SSRG International Journal of Electrical and Electronics Engineering
ISSN: 2348-8379/ https://doi.org/10.14445/23488379/IJEEE-V12I3P106

Volume 12 Issue 3, 55-62, March 2025

Original Article

Therapeutic Use of Portable Electrotherapy Machine for Muscle Stimulation, Education and Healing

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Received: 20 October 2024 Revised: 24 December 2024 Accepted: 26 February 2025 Published: 31 March 2025

Abstract - *Electrotherapy makes use of well-controlled electrical pulses of various durations as per the patients' requirements either for muscle relaxation, muscle re-education, muscle stimulation, as well as muscle strengthening. The major advantage of a portable stimulator is that the clinician can carry it and use it whenever necessary. The proposed machine contains all types of currents in a very portable and handy unit. The nature of the current used in experimentations, along with various parameters such as intensity, duration, frequency, arrangement of electrodes, and sizes, can induce explicit physiological effects on targeted tissues. Electrical currents have a direct impact on excitable tissues like muscle fibres, cell membranes and nerves. These effects help manage both acute and chronic pain, decrease edema, alleviate joint contractures, prevent muscle spasms, combat disuse atrophy, promote tissue healing, assist in muscle re-education, aid in fracture healing, and strengthen muscles, even serving as an orthotic substitute. Electrical stimulation can even be applied to trigger muscle contractions during activities like gait training.*

Keywords - *Electrical stimulation, Electrotherapy, Muscle stimulation, Pain relief.*

1. Introduction

Electrotherapy highlights its growing use in pain management, particularly for conditions like musculoskeletal pain, fibromyalgia, and nerve injuries. Electrotherapy is a method of medical treatment conducted using electrophysical agents [1]. Physiotherapists commonly use electrical stimulation to treat various conditions, including chronic pain, muscle atrophy, musculoskeletal injuries, and nerve pain. As a noninvasive therapy, it is generally not painful [2-4]. However, some patients may feel a mild tingling or vibration in the area where the electrodes are applied. The electrical impulses work by blocking pain signals and improving local blood circulation, which helps to alleviate discomfort [5, 6].

Interferential Therapy (IFT) is a key modality in electrotherapy support in releasing endorphins that lessen aching or distress [4]. Emerging technologies in electrotherapy, such as wireless, portable devices with controller-based systems, enhance usability by allowing patients to adjust settings easily and even track their treatment progress through paired smartphone apps.

This is useful for both real-time monitoring and long-term treatment assessments by healthcare providers. This work proposes a machine that is effective in terms of pre-set programs and also user adjustment mode. The proposed system is an indication-based, User-friendly machine offering both Low-Frequency (LF) and Medium-Frequency (MF) Currents, IFT, Muscle Stimulation (galvanic and faradic), and Transcutaneous Electrical Nerve Stimulator (Low, medium, and high).

It contains 2 self-regulating channels with 4 electrode pads to focus on 2 areas simultaneously in TENS or MS mode, and it also allows IFT. The microcontroller-based machine makes this unit very user-friendly, informative and easy to operate with various alarm and safety messages.

A dedicated Android application is paired to the machine with the use of Bluetooth technology, which can collect the treatment data like treatment mode, duration and treatment intensity and will keep a log of this data, which in turn will help the doctor assess the effects of the given treatment and also can decide the future goals based on the progress. The effectiveness of different currents, like galvanic and faradic currents, are used for re-educating paralyzed muscles.

Transcutaneous Electrical Nerve Stimulator (TENS) is used for acute pain healing through nerve stimulation and chronic pain relief. At the same time, Interferential Therapy (IFT) is used for muscle relaxation and reducing muscle spasms [4, 6-8]. Electrotherapy is widely used for pain management and rehabilitation, but existing devices face limitations such as limited functionality, lack of portability, insufficient customization, and absence of real-time monitoring.

This work proposes a portable, microcontroller-based electrotherapy machine that integrates multiple modalities (TENS, IFT, galvanic, faradic) into a single unit, offering user-friendly operation, adjustable settings, and real-time data tracking via a Bluetooth-connected Android app. By addressing these gaps, the device enhances versatility, usability, and data-driven care, making it suitable for both clinical and home-based use. This innovation aims to revolutionize electrotherapy by providing a comprehensive, accessible, and effective solution for diverse therapeutic needs. Using Therapeutic Use of a Portable Electrotherapy Machine for Muscle Stimulation is described.

Section 2 describes the complete methodology of operation of the electrotherapy machine. Section 3 describes muscle stimulation action. Section 4 covers Transcutaneous Electrical Nerve Stimulation with high and low-value conditions and precautions required during use. Section 5 Comprises the result section, and Section 6 concludes the complete design procedure.

