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Managing post-operative complications in a patient with excessive ankle stiffness: A case study addressing gait biomechanics and EMG

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Article Info	Abstract

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Background: Instrument Assisted Soft Tissue Mobilization (IASTM) and electrotherapy have shown to help alleviating post-operation complications and affect gait kinematics and muscle strength.

Aim: This case study aimed to manage the post-operative complications in a patient with investigate excessive ankle stiffness with kinetics, kinematics and Electromyography (EMG) approach.

Materials and Methods: A 41-year-old female with post-operation complications including decreased right ankle range of motion (ROM) and strength underwent a 12-week of IASTM and Electrotherapy. Gait analysis was performed before and after the intervention.

Results: The results showed notable improvements in ankle 3-dimensional (3D) ROM, power, moment, velocity, cadence, step length, ground reaction force (GRF) and decreased stiffness, muscles activity, single and double support time. Ankle dorsiflexion ROM was not notably increased during gait.

Conclusion: Findings suggest that a 12-week intervention of IASTM and electrotherapy can improve gait mechanics and reduce muscle activity in a patient with excessive ankle stiffness.

Keywords:
electrical stimulation,
muscle activity,
spatiotemporal,
kinetics,
kinematics.

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1. Introduction

Injury to lower limb is the most common injury in outdoor games, sprinting and throwing events, long and high jumps, which needs urgent care and surgery in a great number of injured individuals [1].

The surgery and post-operation (post-op) immobilization lead to altered kinetics and kinematics and several complications; e.g., abnormal joint ROM, joint stiffness [2], power and strength [2], reduced joint moment [2]. Long time below-the-knee cast prevents plantarflexion after heel contact and dorsiflexion after midstance [3]. It is reported that approximately 13.7° (±4.8) ankle dorsiflexion is required for normal gait [4]. There is an increased knee varus moment, particularly when dorsiflexion is less than 8° [4].

To date, numerous surgery and conservative interventions have been investigated for the management of post-op complications. Several exercises and physiotherapy interventions are assessed for rehabilitation; e.g., stretching [5] and Graston [6] reduce muscles and tendons stiffness. Combining multiple techniques has shown promise in achieving superior results, as evidenced by improved outcomes when vibration [7, 8] or heating [9, 10] is used in conjunction with stretching or IASTM combined with electrotherapy [11].

No published case study was found assessing the combination of interventions used in this study for rehabilitation of a patient with similar complications in such a complicated patient with repetitive surgeries and rescued from amputation. Since the participant in this study is an athlete and has tried strength and stretch training in the past 3 years, and considering the decreased ROM and muscle activity, this case study aimed to manage the post-operative complications in a patient with investigate excessive ankle stiffness with kinetics, kinematics and Electromyography (EMG) approach. By focusing on the biomechanical aspects and muscle activity, this study aims to offer valuable insights into the potential benefits of these interventions for optimizing gait patterns and reducing the risk of musculoskeletal complications in individuals with post-operation stiffness-related issues.

2. Methods and Materials

2. 1. Participation

A 41-year-old female athlete who had regular exercise since the patient was 10 years old and her right shank (facture of tibial, fibula and calcaneus and Achilles tendon rupture) was broken in a big jump when the patient was 34 years old and had gone through several surgeries and complications. The patient was able to walk after 3.5 years (age: 37.5 years). It has been 3.5 years that the patient has recovered from infection and fracture (age: 41 years, height: 1.68 m, mass: 59 kg, BMI: 20.9, leg length: (right: 84.5 cm, left: 86.5 cm)). Participant continued to daily workout during the research including swimming and fitness trainings and did not make any change in exercise routine.

2. 2. Instrument

Fifty passive reflective markers (14 mm) were positioned on the subject according to Oxford Foot Model [12]. A 12 camera 6 Infra-red (Cameras: MX T40-S, 4 IR Cameras: Vero (v2.2); Vicon motion capture system, two Video Cameras: Bonita 720c) was used to capture the position of the reflective markers (Vicon Motion Systems Ltd., Oxford, UK). Six EMG electrodes were positioned on bilateral soleus (S), tibialis anterior (TA), gastrocnemius (GAS) muscles, according to SENIAM guidelines [13]. A 32 Channel Wireless EMG: aktos;

Myon Company was used to capture the activity of muscles at a sampling rate of 1200 Hz.

Two Kistler force plates (Kistler Type 9260AA3 and 9260AA6, Kistler Instrumente AG, Winterthur, Switzerland) at a sampling rate of 1200 Hz. The signals from the force plates and EMG were recorded using an analogue signal data acquisition card provided with the Vicon system and with the Nexus Oxford Foot Model (OFM) [14] were used to capture the motion of 5 gait trials at a sampling rate of 120 Hz. The motion capture was synchronized with the force and EMG data and was recorded at a rate of 120 Hz.

