and para clinic evidence (radiography) were closed fracture, without displacement, with a spiroid path, at the level of the healthy bone as Fig. 1 shows.

Fig. 1 Left lower limb radiography - distal third anteroposterior view

The main objectives established for physiotherapy were to reduce pain, increase the normal and functional range of motion, improve muscle strength, reduce stiffness

of the muscles, tendons, and fascia improve performance in daily activities and improve circulation, respiratory capacity, and coordination, and the most important goal, gait facilitation.

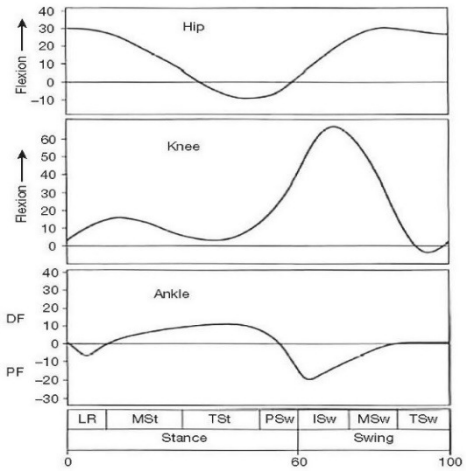
Results and discussions

Patient functional examination after plasterboard removal revealed the following deficiencies: decreased range of motion in the ankle joint, joint play and muscle flexibility, muscular hypotrophy (left leg circumference 32 cm vs. 34 cm right), weakness and decreased endurance. The pain was felt during passive and passive-active movement, with a score of VAS = 5. Ecchymosis in the distal third lateral of the tibia due to the plaster cast and per articular edema determined left ankle joint stiffness. Foot support on algae-limited soil was VAS = 9. Preserved circulation and warm skin were noticed.

The gait was unstable, with short steps, over short distances with pain felt along the kinetic chain in the degrees established after the gait analysis (Tab. 1 and Fig. 2)

Table 1 Gait analysis (Cifu, 2021 adaptation real values of the patient)

Joint angles (degrees)	Left	Right	Normal
HIP - ROM	31	33	36
Hip maximum (flexion)	30	31	33
Hip minimum (extension)	-1	-2	-3
Knee - ROM	51	53	55
Knee maximum (flexion)	54	56	58
Knee minumum	3	3	3
Ankle - ROM	11	22.5	24
Ankle maximum (dorsiflexion)	8	14	14.5
Ankle minimum (plantar flexion)	-3	-8.5	-9.5