2. Material and Methodology

The electronic hardware consists of a 230v power supply, which provides power to the whole unit. The oscillator used to generate pulses ranging from 50 µsec to 1msec is controlled using ML51 micro-controller. The frequency range varies from 30Hz to 10Khz, as shown in Figure 1. The modulating circuit, along with the gain control amplifier, assures that a train of different square wave signals is transmitted through the electrodes. The pair of electrodes used are carbon electrodes, as carbon is a highly conducting material with a very high melting point. There are 2 channels through which the currents are passed. In each channel, the cathode is the active electrode, and the anode acts as a passive electrode, which is used to complete the circuit. The working of an electrotherapy machine can be performed using keypad switches for mode selection on the actual machine, plus the Bluetooth-connected android application gives the physiotherapists an option to operate the machine from their workplace, giving them the ability to treat multiple patients at the same time.

Some areas of the skin conduct electricity more effectively than others, which are denoted as stimulation points. These points on the body require less electrical current to induce muscle contractions, sensations, or pain. Many therapeutic procedures are specifically designed to target one or more stimulation points [10, 11], as shown in Figure 2. Due to the proximity of these points, a single electrode can stimulate all three at once.

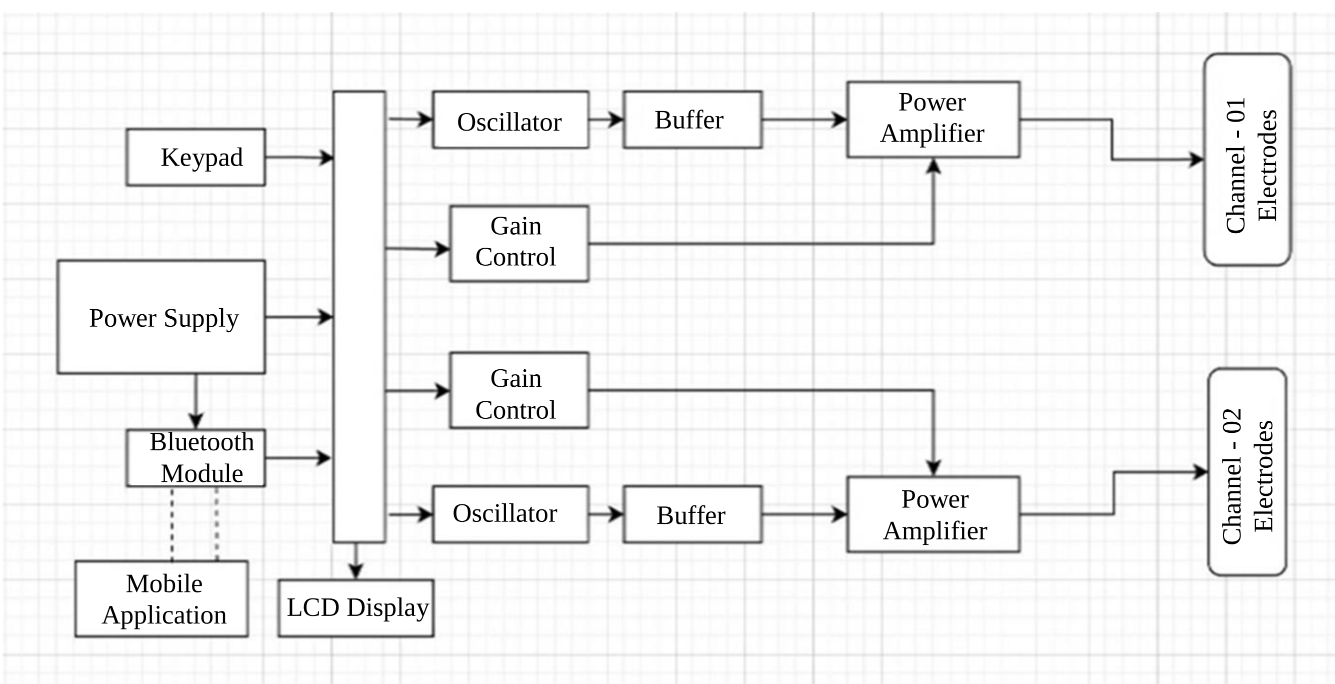

Fig. 1 Electronic operation of electrotherapy machine

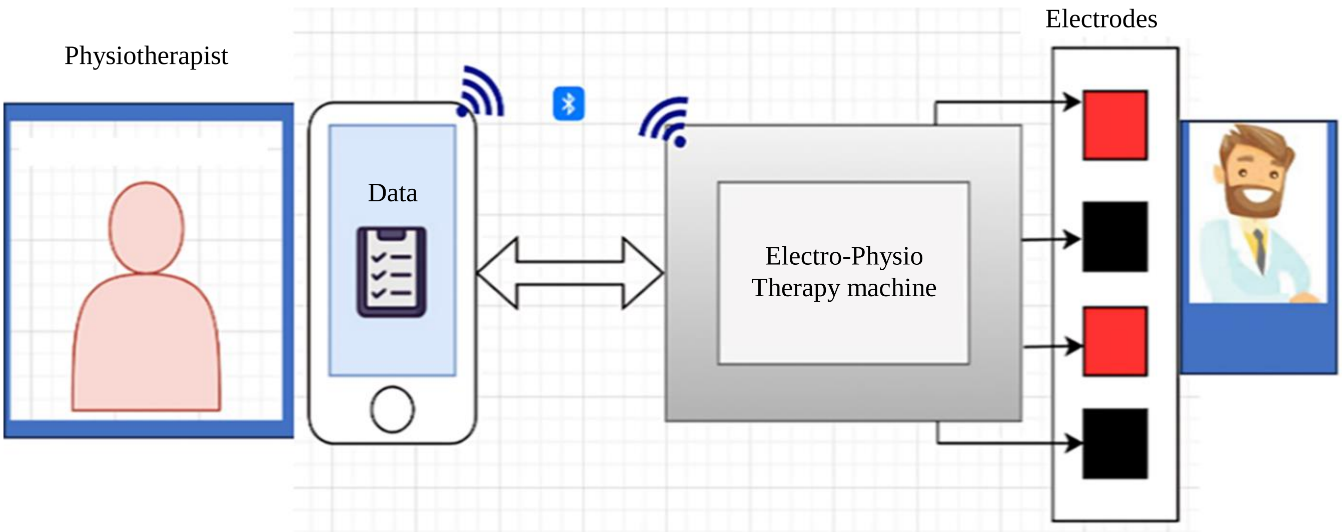

Fig. 2 Stimulation points

2.1. Motor Points