2. 3. Procedure

2. 3. 1. Data acquisition

After installing the electrodes in the mentioned places subject initially carried out maximal voluntary isometric contractions (MVICs) of all muscles measured three times, or until the EMG amplitude for the relevant muscle ceased to increase with a subsequent contraction. Then patient was asked to walk barefoot at a comfortable speed along the 5-meter walkway until 5 clean foot strikes had been recorded from each force plate.

2. 3. 2. Interventions

The assessment of the interventions took place between December 2022 and February 2023. These interventions were administered by a registered physiotherapist (HM) and an instructor (FKH). The program involved 3 sessions per week for a duration of 12 weeks, with the interventions being alternated on separate days. One day involved EMG [15] using the (Beurer EM 49 Digital TENS/EMS with an impulse duration of 250 µs and a frequency of 25 to 50 Hz). On the other day, myofascial release [13], friction massage [14], and the Graston technique [6] (using GT5, GT6, and GT2) were applied to the calf muscles, Achilles tendon, sole of the foot, and areas with adhesions. Progression occurred when the participant indicated readiness and reported no pain or discomfort after the initial session with increased time and pressure. The duration of each intervention was gradually extended by 2-3 min every two weeks, provided that the participant did not experience any discomfort or pain and expressed readiness for longer durations.

2. 3. 3. Data analysis

Spatiotemporal and kinematic (angle and velocity) measurements were derived from fifty passive reflective markers, while kinetics (ground reaction force (GRF), power, moment, stiffness) data were obtained from force plate readings. EMG signals were processed using a 30 HZ high-pass 5th order butter worth filter and normalized by dividing them by the peak values of the corresponding muscles. To eliminate offset, average values were assumed to be zero to cancel offset. Absolute values were then established in MATLAB, followed by the application of a 10 HZ low-pass 4th order butter worth filter. The markers (using woltring marker, MSE mode) and kinetics, kinematics data was automatically filtered by NEXUS software [1]. The results were averaged across 5 trials.

For reporting the percentage of differences between pre and post-test, we divided the post-test value by the pretest value and multiplied by 100 get the percentage.

3. Results

After 12-week intervention, the patient has made notable progress in achieving the goals established in the plan on care.

3. 1. Kinematics

All ankle kinematics variables were changed notably except ankle dorsiflexion angle. The results showed notable improvements in ankle ROM increased by 173, 220% in sagittal and frontal planes, velocities by 120%, 205%, 241% in transverse, frontal and sagittal planes respectively (Table 1, Figure 1).

3. 1. 1. Spatiotemporal

Step rate and length increased and step width and double support time decreased notably (Table 1).

3. 2. Kinetics

Loading response peak, terminal stance peak, force duration in lateral direction, lateral impulse, impulse of terminal stance and pre-swing, total impulse of vertical GRF were decreased. There was an earlier loading response peak, propulsive peak and terminal stance peak and later lateral peak. Medial, braking, propulsive and time to terminal stance peak were increased. Duration of braking phase, braking impulse, propulsive impulse, medial impulse, impulse of loading response and midstance, loading rate (20-80% time to impact peak) were increased.

Table 1. Ankle Angles, velocity, spatiotemporal

Kinematic outcomes (°)		**Pre-test**	**Post-test**
Ankle sagittal plane ROM		18.809	32.6
Ankle frontal plane ROM		9.898	22.05
Ankle transverse plane ROM		27.61	25.16
Peak ankle dorsiflexion		3.6	4.02
Peak ankle plantarflexion		-14.78	-29
Peak ankle eversion		-8.37	-16
Peak ankle inversion		-1.54	-6.05
Peak ankle adduction		5.63	14.55
Peak ankle abduction		33.24	14.55
Ankle sagittal plane angle at midstance		1.76	1.44
foot progression angle at midstance		-11.75	-14.6
Ankle velocity (°/s)		**Pre-test**	**Post-test**
Peak ankle sagittal plane velocity		-120.367	-290.568
Peak ankle frontal plane velocity		38.27408	78.05215
Peak ankle transverse plane velocity		157.91	191.31
Spatiotemporal		**Pre-test**	**Post-test**
Walking speed	m/s	0.697023	0.935772
Stride time	s	1.355	1.145
Stride length	m	0.93252	1.070551
Step time	s	0.715	0.581667
Step length	m	0.461566	0.528075
Step width	m	0.168614	0.123281
Cadence	step/min	85.04867	103.2394
Single support	s	0.408333	0.398333
Double support	s	0.525	0.345
Stance phase	%	68.49798	64.66067

