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CLINICAL RESEARCH

Enhancing Musculoskeletal Healthcare through Mobile Application-Integrated Infrared Thermography: A Promising Approach for Diagnosis and Monitoring

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ABSTRACT

Musculoskeletal injuries, encompassing conditions affecting muscles, bones, ligaments, tendons, and joints, pose significant diagnostic and treatment challenges, often requiring subjective assessments by healthcare providers. In this study, an innovative approach was employed using infrared imaging technology integrated with a mobile application to enhance objective assessment, particularly during massage therapy. Thermal imaging captures of patients' backs during pre- and post-therapy sessions were conducted *via* the developed app to identify abnormal temperature patterns indicative of underlying conditions. This novel method of diagnosis offers a departure from traditional subjective assessments by providing quantitative thermal data for analysis. The utilization of deep learning algorithms and thermal image processing techniques further facilitated data management and analysis, offering a more precise diagnostic approach. The application's diagnostic capabilities, coupled with its ability to streamline data management, distinguish it from conventional diagnostic methods, offering potential advancements in musculoskeletal injury diagnosis and treatment. This paper elucidates the methods employed, highlights the observed results, underscores the potential of integrating advanced technologies for musculoskeletal injury diagnosis and treatment, and provides a brief overview of musculoskeletal injuries to contextualize the study.

KEYWORDS

Musculoskeletal healthcare; Infrared thermography; Mobile application; Diagnosis; Monitoring; Deep learning algorithms; Thermal image processing; Massage therapy; Objective assessment; Healthcare technology

INTRODUCTION

Musculoskeletal injuries encompass a broad spectrum of conditions affecting the muscles, bones, ligaments, tendons, and joints, often arising from trauma, repetitive strain, or underlying health issues. Musculoskeletal pain is frequently characterized in words that imply a specific cause or precise site of tissue injury [1]. The diagnosis and treatment of these injuries present significant challenges, typically relying on subjective evaluations by healthcare providers. Medical applications already implemented in microscope/imaging systems have been developed as a platform for diagnosis at POC (Point of Care) [2], infrared thermography, and phone-based oxygen level estimation system [3]. Medical applications may also assist clinical professionals with time management, patient data access, communication, consultation, patient monitoring, and medical training [4]. Hema App [1] from the University of Washington, for example, uses a sophisticated machine-learning approach to detect hemoglobin concentration using the phone's camera by employing external light sources such as an incandescent light bulb or a set of LEDs. However, these extra light sources are not widely available, and their use is limited in newer smartphones with an IR filter built into the camera lens [2].

Traditional diagnostic methods, such as physical examinations and imaging studies like X-rays or MRIs, have limitations in providing real-time, quantitative data on the physiological changes occurring within the body. Recent advancements in medical imaging have sparked interest in the use of infrared thermography for assessing musculoskeletal injuries. The treatment methods discussed here can also be used for non-specific musculoskeletal problems in general [5]. While pain may appear to be non-specific from a musculoskeletal aspect, it is critical to recognize and evaluate particular processes such as central sensitization [6].

Infrared thermography is a non-invasive imaging technique that detects thermal patterns on the body's surface by measuring infrared radiation emitted by the skin. Changes in skin temperature can signify underlying physiological alterations, including inflammation, muscle tension, or alterations in blood circulation. As such, thermal imaging holds promise as a valuable tool for objectively assessing musculoskeletal injuries.

This study aims to explore the integration of infrared thermography technology with mobile applications to enhance the objective assessment of musculoskeletal injuries, particularly in the context of massage therapy. The average normal body temperature is 37°C and a few degrees Celsius difference to this range is considered as physiologically abnormal [7]. In most cases, a raised temperature in different regions of the body is an indication of inflammation, tension, lack of blood circulation, etc. [7]. By capturing thermal images of patients' backs before and after therapy sessions, we seek to identify abnormal temperature patterns indicative of underlying conditions. Medical Infrared thermography (MIT)is a promising solution to measure the body temperature across a large area or the full body surface [8]. The development of a mobile application facilitates data management and analysis, offering a novel approach to musculoskeletal injury diagnosis and treatment.

In this research, we have developed a mobile application for the diagnosis of musculoskeletal injuries, where in an infrared camera is connected to a mobile device. This integration allows clinicians to capture thermal images of patients' bodies using the mobile application, facilitating non-invasive and efficient assessment of musculoskeletal health.

Through the mobile application, clinicians can easily access and analyze thermal images captured by the infrared camera, enabling the detection of abnormal temperature patterns associated with musculoskeletal conditions. The connectivity between the infrared camera and the mobile device presents a significant advancement in the field of musculoskeletal medicine, offering clinicians a convenient and accessible tool for diagnosing and monitoring patients' conditions in real time. By leveraging infrared technology and mobile platforms, our research aims to improve the diagnosis and treatment of individuals with musculoskeletal issues, ultimately enhancing patient outcomes and quality of care.