Every muscle has one or more areas on the skin that are particularly sensitive to electrical stimulation, known as motor points. These are specific spots located above the muscle where motor nerves and blood vessels enter. Due to their lower electrical resistance, stimulating these motor points initiates a stronger contraction at lower intensities compared to surrounding tissues. Injured areas frequently exhibit heightened sensitivity to both current and palpation at these points. While motor points generally have consistent locations, there can be individual variations, and they may shift over time depending on the underlying pathology. The thickness of the fat layer over the muscle also affects the current intensity needed to stimulate the motor nerve-thicker adipose tissue requires higher intensity. Common motor points are referenced in [1, 9, 10], though they should be individually identified for each patient by locating the point where the strongest contraction is achieved with the least stimulation [9].

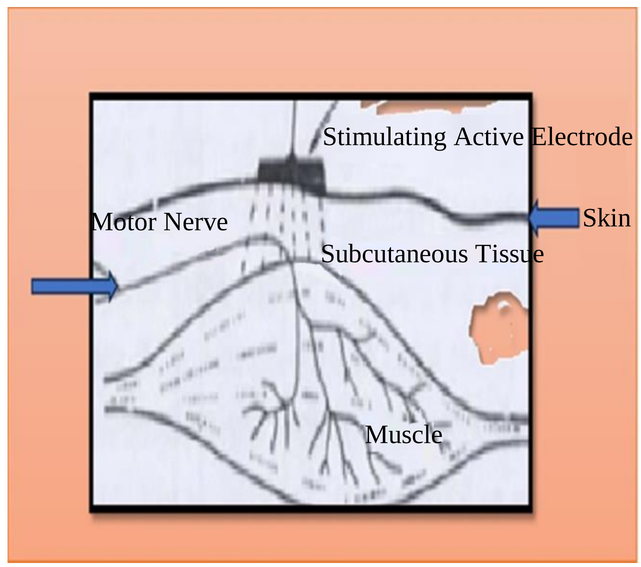

Fig. 3 Pathological areas that are hypersensitive to stimulation [9]

2.2. Trigger Points

Trigger points are specific pathological areas that exhibit more sensitivity to stimulation. When stimulated, they can cause radiating or referred pain. Contrasting motor points, trigger points are not limited to muscles but can also be found in other soft tissues such as ligaments, tendons, and fascia, as shown in Figure 3 [1, 8].

3. Muscle Stimulation

3.1. Faradic Currents

A faradic current is a low-frequency pulsed current similar to that in Figure 4. The pulses originally produced were asymmetrical biphasic with a frequency range between 30Hz up to 70 Hz and a pulse duration of 1ms or less but usually greater than 300µs. These parameters are within the usual range used for stimulating innervated muscle.