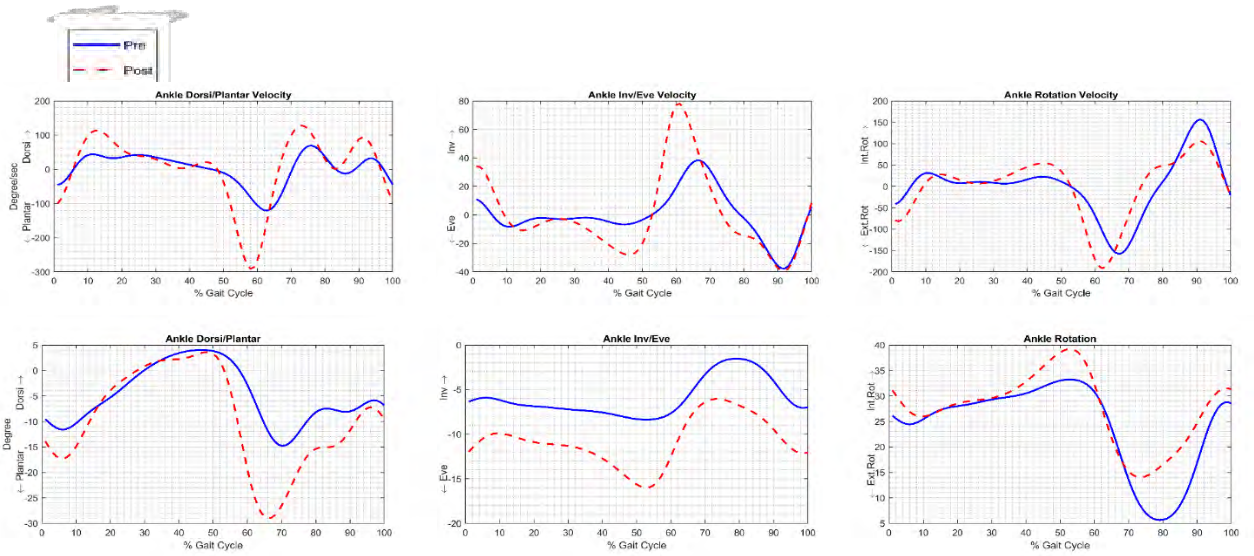


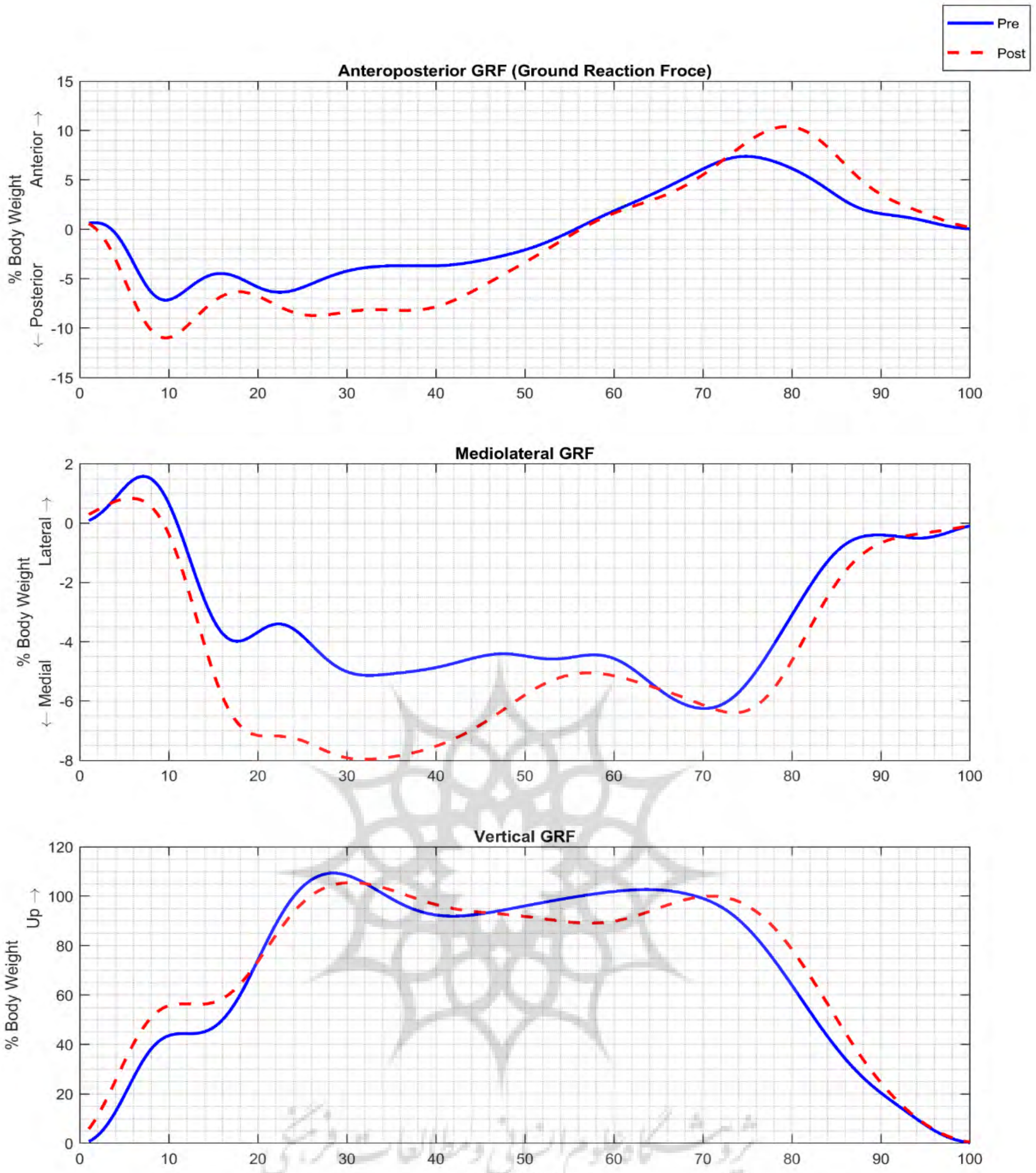
Figure. 1. Ankle velocity and angles in 3 dimensions