LITERATURE REVIEW

Musculoskeletal

The musculoskeletal system encompasses bones, muscles, joints, and related tissues like cartilage, ligaments, tendons, and bursae. It supports both stability and movement in the body. Common complaints include neck pain, limb pain, low back pain, joint pain, and generalized discomfort, often leading to primary care visits. Low back pain, being prevalent, serves as an example due to its extensive treatment evidence. Treatments discussed here are applicable to various musculoskeletal issues. While pain may seem non-specific, it's essential to address specific processes like central sensitization.

Clinical Treatment

Clinical therapy for musculoskeletal pain comprises pharmacological and non-pharmacological approaches. Pharmacological treatments, including the WHO analgesic ladder, are less effective for non-specific, chronic, or widespread pain. Tricyclic antidepressants like amitriptyline show efficacy in neuropathic pain associated with conditions like fibromyalgia and low back pain. Non-pharmacological interventions, such as physical exercise and cognitive patient education, are cornerstone treatments, ideally delivered together as part of a multidisciplinary rehabilitation program. Various physical activities, from walking to swimming, have shown to reduce pain and improve function in musculoskeletal disorders. Close monitoring of pain and adverse effects is essential when using analgesics for chronic musculoskeletal conditions [1,9].

Thermography

Thermography, utilizing infrared cameras, gauges surface temperature distribution to assess underlying structural issues or behaviour. It comes in two forms: passive and active. Passive thermography identifies temperature changes by heating the surface, revealing anomalies that may indicate underlying concerns. Active thermography, on the other hand, directly measures item temperature to pinpoint damage. Its applications span various fields such as agriculture, industry, medicine, and veterinary practice [10].

Deep Learning

Deep learning, a subset of machine learning, involves learning data representations through layers in a Deep Neural Network (DNN). Each layer transforms input data into increasingly abstract representations, culminating in predictions [11,12].

This architecture finds applications in musculoskeletal imaging, such as tissue segmentation, mage reconstruction, and illness identification [13]. Inspired by the brain's interconnected neurons, DNNs consist of input, hidden, and output layers. Convolutional Neural Networks (CNNs), prevalent in medical imaging, feature convolutional and pooling layers [12,14]. Activation functions ensure only relevant features pass between layers. Typically trained with supervised learning using paired images and labels, CNNs are evaluated for diagnostic performance post-training.

Conclusion

In this literature review we discussed every related paper with the study. But when we concentrated on the specifically musculoskeletal pain, we didn’t find any valid context for reference. For example, as mentioned earlier Hema App [3,15] from the University of Washington, uses a sophisticated machine learning approach to detect hemoglobin concentration using the phone's camera by employing external light sources. That’s where this research is valuable for finding the pains and provide a new solution to the world. This study goal is to enhance the diagnosis and treatment of individuals with musculoskeletal issues by combining infrared mobile technology with a mobile application.

According to the findings, the benefit of this technique is to track and provide a proper solution for the clients.

FUTURE WORKS

Future research in this field could focus on optimizing deep learning algorithms for more accurate detection of thermal anomalies, conducting longitudinal studies to assess long-term treatment outcomes, and developing standardized protocols for thermal imaging in musculoskeletal assessments. Integrating additional sensor data and expanding research to include larger patient populations would further enhance the utility and applicability of thermal imaging technology in clinical practice.

Future work can also focus on enhancing the mobile application's functionality and user experience, integrating features for real-time data analysis, automated report generation, and secure cloud storage. Interactive elements like educational resources and exercise programs could also be incorporated to empower patient engagement in rehabilitation. Exploring telemedicine and remote monitoring opportunities would extend the application's reach beyond clinical settings, enabling healthcare providers to assess and monitor patients' musculoskeletal health remotely. Collaboration with software developers and human-computer interaction experts would ensure the application meets diverse needs, enhancing its usability and impact in musculoskeletal healthcare.

CONCLUSION

the integration of mobile applications with infrared thermography presents a promising avenue for enhancing musculoskeletal healthcare. The developed mobile application not only enables real-time thermal imaging but also provides clinicians with convenient access to patient data, facilitating efficient monitoring and analysis. Future research could explore further enhancements to the mobile application interface, such as incorporating features for data visualization, patient management, and treatment tracking. Additionally, efforts to optimize the application for compatibility with different smart phone models and operating systems would broaden its accessibility and usability in clinical settings. By leveraging the capabilities of mobile technology, infrared thermography can be seamlessly integrated into routine clinical practice, empowering healthcare professionals with valuable tools for diagnosing and managing musculoskeletal conditions effectively.