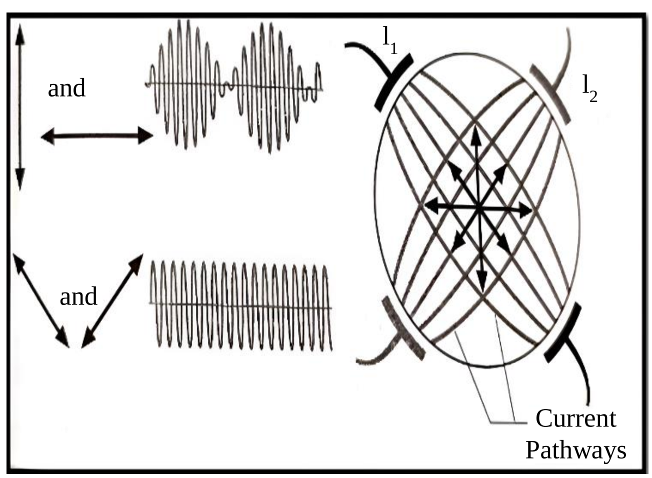

Fig. 4 Interferential current (IFC) therapy [6]

For that reason, many users label the current intended for stimulating innervated muscle as 'faradic'. Biphasic pulses with a similar phase duration and frequency are called 'faradic currents' [9, 12]. Faradic current is regularly interrupted to prevent muscle fatigue. A modification known as surging involves a steady increase in intensity, with each successive pulse reaching a higher level than the previous one, followed by a sudden or gradual decrease after hitting the peak. This process is also referred to as ramping [3]. The physiological effects of faradic current include stimulation of sensory and motor nerves and contraction of innervated muscles, mimicking the natural voluntary contraction of muscles [12]. This current type facilitates muscle contraction, re-educates muscles, trains newly replaced muscles, and stimulates mildly affected motor nerves. The stimulation of sensory nerves with faradic currents produces a pricking sensation [2, 3, 9].

3.2. Galvanic Currents

Galvanic current is another name for continuous, Direct Current (DC). Because of this, there is no point in interrupting or pulsing the current flow, as this would only increase the required treatment time. Nor would reversing current flow be appropriate (to avoid electrolytic effects), as this would drive the therapeutically beneficial ions back across the skin. In terms of the descriptive system, a galvanic current is defined as a current that flows for 1sec or more [9, 10].

Interrupted galvanic current is a modified form of direct current where the flow starts and stops at regular and consistent intervals. The waveform can be rectangular, triangular, sawtooth-shaped or trapezoidal. This type of current is primarily used to stimulate denervated muscles and for electrodiagnostic purposes [1]. The stimulation period can be adjusted on a logarithmic scale, ranging from 300ms to 1ms, with 100ms being the most common. It effectively produces contractions in denervated muscles, which often become atrophied or fibrosed due to lack of use. While re-innervation is a natural process, the muscle needs to remain viable during this period until the re-innervation is complete [1, 10]. This stimulation is typically applied over the muscle belly or near motor points, and sometimes entire muscle groups are stimulated together [9, 4].

In direct current, the most common modification is interruptions, where the current starts and stops regularly. The intensity may rise and fall either suddenly or gradually. The duration and frequency of impulses can be adjusted, with 100ms being the most commonly used. For impulses of 100mA, a frequency of around 30 per minute is typical, and as the duration increases, the frequency must decrease. Some equipment provides a depolarized impulse by delivering low-intensity reversed current between impulses. When sensory nerves are stimulated using galvanic current, it often results in a burning sensation [9, 10]. Stimulation of sensory nerve with galvanic current results in a burning sensation [4, 10].

4. Transcutaneous Electrical Nerve Stimulation (TENS)

TENS is the popular name for electrical stimulation produced by a wearable stimulator and used to treat pain. However, TENS stands for Transcutaneous Electrical Nerve Stimulation and covers all electrical currents applied transcutaneously for nerve stimulation [1, 10]. However, the term TENS is often used with a stricter intent to describe the type of pulses produced by wearable stimulators used to treat pain. Pain control TENS devices typically produce a continuous series of pulsating currents with frequencies ranging from 1 to 120 Hz, with some even reaching 200 Hz [9, 11]. The pulses are typically rectangular or nearly rectangular in shape, biphasic, with a pulse duration ranging from 50-200µs. Sensory stimulation is generally pragmatic at a "strong but relaxed" intensity, targeting the excitation of A-beta (sensory) nerve fibers to create an analgesic effect by "gating" the pain signals transmitted by A-delta and C fibers. This approach, referred to as TENS, is a method used in pain management [6, 13, 14]. The term "transcutaneous" means "through the skin," and "nerve stimulation" refers to the application of electrical current at an intensity sufficient to depolarize sensory, motor, or pain nerves [1, 9, 10, 14, 21].