The results showed notable increase in ankle power by about 260, 347, 374% in sagittal, frontal and transverse plane, respectively. Ankle moment changed notably in transverse and frontal plane. Anteroposterior and braking, propulsive, lateral and medial impulses increased notably. Ankle stiffness decreased by which is due to notable increase in ankle sagittal plane ROM (Table 2, Figure 2).

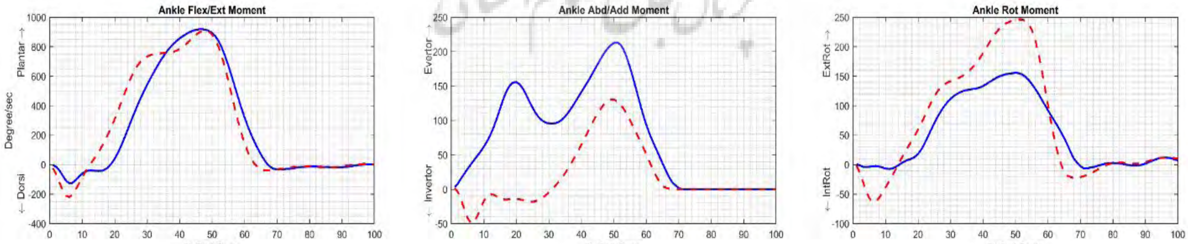
Table 2. GRF, ankle 3D power

GRF variables	Units	% Stance	Pre-test	Post-test	% Stance
Lateral peak	N	6.3	9.14	4.86	4.9
Medial peak	N	31.9	-29.71	-46.135	31.3
Braking peak	N	8.80	-41.41	-63.569	8.8
Propulsive peak	N	74.60	42.77	60.2	79.20
Loading response peak	N	28	633.02	610.79	30.2
Terminal stance peak	N	63.6	594.69	579.04	70.7
Time to terminal stance peak	%		41.7	57	
Force duration in lateral direction	%		0-10.1	0-8.5	
Duration of braking phase	%		0-55.3	0-55.9	
Braking impulse	Ns		-11.48	-15.86	
Propulsive impulse	Ns		8.61	9.2	
Lateral impulse	Ns		0.5	0.23	
Medial impulse	Ns		-17.95	-19.98	
Impulse of loading response and midstance	Ns		150.04	173.04	
Impulse of terminal stance and pre-swing	Ns		230.43	140.12	
Total impulse of vGRF	Ns		380.03	312.74	
Loading rate (20-80% time to impact peak)	m/s		3687.21	4696.07	

Power (W/kg)	Pre-test	Post-test
Ankle sagittal plane peak power	0.5	1.3
Ankle frontal plane peak power	0.141	0.49
Ankle transverse plane power	0.06753	0.251


Pre
Post
Anteroposterior GRF (Ground Reaction Froce)
% Body Weight
← Posterior
Anterior →
15
10
5
0
-5
-10
-15
Mediolateral GRF
← Medial
Lateral →
2
0
-2
-4
-6
-8
Vertical GRF
Up →
120
100
80
60
40
20
0
0
10
20
30
40
50
60
70
80
90
100
% Stance

(a)