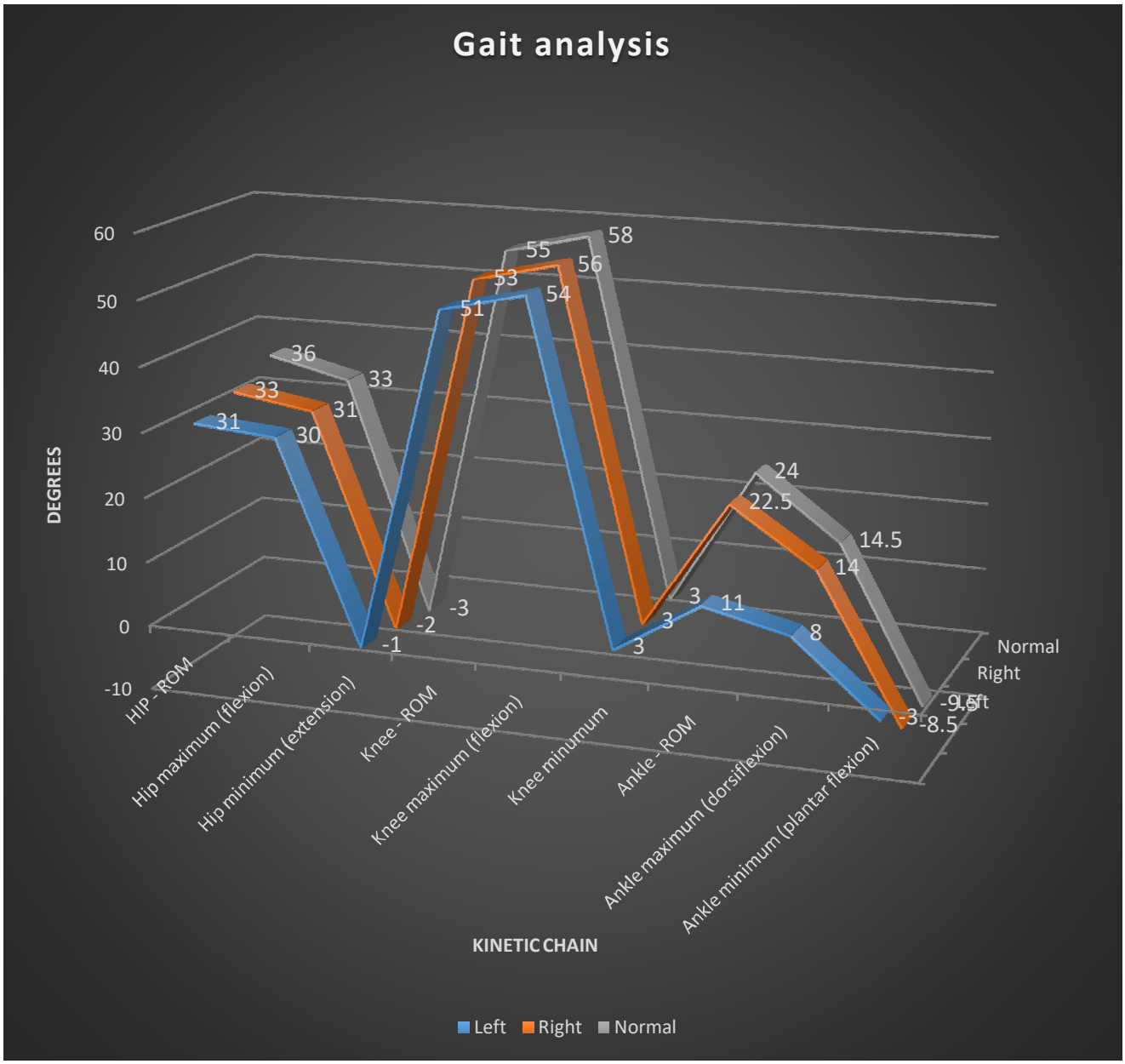


Figure 2 Gait Analysis

The patient movement diagram for the left ankle is presented according to Table 3 and Figure 4.

Table 3 Movement diagram for left ankle

Left ankle	**Plantar flexion**	**Inversion**	**Dorsiflexion**	**Eversion**
Normal maximum	50	35	20	20
Intial goniometry of the patient	**3**	**2**	**8**	**2**
Functional coefficient for gait	20	5	15	5
Functional coefficient for stairs	25	7	20	7