4.1. High TENS

High-Frequency TENS, also known as sensory-level TENS, is a conventional TENS treatment characterized by a high pulse rate (60 to 100 pps), a short pulse duration (less than 100 µs, with a phase duration of approximately 50 µs), and sensory-level intensity. This stimulation targets A-beta fibers, activating the pain-relieving gate mechanism at the spinal cord level [1, 9, 13]. It is particularly effective for treating acute soft tissue injuries. However, caution is needed to prevent unintended muscle contractions during treatment [8].

4.2. Low TENS

Low-Frequency TENS (Motor Level) uses a lower pulse rate (2 to 4 pps) and longer phase durations (150 to 250 µs, approximately 75 to 125 µs per phase). This results in an effective, non-painful motor-level intensity applied for at least 45 minutes [9, 11]. These stimulation parameters activate small-diameter motor nerve fibers, potentially C fibers and A-beta fibers [14, 15]. Sensory data travels via afferent nerves in the muscle spindle, activating descending pain suppression mechanisms. Pain relief is believed to result from the release of β-endorphin, which produces narcotic-like effects [1, 3, 11].

4.3. Interferential Therapy

The term 'interferential', advocates a sort of interference that outworths the basis for its name. Interferential Currents (IFC) are two kHz frequency alternating currents applied in a constant train. The currents have a minutely different frequency (one can be 5000 Hz, the other 4000 Hz) [1, 9, 16]. As shown in Figure 4, Two pairs of electrodes are positioned so that the currents traverse deep within the tissue volume [6]. A claimed advantage of interferential currents is the depth efficiency of stimulation. It is claimed that in the region of intersection, the reinforcement of the currents will result in greater total stimulus intensity, so maximum stimulation is produced at depth rather than superficially, as occurs with normal bipolar stimulation [9, 6, 17].

Whether this is true is questionable as current spreading reduces the intensity at depth, so even if two currents are superimposed, the total intensity could (and probably would) still be less than immediately under the electrodes. Modern interferential stimulators offer a selection of AC frequencies in the range of 1 to 10kHz and may use either sine wave or square wave pulses [6, 15]. The inventive interferential stimulators used sinusoidal AC at a frequency of 4kHz. As noted earlier, there is little difference in kHz frequencies in terms of whether the shape is sinusoidal, rectangular, or triangular [1, 15].

The image above explains how interferential therapy works. Wherein two different frequencies are generated, and the electrodes are placed in such a manner that they form a clover leaf pattern in which the center where both frequency signals meet should be placed at the affected area. Interferential Therapy (IFT) delivers noninvasive electrical stimulation at medium frequencies, which helps reduce resistance in soft tissues with minimal adverse effects. This approach improves tissue conductivity, making it a safer option for pain relief with fewer complications [18, 19].

4.4. Precautions

In electrotherapy, the EPA passes currents of varied frequency and intensity through the patient's body for varied time duration. So, the person treating with electrotherapy should ensure that the patient is fit and avoid using electrotherapy under these conditions: -

1. Patient is equipped with a cardiac pacemaker.
2. Lower back or abdomen of pregnant women.
3. The regions of known malignancy.
4. To actively bleeding tissues.
5. Areas over or near eyes.
6. On the carotid artery.

5. Results and Discussion

Galvanic current may show more gradual or minimal improvement in range of motion, as its primary role is healing and pain management, rather than actively inducing movement [20] faradic current is dynamic and primarily used for muscle stimulation, helping to regain muscle function and enhance movement. At the same time, galvanic current is more therapeutic, focusing on pain relief, tissue healing, and iontophoresis, with less emphasis on active motion.

Faradic current is likely to show a steeper improvement in the range of motion as it actively stimulates muscle contractions, leading to faster functional gains. Figure 5 illustrates the effect of galvanic currents on Range of Motion (ROM) over eight therapy sessions. The data shows a steady improvement in ROM as the number of sessions increases. The trend indicates a consistent improvement in ROM, suggesting the effectiveness of galvanic currents in enhancing flexibility and movement through multiple sessions.