Ankle Flex/Ext Moment
Degree/sec
Plantar →
← Dorsi
1000
800
600
400
200
0
-200
-400
% Gait Cycle
Ankle Abd/Add Moment
Evertor →
← Invertor
250
200
150
100
50
0
-50
Ankle Rot Moment
ExtRot →
← IntRot
250
200
150
100
50
0
-50
-100
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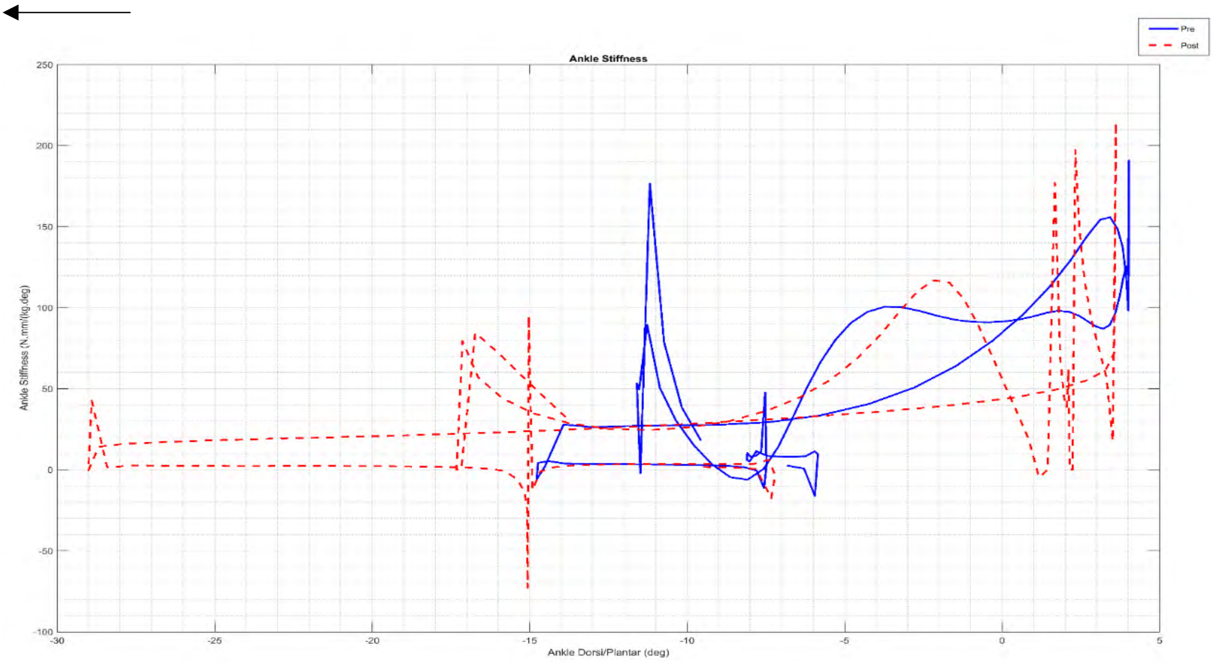
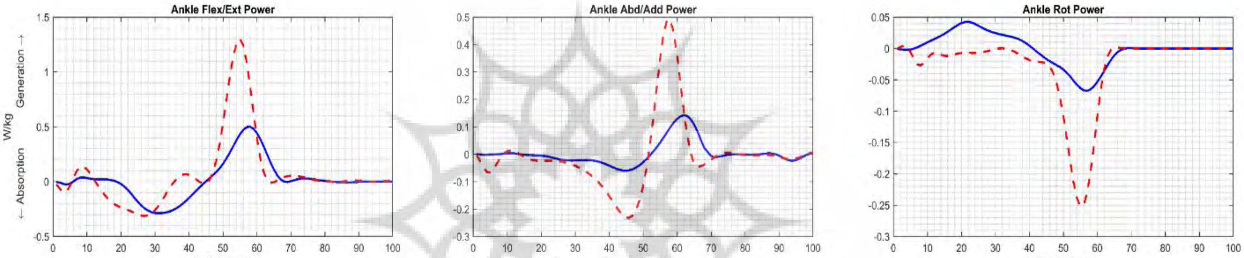
10
20
30
40
50
60
70
80
90
100

(b)

⟶



(c)



(d)

Figure 2. Curves for (a) GRF, (b) Moments, (c) Powers in 3-dimensions in gait cycle, and (d) sagittal plane stiffness

3. 3. EMG

EMG amplitude patterns improved notably in the tibialis anterior, medial and lateral gastrocnemius and soleus muscles (Figure 3).

4. Discussion

This case study aimed to manage the post-operative complications in a patient with investigate excessive ankle stiffness with kinetics, kinematics and EMG approach. The study was conducted on a 41-year-old female who had a history of right Achilles tendon rupture. The patient underwent a 12-week intervention program consisted of IASTM and electrotherapy.

