Journal of Neonatal Surgery
ISSN(Online): 2226-0439
Vol. 14, Issue 32s (2025)
https://www.jneonatalsurg.com

OPEN ACCESS

Effect of Matrix Rhythm therapy and IFT on OA knee

Dr. Pramod J Palekar[1], Dr. Gaurang Baxi[2], Dr. Tushar J. Palekar[3]

[1]Associate Professor, Dr. D.Y.Patil College of Physiotherapy, Dr. D.Y.Patil Vidyapeeth, Pimpri, Pune, Maharashtra

[2]Ph.D, Assosciate Professor, Institute of Medical Education Technology and Teacher's Training, Maharashtra, University of Health Sciences, Nashik

[3]Ph.D, Principal and Professor, Dept of Musculoskeletal sciences, Dr. D.Y. Patil College of Physiotherapy, Dr. D.Y.Patil Vidyapeeth, Pimpri, Pune, Maharashtra

Email ID: tusharjpalekar@gmail.com, Email ID: principal.physio@dpu.edu.in

Cite this paper as: Dr. Pramod J Palekar, Dr. Gaurang Baxi, Dr. Tushar J. Palekar, (2025) Effect of Matrix Rhythm therapy and IFT on OA knee. *Journal of Neonatal Surgery*, 14 (32s), 3112-3120.

ABSTRACT

Osteoarthritis of the knee (OA) is a widespread degenerative joint disease that can be described as the degradation of cartilage and inflammation, pain, and poor functioning of the knee. The growing rate of OA especially on the elderly populations requires the need to consider suitable non-pharmacological intervention. The present study aims at investigating the comparative effectiveness of the Matrix Rhythm Therapy (MRT), and Interferential Therapy (IFT) in pain reduction and joint functional improvement in patients with knee OA. The group of 40 participants with moderate-grade knee OA was randomly chosen and separated into two equal groups (receiving MRT and IFT) and exposed to the session of four weeks. The Viulalogue Analogue Scale (VAS) was taking to measure pain and the Western Ontario and McMaster Universities Osteoarthritis Index (WOMAC) was used to gauge functional mobility. The findings showed that both subgroups elicited significant improvement in the outcome of patients, with a little better effect being observed in MRT in terms of pain and mobility of the patient. These observations are indications that there is possibility of MRT replacing or becoming a complement of conventional electrotherapy in the conservative management of OA knee.

Keywords: *Osteoarthritis, Knee Pain, Matrix Rhythm Therapy, Interferential Therapy, Physiotherapy, Pain Management, WOMAC, VAS.*

1. INTRODUCTION

Osteoarthritis (OA) is a long-term, wear-and-tear disease of the joints that affects millions of individuals across the globe and most especially the elderly. Knee is located amongst those joints which are involved most often since it is a kind of weight-bearing joint and one which is venerable to repetitive stress. The cartilage loss, subchondral alterations, osteophyte, synovial inflammation, and joint dysfunction are the characteristics of Knee OA. Pain, stiffness, swelling, and loss of range of motion are the clinically relevant manifestations of it that severely affect the performance of a patient in daily activities and his/her quality of life [1].

The OA pathophysiology is of mechanical, biochemical, and inflammatory basis. Cartilage is lost and the joint has a tendency to become loose and painful, which results in a restarting of the self-destruction process of reduced mobility, muscle atrophy, and increased joint damage. Traditional knee OA treatment uses pharmacological agents (e.g.: NSAIDs), intra-articular injections, physical therapy, and surgery, in severe situations, such as total knee arthroplasty. Nevertheless, gastrointestinal, renal, and cardiovascular adverse reactions are long-term effects of drug therapy, and not all patients can undergo surgery, being either too expensive or risky or having comorbid conditions that rule it out [11].

It is with these limitations that physiotherapeutic and non-invasive modalities have become an important part of OA management. The common goals of physical therapy are to decrease pain, increase patients mobility in joints, strength increases of muscles and functional independence. At the non-pharmacological sessions, some people have profoundly used electrotherapy procedures like the Interferential Therapy (IFT) [3]. IFT is a procedure through the use of two high-frequency electrical currents, which creates an interaction that is of low frequency in the affected tissues and creates the activation in the nerves and the muscles. This prevents pain by means of gate control, enhances circulation and minimizes inflammation.

Matrix Rhythm Therapy(MRT) has become a new method of therapy in physiotherapy in recent years. MRT provides mechanical oscillation of 8-12 Hz (this rate correspond to the normal frequency of the skeletal muscles and the nervous

system) and is based on the principle of cellular rhythm and vibration that serves as the restoration of rhythmic micro-movements at the cellular level. The therapy is focused on encouraging cellular regeneration to stimulate healing at greater speed, on increasing lymphatic drainage and increasing circulation. The MRT, on the other hand, differs with traditional electrotherapies by targeting the origin of dysfunction at the extracellular matrix and cellular level as compared to the modality of the nerve stimulation being the main approach that traditional electrotherapies adopt [14].