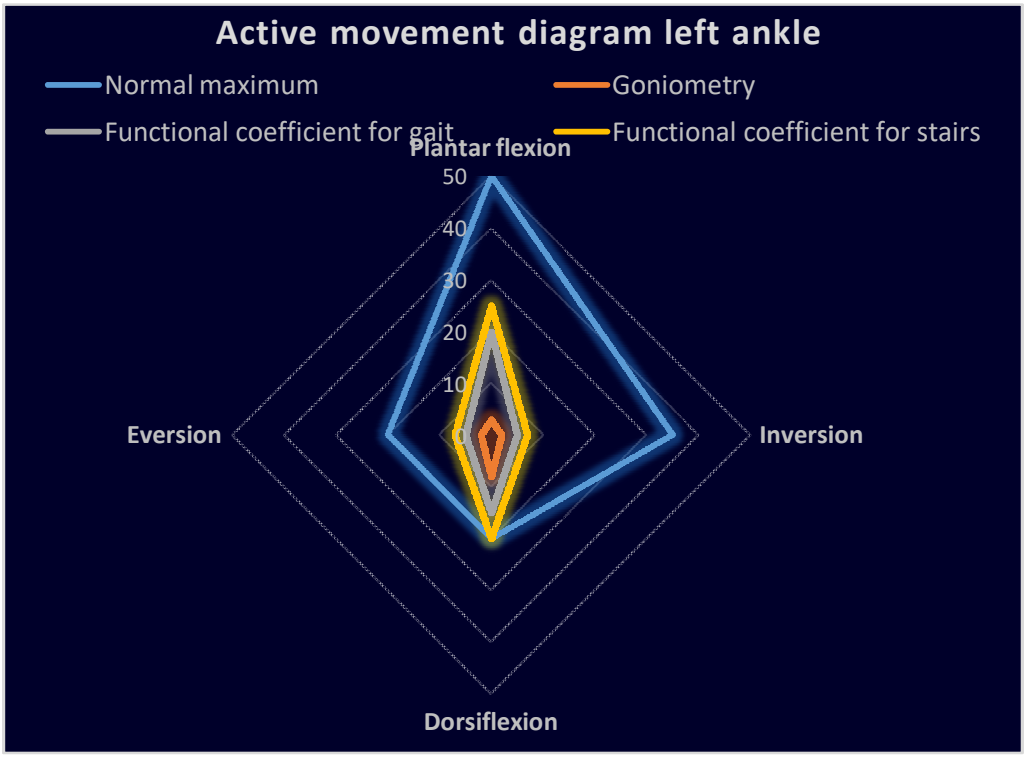


Figure 4 Active movement diagram left ankle

Muscular testing Left leg flexor muscle strength is **4**-/5 MRC (Medical Research Council) and left leg extensors are **5**-/5 MRC due to post-immobilization muscle hypotrophy.

The patient's risk chart was established based on the bioimpedance parameters (Murgoci, 2021) for determining the body composition SM / FM / FFM (skeletal muscle, adipose tissue, and non-adipose tissue), determined by Zepp Analyzer adjusted with the patient's height square. BMI = 20.61 - normal; FMI = 6.26 intermediate to normal (Hattori et al., 1997); SMI = 7.49 normal (Cruz-Jentoft et al., 2019); FFMI = 13.55 slender (athletic / slim / thin), so the **proposed pedaling rehabilitation program** can be applied, total time 35 minutes including warm-up, cool-down, pauses and intensity changes for adherence treatment.(Fig. 5).

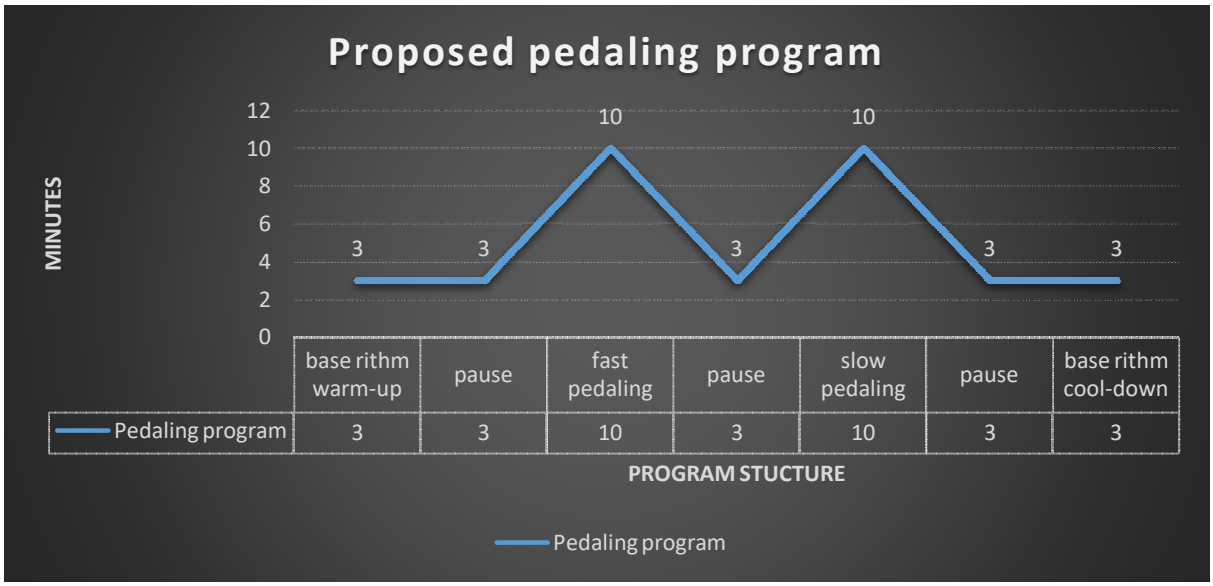


Figure 5 Proposed pedaling rehabilitation program

Applying the Borg scale (Scherr et al., 2013; Borg, 1982) **the perception of effort** was level **4** to establish the basic rhythm that corresponded to the intensity level 3/5, the conditioning being aerobic.

Table 4 Borg Analysis

Borg Analysis	RPE subjective	Objective power	Rehabilitation Zone [21]
hard	7	4	threshold
slightly hard	6	3	tempo
moderate all-day	5	2	endurance
moderate all-day	4	2	endurance
easy	3	2	endurance
realy easy	2	1	active rehabilitation
e-bike	1	1	active rehabilitation

Rehabilitation treatment consisted of applying for the therapeutic program according to the rehabilitation phases for 5 weeks maintaining a perceptual level of 4/10 Borg with progressive intensity from 3 to 5. Phase I of anti-inflammatory rehabilitation, intensity 3, lasted one week followed by Phase II of early regeneration - 2 weeks, intensity 4 and Phase III - maturation and remodeling and removal of excess fibrotic tissue - 2 weeks of pedaling, intensity 5.