The evidence suggests that both IASTM and electrotherapy can lead to improvements in dorsiflexion and plantarflexion outcomes. This may be due to IASTM 's ability to reduce adhesions and improve tissue mobility, and electrotherapy increases muscle activation and facilitates healing. Combining IASTM and electrotherapy, potentially enhances the effects of each treatment method. Also, Kim et al. (2021) [15] investigated the effects of combining IASTM and ES on back pain and motor function, which showed notable improvements after the combined treatment.

4. 1. Kinematics

Ankle kinematics and spatiotemporal outcomes were improved notably during gait which suggest that IASTM is able to directly affect joint ROM and electrotherapy helps improving ankle kinematics by decreasing pain and increasing mobility.

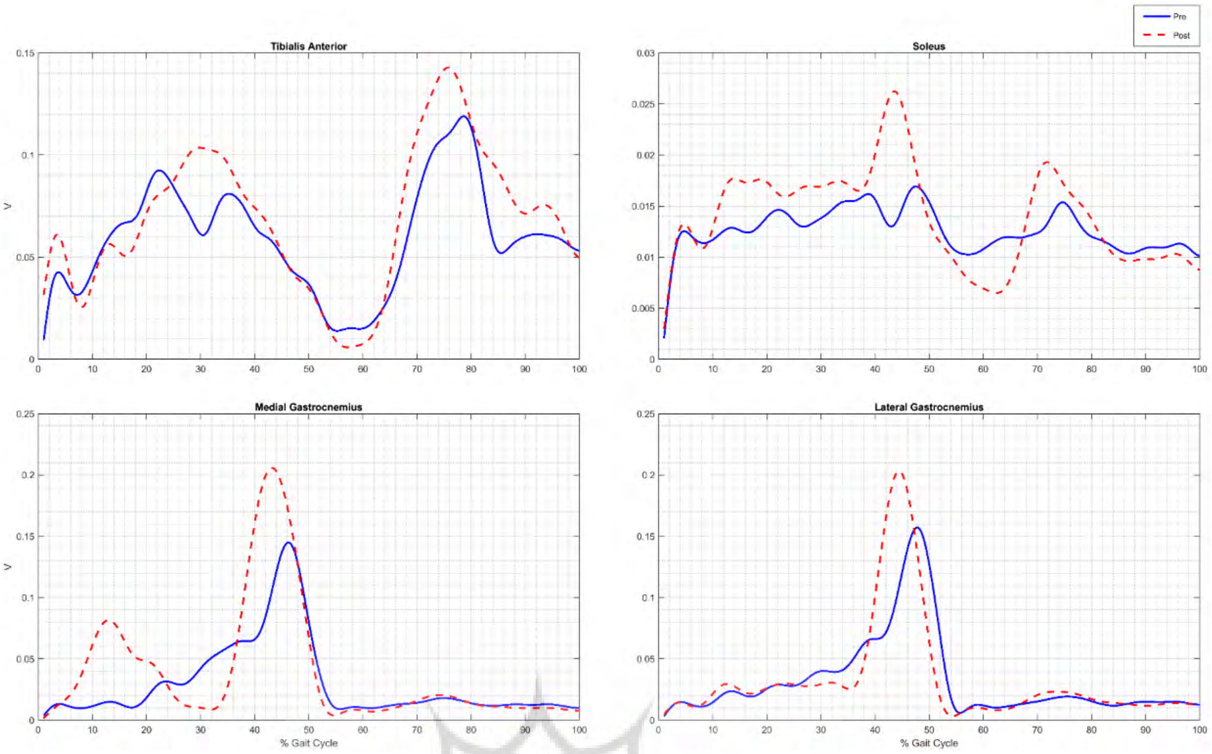


Figure 3. Muscle activity of Tibialis Anterior, medial and lateral Gastrocnemius, Soleus muscles (mv)

One unexpected finding is that ankle dorsiflexion ROM was not increased notably after intervention which is in contrast to earlier findings by Ikeda et al. (2019) [16] investigating the effect of IASTM on musculoskeletal properties which leaded to dorsiflexion ROM increase. The ROM of Talocrural joint in sagittal plane is 20° for dorsiflexion and 30-50° for plantarflexion. The causes of painful restriction of ankle dorsiflexion are anterior impingement, degenerative changes of the ankle joint [17], Achilles tendon tightness, and gastrocnemius contracture [18]. Contracture of the posterior fibulotalocalcaneal ligament (also known as Rouvière and Canela ligament) may contribute to reduced ankle dorsiflexion [19]. Severe soft-tissue trauma following injuries such as ankle fracture–dislocation may result in capsular fibrosis with limited ankle dorsiflexion despite anatomical reduction and appropriate fixation [20].