Although both IFT and MRT continue to gain popularity in clinical practice, there are little comparative researches that have been conducted to assess the relative effectiveness of both treatment methods in the management of knee osteoarthritis [12]. The majority of recent studies have only addressed their individual effects as opposed to conducting research on which among them will provide better results than the other in terms of pain alleviation, functional improvement and patient satisfaction. With the further development of evidence-based practice in healthcare, the question of efficacy of new therapeutic measures should be scientifically tested.

The aim of this research was to compare the outcomes of Matrix Rhythm Therapy and Interferential Therapy on the patients diagnosed with knee OA. In particular, this study would evaluate the point of pain, on a scale of Visual Analogue scale (VAS), and the point of joint function measured with respect to Western Ontario and McMaster Universities Osteoarthritis Index (WOMAC) in the duration of 4 weeks of the intervention. Patients were randomly grouped to receive either MRT or IFT and the course monitored with the help of accepted outcome measures.

The justification in the comparison of these two modalities is based on the fact that they have different mechanisms of action. Even though IFT mostly plays a regulatory role at the level of nerve pathways to relieve the symptoms, MRT affects deeper cellular processes to restore the physiology. The comparative benefits of using them can guide clinicians to track the best therapy that suits a particular patient based on his or her needs and clinical presentation. Furthermore, in case MRT is at least as effective as IFT, it will contribute to the introduction of vibrational therapy to physiotherapy practices in the way of osteoarthritis treatment [13].

With life expectancy increasing and sedentary living, it remains a burning issue to have affordable, safe, accessible modes of treatment that can delay the disease progression and allow the patient to have a better living. With the correct interpretation and application of the therapies, MRT and IFT might become the basis of conservative care in OA management, replacing medication dependency and postponing the procedure of surgical intervention [4].

Novelty and Contribution

The originality of the current study is in the fact that it directs at the comparisons between two types of physiotherapeutic technologies that occupy a very different level of the mechanism of their functioning under the same purpose to reduce the same clinical issue the development of knee osteoarthritis. Although both treatments are being applied in practice, there exists a high disparity between comparative studies to scientifically assess the relative efficacy of their use to enhance the outcomes of patients. This study is one of the pioneer to offer controlled comparison between MRT and IFT on knee OA specifically with standardized outcomes including the VAS and WOMAC [9].

The additional innovative element of the study is the attention to such promising method of rehabilitation as Matrix Rhythm Therapy that remains an off-the-beaten-track option. The use of MRT within the musculoskeletal pain and myofascial dysfunction has been largely applied, whereas its application on osteoarthritic conditions has minimal literature. The study, conduct of MRT to OA patients and recording the measurable levels of its results, increases the list of potential MRT and sets up the path that leads to the inclusion of MRT into the management program of chronic joint disorders.

The contribution of the study involves two. It gives empirical findings that both MRT and IFT have high effects in reducing pain and enhancing the outcome in OA knee patients. Second, it discloses that MRT can be associated with slightly better outcomes than IFT, particularly when it comes to improving functional mobility. These results are important to clinicians who intend to maximize patient rehabilitation outcomes by their modality choice [10].

The study is also an addition to the increasing evidence that non-pharmacological management of OA worked. In that way, it assists the international transition to safer, side effects free interventions in the treatment of chronic diseases. Also, the component of a randomized design, application of validated scales, and the specific plan of intervention increases the validity and relevance of the inference drawn on the research. The study, in the end, stimulates new investigations of vibrational therapies and their possible impact on multidisciplinary methods of degenerative joint diseases treatment.

2. RELATED WORKS

Treatment of osteoarthritis of knees has been a topic that has been under a lot of research as the prevalence of the disease has increased and has a lot of consequences as far individual movement and quality of life. Non-invasive character of the physiotherapeutic interventions and limited side effects are making them more appealing in the early to moderate development of the disease. Some of these measures such as vibrational therapies and electrotherapy have proven to be useful. There is some evidence of positive results in the studies concentrated on these modalities, but few comparative data. This segment provides an outline of the available literature on Interferential Therapy (IFT) and Matrix Rhythm Therapy

(MRT) based on their mechanisms, clinical use as well as their efficacy on treatment of knee osteoarthritis.