The lactate threshold was maintained to target heart rate in the range (of 108-168), the intensity of 40-60% to maintain aerobic effort.

The maximum heart rate was calculated as follows: 220 - age (40) = 180 bpm Heart rate reserve as well as heart rate training were calculated according to Karvonen's formula. (Sbenghe, 2008; Wood, 2010) and supervised with Smartwatch Huawei Watch GT 2 during the cycling rehabilitation program.

Target heart rate (HR) = [(maximum HR - resting HR) ×% Intensity] + resting HR where resting PF = 60 bpm;

A gradual intensity of 40-60% was proposed, thus not exceeding the lactate threshold.

Phase I - 40%; FCT I = (180-60) * 40% + 60 = 108 bpm (60% of maximum heart rate)

Phase II - 50%; FCT II = (180-60) * 50% + 60 = 120 bpm (66.67% of maximum heart rate) Phase III - 60%. FCT III = (180-60) * 60% + 60 = 168 bpm (93.34% of maximum heart rate.

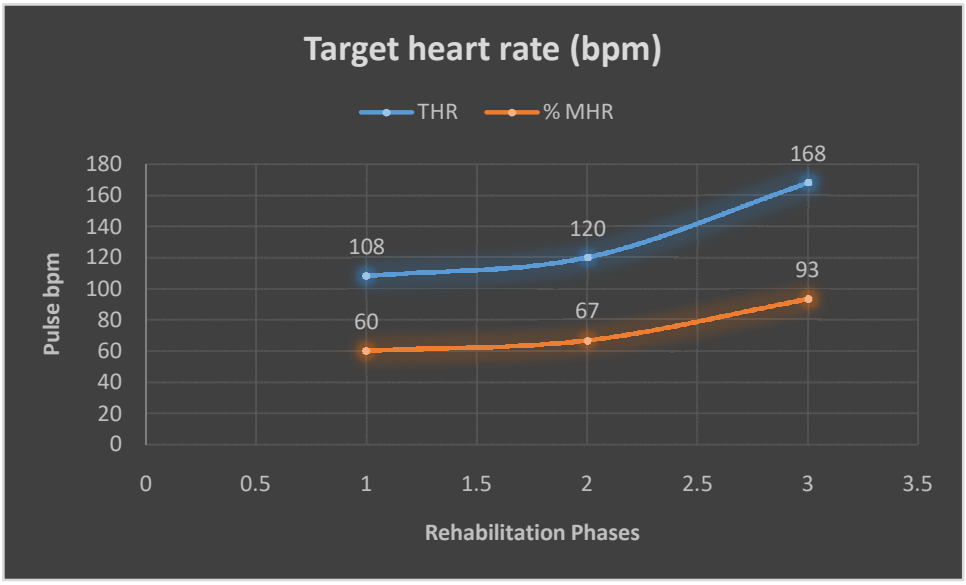


Figure 6 Target heart rate (bpm)

Phase I recovery - anti-inflammatory (1 week) facilitates venous return, lower limbs being raised, eccentric/concentric contractions in flexion/extension acting as a mechanical pump, reducing edema, improving general circulation and range of motion due to reduced effusion. Step 3 of intensity is applied - Borg scale level = 4.

Phase II of early regeneration (2 weeks) - average ROM is determined by possible ROM and not according to regulations. Adjusted exercises with progressively applied load - intensity level 4 - Borg scale level = 4. Resistance Zone 2 involves physiological adjustments (improves fat metabolism and the ability to use oxygen, produces power and increases efficiency, increases energy savings) and actions (more efficient use of energy, recovery training capable of producing more power with the same level of effort, works on technique/skill) Tissue regeneration occurs in response to proper loading. Monitoring for side effects - is not the case.

Phase III - maturation and remodeling and removal of excess fibrotic tissue (6 weeks of which 14 days - pedaling) - loading (stress/strain) is increased according to functional requirements, active movements emphasizing coordination, strength, speed by maintaining rhythm, area 2 training - endurance. Apply step 5 intensity, Borg scale level = 5-, transition to Tempo zone - psychological adaptations: improves carbohydrate metabolism, develops lactate threshold, and changes some muscles with rapid contraction into slow contraction, actions: improved sustainable rhythm. The break determined adherence to treatment and a state of eustress that replaced the phase of exhaustion according to the general adaptation syndrome, the fast pedaling followed by the slow one favoring a minimum stable energy consumption to maintain the homeostasis of the organism.