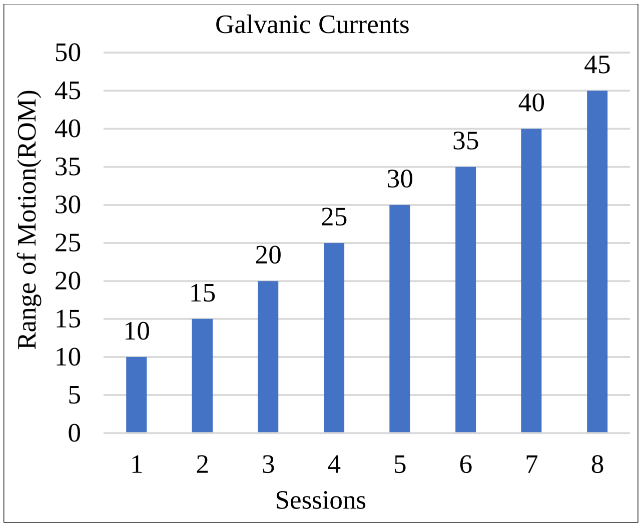

Fig. 5 Range of motion for galvanic current

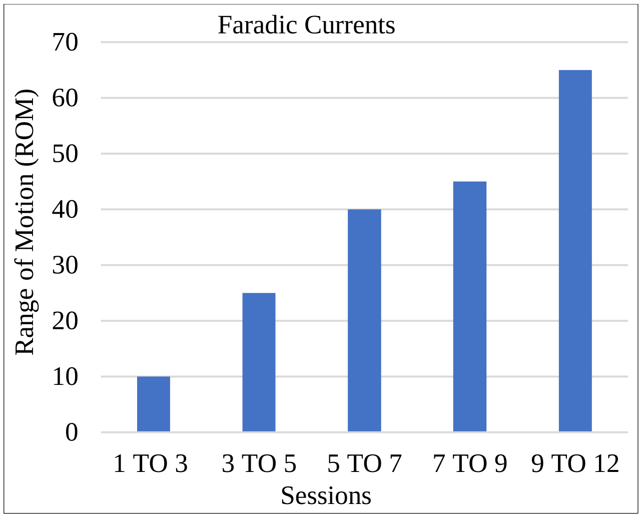

Fig. 6 Range of motion for faradic current

Figure 6 shows a gradual and consistent improvement in ROM as the number of faradic current therapy sessions increases, showing the modality's effectiveness in enhancing movement over time. Table 1 summarizes the therapeutic effects of various electrical stimulation treatments on different patients. Patient SK (56) improved ankle dorsiflexion post-foot drop after receiving galvanic square wave signals (100-600ms).

Patient PC (22) experienced enhanced pronation and supination in the right radioulnar joint following faradic biphasic pulse application (300us to 1ms, 30-70Hz) after tendon transfer. Patient RD (40) reported significant pain relief from postoperative pain after 10 sessions of high-frequency TENS (60-100pps). For Patient MV (66), low-frequency TENS (2-4pps) reduced phantom limb pain after below-knee amputation. Patient AK (27) showed reduced low back pain intensity through interferential currents. At the same time, Patient AK (87) experienced decreased pain and swelling from osteoarthritis in the knee after treatment at a frequency of 80-100Hz.

Table 1. Evaluation of electrical current types and their therapeutic effects in rehabilitation

Sr. No	Chief Complaints	Type of Current Used	Therapeutic Effects
1-SK (56)	Loss of ankle dorsiflexion post foot drop.	Galvanic square wave signal of 100-600ms was applied.	The patient showed improvement in control of ankle dorsiflexion
2- PC (22)	The patient complained of loss of movement after tendon transfer of the right hand.	Faradic Biphasic pulses of 300us to 1ms with freq. 30-70Hz was applied.	Increase in range of pronation and supination of the right radioulnar joint.
3-RD (40)	Postoperative pain.	TENS (high) High-frequency TENS with 60-100pps was applied.	After 10 sessions of 30 minutes each, Significant pain relief was observed.
4-MV (66)	Post lower limb (below knee) amputation surgery.	TENS (Low): Low frequency signals with 2-4pps for long duration were applied.	Reduce phantom limb pain after 10 sessions of 45 minutes each.
5 AK (27)	Low back pain	Interferential currents of slightly different frequencies were applied.	Reduction in pain intensity was verified using a Numerical Pain Rating Scale (NPRS).
AK (87)	Osteo Arthritis knee	A frequency of 80-100Hz was applied.	A reduction in pain and swelling was observed.
1-SK (56)	Loss of ankle dorsiflexion post foot drop.	Galvanic square wave signal of 100-600ms was applied.	The patient showed improvement in control of ankle dorsiflexion