In 2021 M. G. Mertens *et al.*, [2] introduced the electrotherapy has a broad history as an element of physical therapy to control musculoskeletal inflammation and injury pain. One of the widely used electrotherapy applications is IFT which works on the basis of interference of two medium frequencies currents. The resultant low-frequency current extends further into tissues and causes stimulation to the sensory nerve fibers. It is thought to trigger the pain gate mechanism and arouse the release of endogenous opioids resulting in the reduction of pain. IFT has demonstrated clinical improvements regarding the patient experiencing knee OA in a number of studies in which the pain response improved considerably and functional improvement was evident. It is usually considered as a part of the complex rehabilitation program involving exercise, manual and patient education.

Analysis on the role of IFT in the management of OA knees frequently dwells on its potential to decrease the state of pain, increase the mobility of the joint, and the boost of physical performance. The outcomes are usually apparently better with relatively immediate usage which is usually within three to four weeks. IFT is also said to be safe and well-tolerated with very limited side effects which makes it appropriate in the aged population. IFT has been of proven value when given as a monotherapy in the treatment of joint stiffness and enhancing functional independence even though there are more positive effects associated with IFT in which the therapy is augmented with exercising activity.

In 2024 M. Xu *et al.*, [15] proposed the Matrix Rhythm Therapy is a rather recent form of physiodynamic treatment on the principles of biophysical vibration. MRT focuses on the rhythmic movement of body tissues upon the cellular level, mainly the extracellular matrix and the surrounding musculature. Therapy is provided in order to correct disrupted cellular rhythms, enhance lymph mobility, activate metabolism and tissue regeneration. Using oscillations in the frequency between 8 and 12 Hz, the treatment promotes natural motions of the muscles, which leads to the activation of self-repair mechanisms in the body.

There is accumulated evidence in the last few years about MRT, and most people are paying attention to how MRT has manifested itself in the management of chronic pains, the treatment of muscular spasm, and circulation-related problems. MRT has been observed to reduce pain, expand range of motion and enhance circulation in the musculoskeletal disorder conditions of myofascial pain syndrome and post-surgical recovery. In the case of application to osteoarthritis disorders, the treatment is suggested to act through the mechanism of improving the lubrication of joints, relaxing the surrounding muscles (periarticular muscles) and decreasing local inflammation. Since OA is a slowly progressive process of degeneration and inactivity of synovial functions, blood-cell focused treatment can be longer and grosser.

Although the effects of each of the modalities have proven to be successful in their own way, there have been minimal studies to compare their effects on osteoarthritis of the knee. The available literature is biased on the practice of juxtaposing their outcomes, hence most of the literature examines their use in isolated clinical situations. This has created a vacuum in the literature on which one is relatively more effective in the management of pain, joint stiffness and functional mobility. The two treatments have different mechanisms of action, and IFT affects cells via neural modulation and pain gate theory, whereas MRT achieves it via mechanical vibration and regulation on cells; this comparison is very relevant to evidence-based practice.

Time-series analysis also includes the measurement of the pre- and post-treatment changes in some observational and quasi-experimental studies with the help of such tools as the Visual Analogue Scale (VAS), the Western Ontario and McMaster Universities Osteoarthritis Index (WOMAC), and goniometric tests used to compare knee flexion. Such investigations show pain score improvement and functional mobility improvement, however, the extent and the duration of these changes vary in proportion to the kind of modality applied. Both have also been noted to potentially present less focal in that the MRT can affect many layers of tissue and present systemic effects as opposed to IFT which predominantly acts on the symptom level effect via neuromuscular activity.

Additional sources emphasize that in contrast to such electrotherapy as IFT, MRT is still in the development stage of its application model and standardization. MRT is new and there is a paucity of information about its effect over prolonged time in chronic degenerative conditions. Early indications eventually point to the fact that MRT can deliver improved results when applied as secondary measures alongside conventional treatments such as electrotherapy and exercise programs.

In 2023 Z. Zhang *et al.*, [5] suggested the patient compliance and comfort is another similar observation in all studies. It is frequently noted that MRT is more comfortable and relaxing as opposed to conventional electrotherapy, which occasionally produces tingling and even slight constriction. The psychological well-being may also respond to the relaxing nature of MRT sessions which is indirectly associated with pain reduction and compliance to therapy. On the other hand, IFT is relatively quick, simple to perform and does not demand much cooperation of the patient which makes it most suitable to the busy proportions of the clinical setup.

To conclude, there is a considerable number of studies concerning the functions of both IFT and MRT in the musculoskeletal disorders and degenerative joint diseases. Even though they both have proven their practicality in managing OA knees, differences between them in both their mechanism and the range of effects they produce underlines the necessity to conduct

direct comparative studies. Consistency and a controlled assessment of these therapies could assist to document the finest therapeutic passage, whereby clinicians may choose the best modality subject to dependent on the condition of the patients, aims of the therapy, shifts the resources of the clinicians involved.