The results obtained (according to Table 5 and Fig. 7) showed:

- An analogous threshold value of 100 corresponding to a force of 0.41 N
- Maximum values obtained after the recovery training of 462.88 analog - 1.89 N for the left leg and 424.37 analog - 1.73 N for the right leg with a difference of 0.16 N;
- the average between the two members being 219/240 analog left / right respectively 0.89 / 0.98 N, the insignificant force difference of 0.09 N in absolute value;
- 200-400 analog working range.

Table 5 Results FSR – analog reading and force determining (N)

Type	Analog reading	Voltage reading in mV	FSR resistance (ohms)	Conductance (microMhoms)	Force (Newton)	Difference A0-A1 force N
A0 threshold	100.88	493	601	33	0.41	
A1 threshold	100.37	491	598	33	0.41	
A0 maximum	462.88	2262	2756	151	1.89	**0.16**

A1 maximum	424.37	2074	2527	138	1.73	
A0 medium	219	1070	1304	71	0.89	**-0.09**
A1 medium	240	1173	1429	78	0.98	

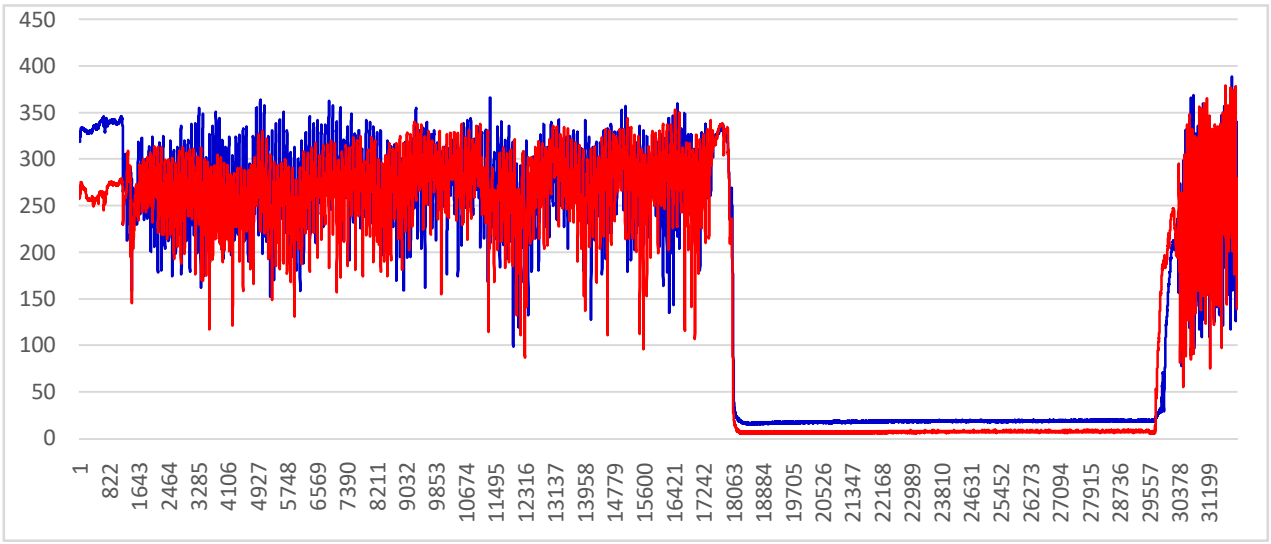


Figure 7 Results – pedaling rehabilitation program - excerpt

Final evaluation:

- Joint balance - goniometry - ankle plantar flexion 28 degrees (initially 3 degrees), dorsal ankle flexion 25 degrees (initially 8 degrees) demonstrates exceeding the values of the functional-coefficient;

- Range of motion for the left ankle is 53 degrees versus 11 previously articular testings.

- Muscle balance (0/5) = 5/5 left MI force - normotonous;

-The target heart rate was maintained within the calculated limits of aerobic effort - monitoring was performed with Huawei Watch GT 2 Smartwatch;

- RPE Borg 4 + / 5- throughout the applied program, maintaining the resistance zone 2.