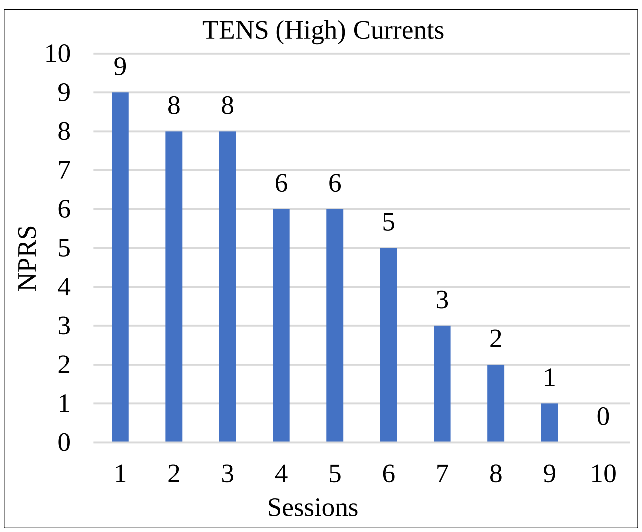

Fig. 7 Effectiveness of TENS (High) currents, with Numerical Pain Rating Scale (NPRS)

Figure 7 shows the bar chart for TENS (High) Currents, which demonstrates the reduction in pain intensity across 10 therapy sessions, measured using the Numerical Pain Rating Scale (NPRS). Figures 7, 8, and 9 show galvanic and faradic currents target mobility (ROM) improvements and TENS focuses on pain relief. Both approaches demonstrate effectiveness but in distinct therapeutic outcomes. TENS High shows a rapid initial decrease in pain, offering immediate relief. However, the effect might plateau after several sessions. While TENS Low Exhibits a slower but more consistent reduction in pain over time, its effects become more pronounced after several sessions [21].

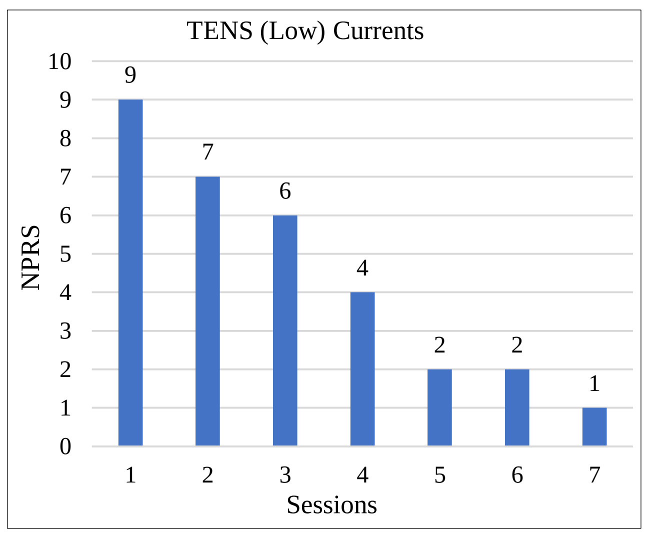

Fig. 8 TENS (Low) currents on pain relief, with Numerical Pain Rating Scale (NPRS)

Figure 8 shows that in session 1, the pain level (NPRS) starts at 9, indicating a high pain level. Over the course of the next sessions, a steady reduction in pain is observed. By session 3, the NPRS has dropped to around 6. By session 6, the pain level is approximately 4. The most significant reduction happens after session 6, with NPRS dropping steeply to 1 or 0 by sessions 9 and 10. The graph demonstrates that applying TENS (High) currents resulted in a significant decrease in pain after multiple treatment sessions. As shown in Figure 8 at session 1, the pain level starts at high pain intensity. As the sessions progress, there is a steady and noticeable reduction in pain. By session 2, the NPRS drops to around 7.

By session 4, the pain level reduces to approximately 4. Pain continues to decline, and by session 6, the NPRS is about 2. Finally, at session 7, the pain level drops to nearly 1, showing a very low pain intensity. The use of TENS (Low) currents demonstrates a progressive reduction in pain over the course of 7 sessions. The patient experienced a significant decrease in pain, especially after the 4th session, with pain nearly eliminated by the end of the treatment. This suggests that TENS (Low) effectively relieves pain over multiple sessions.