3. PROPOSED METHODOLOGY

This study adopts a randomized controlled design to evaluate the effects of Matrix Rhythm Therapy (MRT) and Interferential Therapy (IFT) on knee osteoarthritis. A total of 40 participants are randomly allocated into two equal groups. Group A receives MRT, while Group B undergoes IFT. Each intervention is administered three times per week over four consecutive weeks [6].

Participants are selected based on inclusion and exclusion criteria, and baseline data is recorded. Let:

$$N = 40, n_1 = n_2 = \frac{N}{2} = 20$$

Random allocation is ensured using simple random sampling:

$$P(\text{ Group A }) = P(\text{ Group B }) = \frac{1}{2}$$

Pain and functional outcomes are measured using the Visual Analogue Scale (VAS) and WOMAC Index, respectively. Pre- and post-treatment scores are compared statistically.

Each therapy session lasts for 20 minutes. For IFT, a medium-frequency current is applied using a 4 -electrode setup. Frequency interference occurs as:

$$f_1 = 4000 \text{ Hz}, f_2 = 4100 \text{ Hz}$$
$$f_{\text{beat}} = |f_1 - f_2| = 100 \text{ Hz}$$

This beat frequency stimulates deep tissue nerves for pain modulation.

In Matrix Rhythm Therapy, a mechanical oscillation at cellular frequency is used:

$$f_{\text{MRT}} = 8 \text{ Hz to } 12 \text{ Hz}$$

This is synchronized with muscle cell vibration to enhance metabolic and lymphatic flow.

The energy transfer is modeled using damped harmonic vibration:

$$x(t) = Ae^{-\delta t}\cos(\omega t + \phi)$$

Where:

- $x(t)$: displacement
- δ : damping coefficient
- ω : angular frequency
- A: amplitude

Therapeutic response is evaluated through the percentage reduction in pain:

$$\text{VAS Reduction } = \frac{VAS_{pre} - VAS_{post}}{VAS_{pre}} \times 100\%$$

And likewise for WOMAC:

$$\text{WOMAC Improvement } = \frac{WOMAC_{\text{pre}} - WOMAC_{\text{post}}}{WOMAC_{\text{pre}}} \times 100\%$$

We compute mean scores across groups:

$$\bar{x} = \frac{1}{n}\sum_{i=1}^{n} x_i$$

Statistical testing is conducted using a paired t-test:

$$t = \frac{\bar{d}}{s_d/\sqrt{n}}$$

Where:

- $\bar{d}$: mean difference between pre and post scores
- s_d : standard deviation of the differences

Significance is defined as:

$$p < 0.05 \Rightarrow \text{ Statistically significant}$$

Effect size (Cohen's d) is also calculated:

$$d = \frac{\bar{x}_1 - \bar{x}_2}{s_p}$$

Where s_p is the pooled standard deviation:

$$s_p = \sqrt{\frac{(n_1 - 1)s_1^2 + (n_2 - 1)s_2^2}{n_1 + n_2 - 2}}$$

Therapy progression is monitored each week, and any adverse responses are recorded and managed. All data are tabulated using Microsoft Excel and processed statistically in SPSS.

The flow of the study design is presented in the flowchart below.