The patient reported a bony end feel anteriorly at the ankle which is probably due to a hinge effect and anterior ankle impingement. Contracture of the posterior structures of the ankle may lead to a posterior 'hinge effect', causing the talus rotates through the posterior capsule instead of the center of rotation in the talus. As a consequence, the talus may impinge anteriorly during dorsiflexion and cause anterior pain [21]. Actually, one of the important questions of this study was that whether non-invasive intervention is capable of bringing back the normal dorsiflexion ROM or invasive intervention is mandatory. We prognosticate arthroscopic release of the posterior capsuloligamentous structures is unavoidable.

4. 1. 1. Spatiotemporal

In terms of spatiotemporal, all parameters were improved after intervention. Fast gait spatiotemporal parameters in participant is associated with increased muscle strength [22] and moments [23]. Consistency in moment combined with speed may show improved efficiency in participant [24].

The importance of walking speed is an indicator of functional activity and quality of life for individuals who have been diagnosed with a certain condition [25]. Walking speed affects other aspects of gait, such as increasing cadence, step length, and stride length and decreasing stance phase and double-limb support in both normal individuals and those who had suffered injuries [26].

It is reported in previous studies that step width increases as gait time and step length decrease [27]. On the other hand, electrotherapy has shown to increase step length. Consistent with the literature, in this research the step length increased and step width decreased. Such an increase may be explained by the increase observed in plantar flexion moment in the pre-swing phase. Ankle plantar flexor power has shown to be the best predictor of step length, explaining 52% of its variance [28]. Potential roles of ankle plantar flexor kinetics during gait include initiating the movement of the stance leg into a swing and propelling the body forward. If greater plantar flexor force is generated in the pre-swing phase, a greater push-off force will be generated, contributing to a larger step length [29].

In conclusion, IASTM and electrotherapy were effective in improving ankle kinematics except ankle dorsiflexion ROM which was complicated for our patients and cannot be generalized. Therefore, for further decision for our participant, we prescribe bilateral computer tomography of the lower legs for calculating the exact leg length discrepancy, rotation and angular misalignment and determining suspect osteophyte development and bony fragments caused by osteoarthritis.

4. 2. Kinetics

The study's findings demonstrate that the intervention was effective in improving the kinetics of walking. Ankle 3D power and moments increased, GRF variables were changed and ankle sagittal plane stiffness was decreased during walking.

4. 2. 2. GRF

There is limited research available on the direct effect of IASTM on GRF. However, it is believed that IASTM can indirectly influence GRF by improving joint mobility, ROM, reducing pain and inflammation and breaking up fascial adhesions and scar tissue, which can restrict muscle and joint movement, tissue extensibility, neuromuscular control and coordination and ultimately affect GRF.

On the other hand, electrotherapy enhances muscle strength and power output, which can help improve the GRF during locomotion. Transcutaneous electrical nerve stimulation (TENS), while not directly affecting the GRF, can improve pain and mobility, leading to better overall movement and weight-bearing capacity. For example, electrotherapy of the plantar-flexor muscles increased the force generated during the push-off phase of walking, resulting in increased GRF.

Our study showed an increase in both breaking and propulsive peaks which suggests a stronger push-off and greater control of forward momentum. The curves entropy for braking phase was decreased indicating a smoother pattern. Propulsive peak happened later in the post-test. The later propulsive peak may be due to the more pronounced plantarflexion during push-off phase and generating a greater force in post-test.

The medial peak was increased which might be due to the decreased step width and participant‘s effort for maintaining the balance during walking.

Impulse of loading response and mid-stance increased which may be due to increased walking speed, muscle strength or power. Impulse of terminal stance and preswing decreased which might be due to a reduced push-off power and potentially disrupted functional movements or an issue with timing and coordination of muscle activation or impaired neuromuscular control during gait. Loading rate was increased which might be a result of increased step length. Further research is needed to confirm these findings and investigate long-term effects in larger sample size.

4. 2. 3. Power

Ankle 3D power was increased which indicates that the ankle joint is generating more force during movement. Power is a measure of the rate at which work is done, representing the ability to generate force quickly. It is a critical factor in many athletic activities, including running, jumping, and change of direction. This could be a result of stronger muscles that control ankle movement, improved coordination and control of the ankle joint.

4. 2. 4. Moment

Ankle transverse and frontal plane moment was increased. The ankle moment refers to the torque produced by the muscles around the ankle joint during various activities and plays a crucial role in maintaining balance, stability, and efficient movement. Our findings can be caused by increased ankle stability or strength, proper alignment or foot posture, or efficient movement patterns. These outcomes indicate that electrotherapy could increase ankle strength and IASTM leaded to improvements in kinetics during gait by increasing ROM and putting muscles in optimum length for producing maximum moments.

4. 2. 5. Stiffness

Another important finding is that ankle sagittal plane stiffness during gait decreased after a 12-week IASTM and electrotherapy. This result is most probably due to the increased sagittal plane ROM as IASTM has shown great effect in increasing ROM in previous studies which we stated before in this paper.