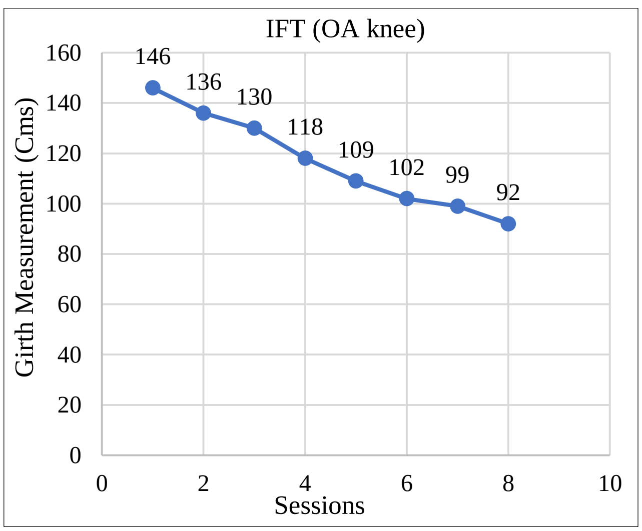

Fig. 9 Effect of Interferential Therapy (IFT) on knee girth reduction in Osteoarthritis (OA) patients over multiple sessions

Figure 9 shows at the start (session 1), the knee girth is around 140 cm, indicating significant swelling due to osteoarthritis. As the treatment progresses, there is a consistent reduction in the girth measurement. By session 4, the girth decreases to around 120 cm. By the final session (session 9), the girth was further reduced to about 80 cm.

The graph shows that IFT treatment effectively reduces knee swelling in osteoarthritis patients over time. After several sessions, there is a noticeable decrease in girth, reflecting a significant reduction in inflammation or fluid accumulation in the knee. Figure 10 shows that LBT focuses on chronic pain and provides gradual relief, while OA delivers faster, more acute pain management. IFT (LBT) would show a slower but consistent decline in NPRS over time.

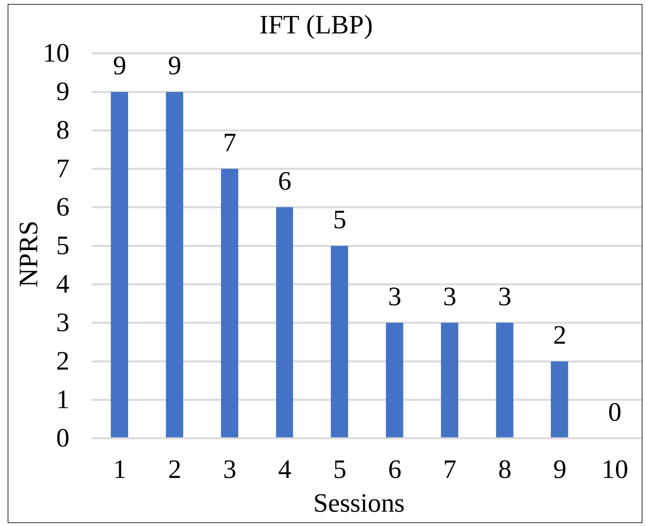

Fig. 10 LBT treatment

6. Conclusion

The above results were taken after successfully treating patient SK (56) suffering from ankle dorsiflexion. Galvanic currents were given, and the ankle's range of motion was achieved at 45 degrees. PC (22) the patient was suffering from loss of hand movement after 12 sessions of faradic currents 0 deg to 65deg, a functional range that was achieved. RD (40) patient was complaining about unbearable pain, and after around 9-10 sessions using TENS high currents, the pain was significantly reduced. MV (66) post-amputation surgery, the pain relief was achieved using TENS low currents.

AK (27) low back pain complaint was treated using IFT currents, and pain relief was noted using the NPRS scale. AK (87) The OA knee patient had complaints of swelling and pain; the girth of the knee was 150 cms; after 6-8 sessions of IFT treatment, the swelling was reduced to around 92cms which is a near normal knee. All the treatments were given under well-educated physiotherapists using various electrotherapy modes such as faradic, galvanic, TENS (High), TENS (Low), and IFT offered by the machine. The results are presented after considering patients' concerns, proving the effectiveness of different currents in therapeutic modalities.

6.1. Clinical Implications and Future Research

The findings demonstrate the clinical efficacy of a portable electrotherapy device in treating various conditions, including pain management, muscle re-education, edema reduction, and joint mobility improvement, using modalities like faradic, galvanic, TENS, and IFT. Its portability and versatility make it suitable for diverse settings, from clinics to home care, offering tailored treatments through customizable parameters. Future research should focus on optimizing treatment protocols, exploring long-term efficacy, integrating wearable technology, and expanding applications to conditions like stroke rehabilitation and peripheral neuropathy. Additionally, studies on cost-effectiveness, safety, and combination therapies can further enhance their clinical utility and accessibility, ensuring broader adoption and improved patient outcomes.

Acknowledgments

The authors would like to thank Ashutosh Kulkarni, Astronic Techno Systems LLP, and Richa Deshpande Health Point Polyclinic, Pune, for their support and the resources, insightful comments and assistance during the various stages of the research.

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