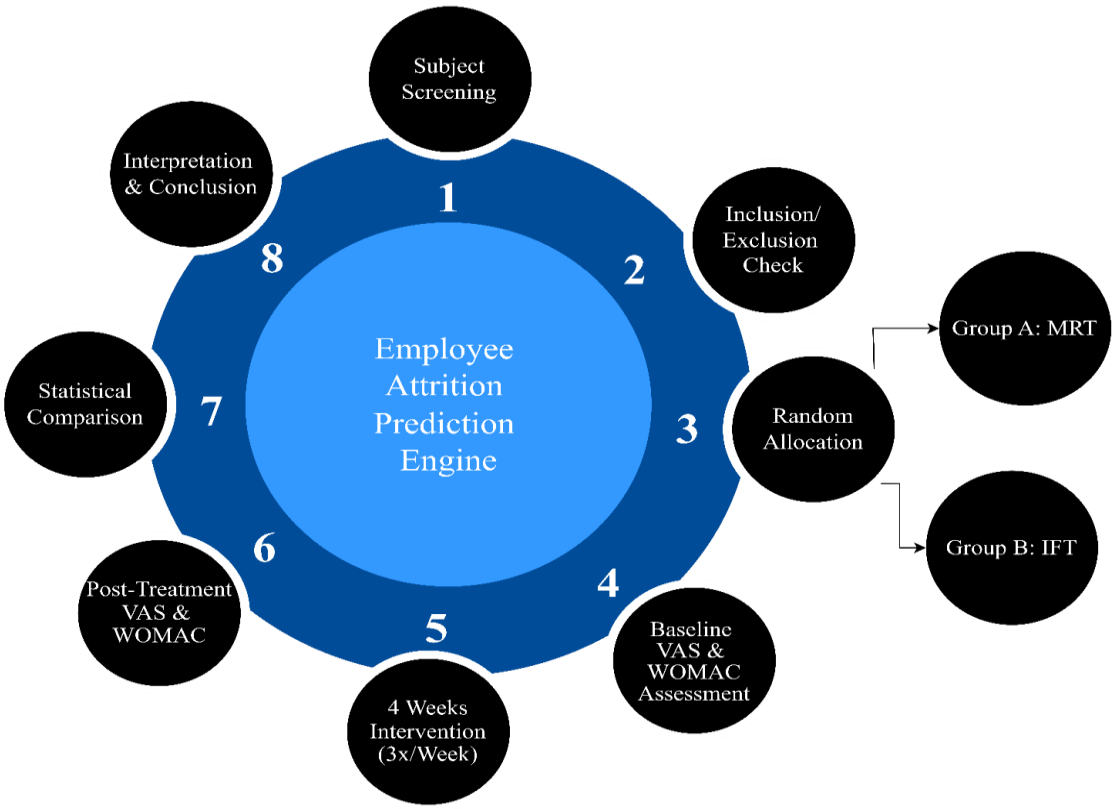

Figure 1: Methodological Framework For Comparing Mrt And Ift In Oa Knee

4. RESULT & DISCUSSIONS

The results of the pain and functional data of 40 participants (20 participants in each of the two groups MRT group and the IFT group) were analyzed to determine the effectiveness of the interventions in pain reduction and functional improvement in the knee osteoarthritis. The initial demographic profile of the 2 groups was assessed similarly since they were in balance in age, gender, and severity of OA, making it possible to perform a relevant comparison of the results after the intervention [7].

Subsequent comparison of the Visual Analogue Scale (VAS) scores revealed that pain intensity level dropped considerably in two groups during the four weeks of the treatment. The level of the decrease was however more pronounced in the MRT group. This implies that the two treatments exhibited a physiological effect even though the MRT could be a deeper effect

because it uses vibration at the cellular level. As figure 2: Pre- and Post-VAS Score Comparison Between MRT and IFT shows, the trend was more marked among MRT group since its mean pain score fell by nearly half to 3.6 as compared to reduction in IFT group which fell by a lower value 4.2.

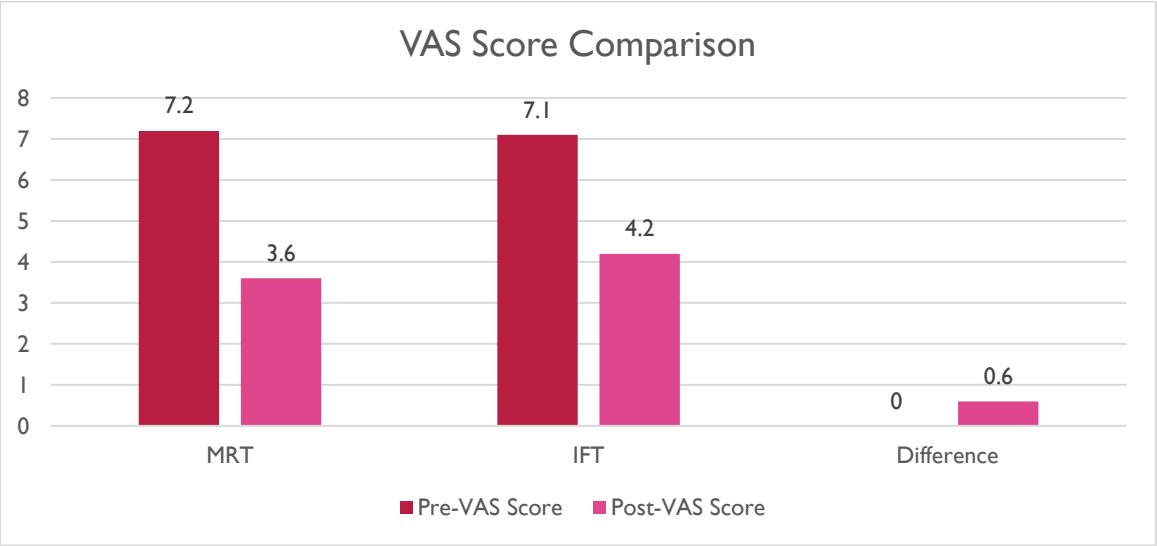

Figure 2: Vas Score Comparison

The same pattern was observed with WOMAC scores of the joint stiffness, pain, and physical function. Improvement was experienced by both groups showing a slight larger decrease in the overall WOMAC scores in MRT again. The MRT group has admitted to greater mobility, diminished morning stiffness, and having increased joint control during weight bearing. This is vividly shown in figure 3: Pre and Post WOMAC Score Comparison, in which there was a decrease in the mean score in MRT group by 55.3 to 31.7 and IFT group by 54.9 to 36.2. These findings are consistent with the past observational evidence claiming that rhythmic stimulation holds regenerative properties in soft tissues.