These results reflect those of Ikeda et al. (2019) [16] who also found that IASTM notably decreased ankle joint stiffness.

We postulate that joint stiffness may affect muscle tendon unit (MTU) strain type injury potential by allowing the MTU to either strain too far under a load or by protecting some passive structures within an MTU at the expense of transferring load to others [30]. For example, the incidence of Achilles tendinopathy [31] may be increased in individuals who have joints with low stiffness, which are consequently less able to resist elongation and therefore deform to injurious lengths, particularly where dorsilfexion ROM is not necessarily. a limiting factor. Conversely, high stiffness may lead to inability to absorb sufifcient strain energy via Achilles tendon in order to prevent other structures from incurring excessive and injurious strains [32].

These measures can be applied in prevention, since they help to identify individuals requiring interventions addressing ankle stiffness levels, aiming to prevent the occurrence of injuries.

Totally, the interventions were effective in improving kinetics during walking. However, further research with larger sample size, control group assessing

IASTM and electrotherapy separately with follow up is required.

4. 3. EMG

The study's findings demonstrate that the 12-week intervention program of IASTM and electrotherapy was effective in improving the patient's EMG amplitude pattern in Soleus, Gastrocnemius and Tibialis anterior muscles during gait. This is consistent with that of Lui (2016) [30] and Schauer et al. (2017) [31] which investigated real-time EMG for transcutaneous electrical stimulation assisted gait training, and with Paillard et al. (2005) [32] who reported that electrostimulation with voluntary muscle contraction exercise could induce different physiologic adaptations compared with electrostimulation or voluntary muscle contraction exercise alone.

The mechanisms behind electrical stimulation are still not fully understood, but it is thought that the electrical current causes depolarization of the muscle fibers, which leads to muscle contraction [33]. This process can improve muscle strength, endurance, and neuromuscular activation [34], involves neural adaptations through reflex inputs to the spinal cord and supraspinal centers [35]. It may involve an increase in muscle fiber cross-sectional area, changes in muscle fiber type and composition, and improved muscle fiber recruitment [36, 37]. Moreover, it is well-documented that electrotherapy over peripheral nerves or muscles reduces spasticity via a multifactorial mechanism [38]. This decreases the resistance of the tibia to rotate forwards during the mid-stance of the gait and decreasing ankle plantar-flexor spasticity allows patients to exert extra force in the swing phase [26].

Overall, IASTM and electrotherapy has had promising results in improving muscle activity during gait.

5. Limitations and Recommendations

There are several limitations to this case study. First, only one patient was reported. Consequently, external validity is limited (inability to generalize results from this case report). Second, it is difficult to discern whether IASTM alone, electrotherapy intervention alone, or a combination of both, contributed most to the patient improvements. Moreover, unilateral ankle injury affects the uninjured ankle. Therefore, it is fundamental to measure asymmetries between two sides. Moreover, suggesting interventions for upper joints may be beneficial due to compensatory movements of the hip joint and trunk and reduced posture control [39].

6. Conclusions

This case study highlights the effectiveness of a 12-week IASTM and electrotherapy program for improving gait kinetics, kinematics, and EMG during gait in a patient with excessive ankle stiffness. The results from this study provide evidence that this intervention can be used as a viable alternative or supplement to traditional physical therapy methods in such complicated patients. Additionally, the findings suggest that further research using larger sample sizes, high quality RCTs assessing the effects of interventions separately and in combination with follow-up is warranted to assess the generalizability of the results and to optimize the duration and dose of intervention required to maximize outcomes for patients with excessive ankle stiffness and muscular atrophy.

Conflict of interest

The authors declared no conflicts of interest.

Authors' contributions

All authors contributed to the original idea, study design. Conceptualization, F.K., S.H. M., H.M.; methodology, S.H.M., H.M.; investigation, F.K., S.H.M., H.M., M.S.; writing - original draft preparation, F.K.; writing - review and editing, F.K., S.H.M., H.M.; visualization, F.K.; supervision, S.H.M., H.M., M.S.; project administration, F.K., S.H.M., H.M., M.S. All authors have read and agreed to the published version of the manuscript.

Ethical considerations

The authors have completely considered ethical issues, including informed consent, plagiarism, data fabrication, misconduct, and/or falsification, double publication and/or redundancy, submission, etc.

The study was conducted in accordance with the Declaration of Helsinki, and study protocol was approved by the Research Ethics Committees of Faculty of Physical Education and Sport Sciences-Tehran University (IR.UT.SPORT.REC.1401.045).

Written informed consent has been obtained from the patient(s) to publish this paper

Data availability

The dataset generated and analyzed during the current study is available from the corresponding author on reasonable request.

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