- No pain detected VAS = 0

Conclusions

1. Muscle imbalances varied depending on the intensity of pedaling, at intensity 5 they were minimal;

2. The pause using strengthened the adherence to the treatment and maintained the patient's homeostasis, with no intention of abandonment;

3. The pulse corresponded to the target range, not exceeding 130 bpm;

4. The kinetic chain deficit has improved, the muscle testing indicating a ROM of 53 degrees in the ankle joint versus 11 degrees after immobilization, the normotonous objective being reached;

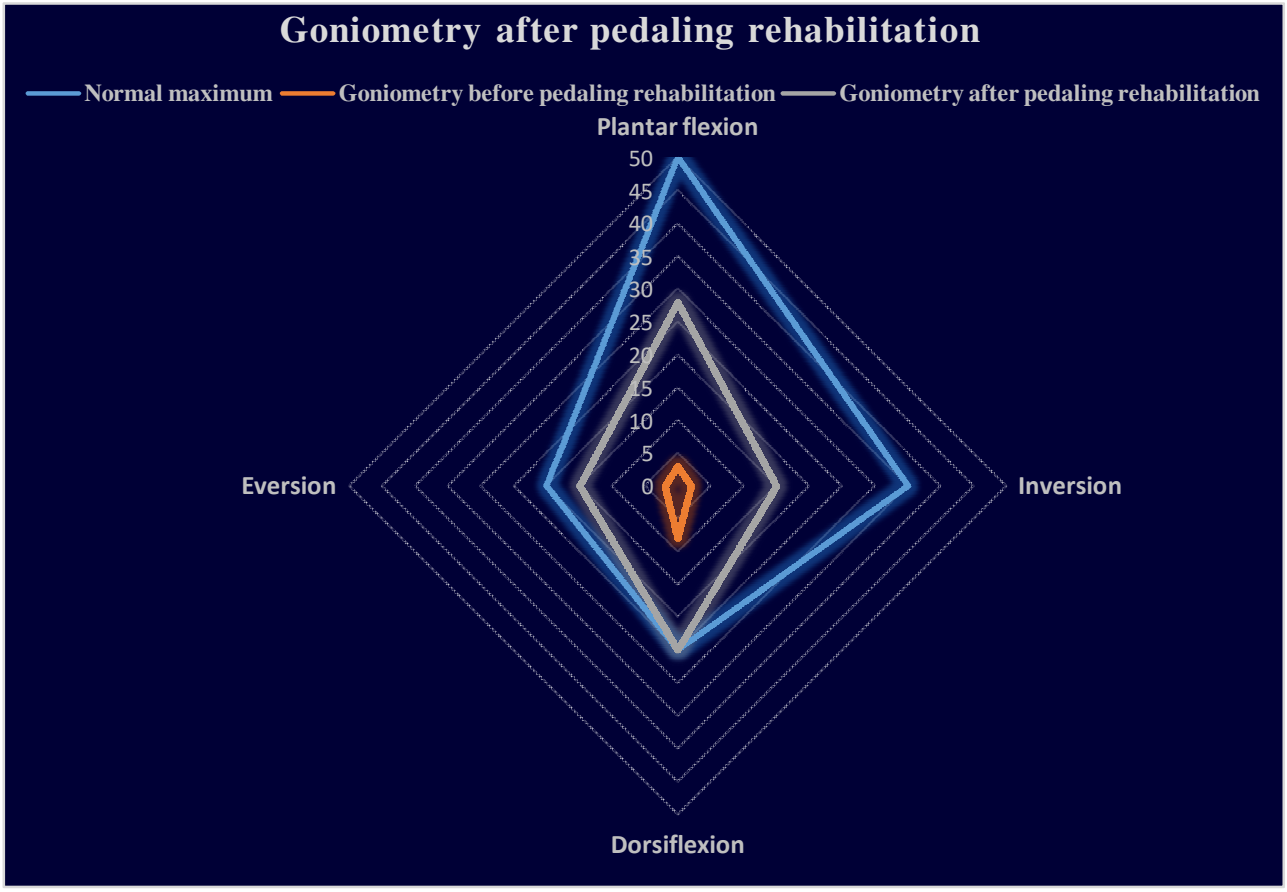


Fig. 8 Goniometry after pedaling rehabilitation

5. Remission of edema and bruising after phase I (first week), proven anti-inflammatory effect;

6. Left versus right leg circumference 0.5 cm, improved by 1.5 cm;

7. Limited foot support on the ground possible without pain VAS = 0;

8. Autonomous walk, unlimited pain;

9. Favorable evolution, the positive prognosis of rehabilitation.

10. The application of the proposed recovery program with the built horizontal bicycle led to the achievement of the objectives regarding the facilitation of the ambulance, the system being reliable and technically functional.

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