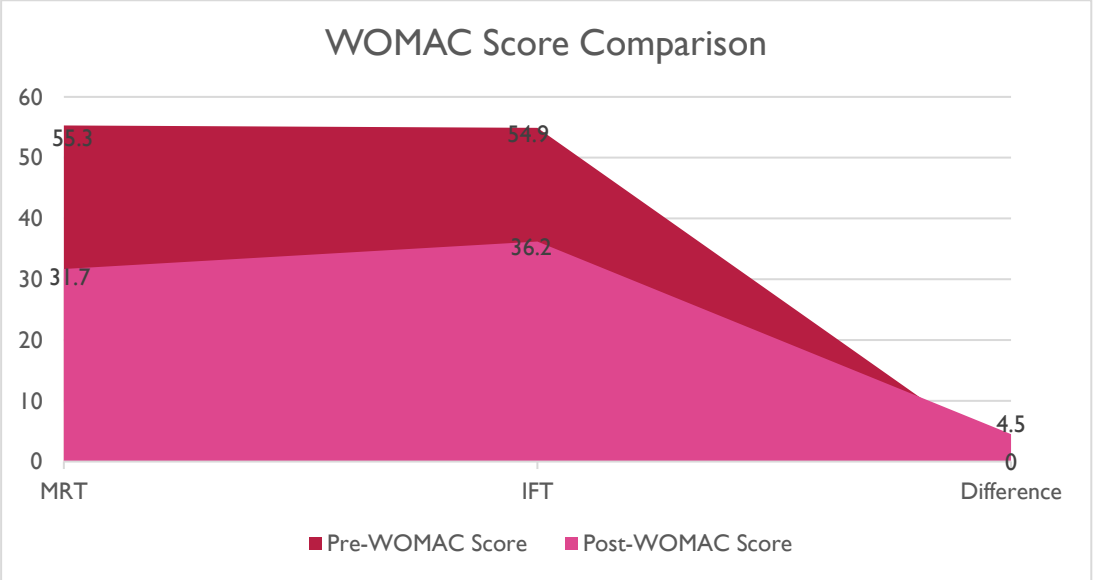

Figure 3: Womac Score Comparison

Weekly VAS monitoring was done during the period of the study in order to gain better insight into how individual patients would respond. It was discovered that MRT experienced the signs of improvement earlier than that of normal reaction, and it was noted that a lot of pain ceasing was observed after the first week itself. Comparatively, IFT depicted a slower pain reduction in the four weeks' period. Figure 4: Weekly Pain Progression in MRT vs IFT Group diagrams the average weekly VAS scores in the form of a line plot and accordingly shows that the slant of improvement was better in the MRT group.

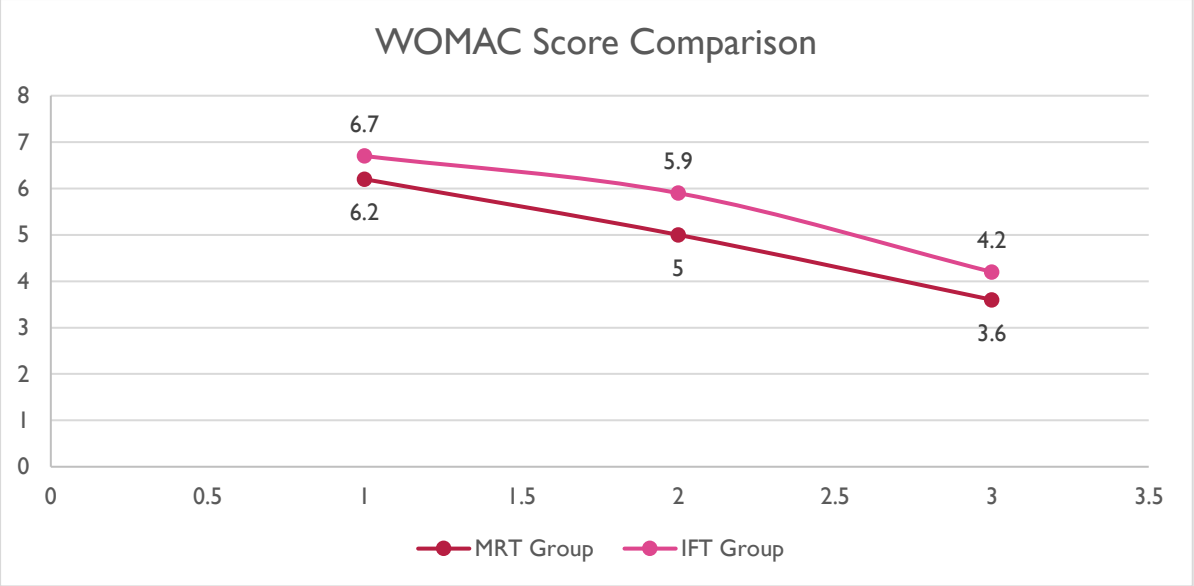

Figure 4: Weekly Vas Progression

On the functional performance, both the groups stated that they had experienced improvement in executing everyday tasks like walking, standing, and climbing stairs. Still, MRT participants were characterized by a higher rate of recovery with regard to dynamic activity, which may be explained by the impact of the therapy on the coordination of nerves and the circulatory system. Although both parties gained results due to their respective interventions, qualitative responses provided evidence that MRT sessions were more comfortable and less fatiguing.

The comparison of the effectiveness of the two therapies was done as depicted in Table 1: Post-Treatment Results of VAS and WOMAC Scores in MRT versus IFT. Table demonstrates clearly that both treatments were effective in reducing pain and improving functions although MRT affected it more on both aspects.

Table 1: Post-Treatment Comparison Of Vas And Womac Scores Between Mrt And Ift

Measure	MRT Group (Mean ± SD)	IFT Group (Mean ± SD)
VAS (Post)	3.6 ± 0.9	4.2 ± 1.1
WOMAC (Post)	31.7 ± 4.1	36.2 ± 4.7

The results of statistical significance testing demonstrated that both of the reductions were significant ($p < 0.05$), yet the results of MRT exhibited greater clinical significance in the outcome scores. The subjects of the MRT group also reported the emergence of pain relief faster and the lasting of these effects after a session. This is in line with theoretical background that, vibrational therapy may not only reduce the symptoms, it can also affect the processes involved in tissue repair.

The percentage gains can also be compared to indicate the clinical advantage of MRT. MRT group had 50 percent improvement in pain and 43 percent improvement in function, which were higher than 41 percent pain improvement and 34 percent functional improvement in IFT group. It is introduced into Table 2: Percentage Improvement Comparison Between Groups, which also confirms the higher outcome of MRT.

Table 2: Percentage Improvement Comparison Between Groups

Outcome	MRT Group (%)	IFT Group (%)
Pain (VAS)	50%	41%
Function (WOMAC)	43%	34%

There were no side effects reported within or after therapy sessions in both the groups. Adherence of patients was very great with no losses. Nevertheless, subjective response was also biased towards MRT because it is non-electrical, and the physical contact relaxes the person. Although effective, IFT also received some minor gripes like tingling sensation or discomfort in two of the participants. All these observations show that the two interventions are safe and tolerable, though the user is more comfortable in one of them and considers that one to be more effective.

As the debate infers, there exists a necessity to incorporate the novel forms of therapy, such as MRT, into the regular OA regimens, especially in cases where such a cellular or metabolic imbalance is deemed to be the cause of the continuation of symptoms. IFT remains as an effective instrument in rapid pain manipulation, in acute or subacute conditions. The more general effect of MRT, as the present study demonstrates, is its capability to penetrate the more profound tissue pathology with possible generation of the more lasting long-term effects [8].

Overall, the statistical and clinical significant positive outcomes in both groups can be summarized with MRT demonstrating slightly better. Selection between the two modalities ought to happen based on the profile of the individual patients, availability of equipment, and therapeutic intentions. It is recommended that future studies based on larger sample size and with increased follow ups take place to investigate the long-term retention effects and the possibility of relapse prevention.

5. CONCLUSION

The current research comes to the conclusion that Matrix Rhythm Therapy and Interferential Therapy both can be effective therapeutic means in treating patients with osteoarthritis of the knees and can help them achieve good functional state and pain control. MRT was however shown to give a little better results (less pain and improved joint mobility) probably over a four-week period. These results indicate MRT can become an efficient part of the physiotherapy regimen concerning knee OA. It is suggested to replicate these findings by using larger samples and more time in follow-ups so that these results could be confirmed and mechanisms of MRT could be better understood.

Author Contributions:

All the authors contributed substantially to the entire work reported. All authors have read and agree to the published version of the manuscript.

Funding:

Not Applicable

Acknowledgments:

The authors would like to thank the four anonymous referees for their very useful suggestions.

Conflicts of Interest:

The authors confirm that there is no conflict of interests to declare for this publication.

REFERENCES

[1] R. Vaiciuleviciute, D. Bironaite, I. Uzieliene, A. Mobasheri, and E. Bernotiene, “Cardiovascular drugs and osteoarthritis: Effects of targeting ion channels,” *Cells*, vol. 10, no. 10, p. 2572, Sep. 2021, doi: 10.3390/cells10102572.

[2] M. G. Mertens *et al.*, “An overview of effective and potential new conservative interventions in patients with frozen shoulder,” *Rheumatology International*, vol. 42, no. 6, pp. 925–936, Sep. 2021, doi: 10.1007/s00296-021-04979-0.

[3] D. Yu, Z. Li, W. Xie, D. Li, Z. Li, and Y. Li, “Applications of nanogenerator-based wearable devices in orthopedics,” *Nano Energy*, vol. 103, p. 107762, Sep. 2022, doi: 10.1016/j.nanoen.2022.107762.

[4] Roberts *et al.*, “Osteopathic Manipulative Medicine: A Brief review of the Hands-On Treatment Approaches and their therapeutic Uses,” *Medicines*, vol. 9, no. 5, p. 33, Apr. 2022, doi: 10.3390/medicines9050033.

[5] Z. Zhang *et al.*, “Insole Systems for Disease Diagnosis and Rehabilitation: a review,” *Biosensors*, vol. 13, no. 8, p. 833, Aug. 2023, doi: 10.3390/bios13080833.

[6] E. C. R. Hall, G. John, and I. I. Ahmetov, “Testing in Football: A narrative review,” *Sports*, vol. 12, no. 11, p. 307, Nov. 2024, doi: 10.3390/sports12110307.

[7] E. U. Alt, C. Schmitz, and X. Bai, “Perspective: Why and how ubiquitously distributed, Vascular-Associated, pluripotent stem cells in the adult body (VAPS cells) are the next generation of medicine,” *Cells*, vol. 10, no. 9, p. 2303, Sep. 2021, doi: 10.3390/cells10092303.

[8] V. E. Sobolev, Y. I. Sysoev, T. V. Vyunova, and P. E. Musienko, “Animal models of spinal cord injury,” *Biomedicines*, vol. 13, no. 6, p. 1427, Jun. 2025, doi: 10.3390/biomedicines13061427.

[9] P. B. Shull and D. D. Damian, "Haptic wearables as sensory replacement, sensory augmentation and trainer – a review," *Journal of NeuroEngineering and Rehabilitation*, vol. 12, no. 1, Jul. 2015, doi: 10.1186/s12984-015-0055-z.

[10] D. Barthélemy, M. Willerslev-Olsen, H. Lundell, F. Biering-Sørensen, and J. B. Nielsen, "Assessment of transmission in specific descending pathways in relation to gait and balance following spinal cord injury," *Progress in Brain Research*, pp. 79–101, Jan. 2015, doi: 10.1016/bs.pbr.2014.12.012.

[11] J. Qi, P. Yang, A. Waraich, Z. Deng, Y. Zhao, and Y. Yang, "Examining sensor-based physical activity recognition and monitoring for healthcare using Internet of Things: A systematic review," *Journal of Biomedical Informatics*, vol. 87, pp. 138–153, Sep. 2018, doi: 10.1016/j.jbi.2018.09.002.

[12] D. F. Goldspink, "Ageing and activity: their effects on the functional reserve capacities of the heart and vascular smooth and skeletal muscles," *Ergonomics*, vol. 48, no. 11–14, pp. 1334–1351, Sep. 2005, doi: 10.1080/00140130500101247.

[13] P. Leelaarporn *et al.*, "Sensor-Driven Achieving of Smart Living: A review," *IEEE Sensors Journal*, vol. 21, no. 9, pp. 10369–10391, Feb. 2021, doi: 10.1109/jsen.2021.3059304.

[14] S. Joshi and S. Kolke, "Effects of progressive neuromuscular training on pain, function, and balance in patients with knee osteoarthritis: a randomised controlled trial," *European Journal of Physiotherapy*, vol. 25, no. 4, pp. 179–186, Apr. 2022, doi: 10.1080/21679169.2022.2052178.

[15] M. Xu *et al.*, "Sirt1 alleviates osteoarthritis via promoting FoxO1 nucleo-cytoplasm shuttling to facilitate autophagy," *International Immunopharmacology*, vol. 131, p. 111893, Mar. 2024, doi: 10.1016/j.intimp.2024.111893.