MATERIALS AND METHODS

Hardware Setup

The first phase of the hardware setup involved procuring a FLIR One infrared camera, meticulously selected for its seamless integration with smartphones and its exceptional high-resolution thermal imaging capabilities. The

FLIR One camera, renowned for its compact design and portability, proved to be an ideal choice for capturing detailed thermal images of participants' musculoskeletal regions. With its advanced infrared sensor technology and precise thermal sensitivity, the camera ensured accurate detection and visualization of temperature variations on the body's surface. The compatibility of the FLIR One camera with smartphones facilitated convenient image capture and real-time analysis through dedicated mobile applications, enhancing the efficiency and accessibility of the thermal imaging process. The images were obtained in a room with a temperature of about 20ºC (68°F). The camera was positioned at a height of 150 cm and a distance of 2 m away from the patient to capture a full-body image. This carefully selected hardware played a pivotal role in enabling comprehensive data collection and analysis for the study's objectives.

Software Setup

The software setup commenced with the utilization of MATLAB, a multifaceted programming environment renowned for its extensive capabilities in scientific computing and algorithm development. MATLAB served as the primary platform for crafting sophisticated algorithms tailored to image processing, analysis, and visualization tasks. Leveraging MATLAB's comprehensive toolboxes and libraries, including the Image Processing Toolbox and Computer Vision Toolbox, facilitated the creation of robust algorithms optimized for thermal image analysis. These algorithms were meticulously designed to enhance the accuracy of temperature measurements, identify thermal anomalies, and extract valuable insights from the captured thermal images.

In tandem with MATLAB, Android Studio, a powerful integrated development environment (IDE) specifically tailored for Android application development, was employed to create a custom mobile application. This application was purpose-built to seamlessly integrate with the FLIR One infraredcamera and smartphones, enabling efficient thermal image capture, storage, and analysis directly on mobile devices. By harnessing the capabilities of Android Studio, developers were able to design an intuitive and user-friendly interface for the mobile application, empowering users to capture thermal images effortlessly and conduct real-time analysis of musculoskeletal regions. The synergy between MATLAB and Android Studio facilitated a seamless work flow, enabling researchers to leverage advanced image processing algorithms within a mobile environment for enhanced data collection and analysis capabilities.

Figure 1: Illustrates the different phases involved in uploading data and an infrared image captured in the application.

Data Collection

The data collection phase commenced with the recruitment of volunteers falling within the specified age range of 25 to 40 years, ensuring a diverse representation of participants for the study. Rigorous screening procedures were implemented to select individuals without pre-existing musculoskeletal conditions or contraindications that could potentially confound the study results. The data collected can be uploaded and stored in the mobile application for future implementation and patient records as shown in Figure 1.

Therapy Sessions

Participants underwent targeted traditional massage therapy aimed at musculoskeletal regions with thermal anomalies. Following therapy, a 15-minute rest period was observed to stabilize physiological responses. Post-therapy thermal imaging immediately followed the rest period to assess changes in temperature distribution. This synchronized approach enabled real-time evaluation of treatment effectiveness, providing valuable insights into the impact of massage therapy on thermal abnormalities. By allowing time for physiological equilibrium and minimizing potential confounding factors, the rest period ensured accurate thermal imaging results. Patients with persistent musculoskeletal pain disorders, such as fibromyalgia and low back pain, have discovered that tricyclic antidepressants (TCA), particularly amitryptiline, are effective in treating neuropathic pain [10]. Physical exercise and patient education with a cognitive approach are the pillars of non-pharmacological treatment, which are best delivered in tandem as part of a multi-professional rehabilitation program [10]. The difference between the image analysis before and after massage therapy is aligned in the Table 1.

Table 1: In this table summarizes the key observations and clinical significance of thermal imaging before and after therapy in individuals with and without musculoskeletal issues.

Aspects	**Before Therapy**	**After Therapy**
Healthy participants	Relatively uniform temperature distributions	Consistent thermal pro les, minimal temperature alterations
Participants with MSK issues	Localized temperature variations, indicative of inflammation, tension, or circulation issues	Reduction in localized temperature anomalies, indicating therapeutic efficacy
Observations	Baseline measurements providing insights into physiological status	Immediate physiological responses to therapeutic interventions
Clinical Significant	Understanding baseline thermal pro les for healthy individuals	Assessing treatment effectiveness and guiding therapeutic decisions
Utilizations	Monitoring patient progress and optimizing therapy protocols	Tracking treatment outcomes and guiding patient care strategies

The therapy sessions were conducted in a controlled environment, with careful temperature regulation to optimize imaging conditions. Licensed massage therapists administered the massages, utilizing manual manipulation techniques to alleviate tension and improve circulation in targeted areas. Throughout the sessions, participant comfort and safety were prioritized, with therapists adjusting techniques as needed to accommodate individual preferences. Feedback from participants was encouraged to ensure treatment effectiveness and address any concerns. The integration of thermal imaging with massage therapy allowed for comprehensive assessment and monitoring of musculoskeletal conditions. This holistic approach provides a promising avenue for enhancing diagnosis and treatment outcomes in individuals with thermal anomalies indicative of musculoskeletal issues. The complete musculoskeletal analysis is represented in the flow diagram in Figure 2.

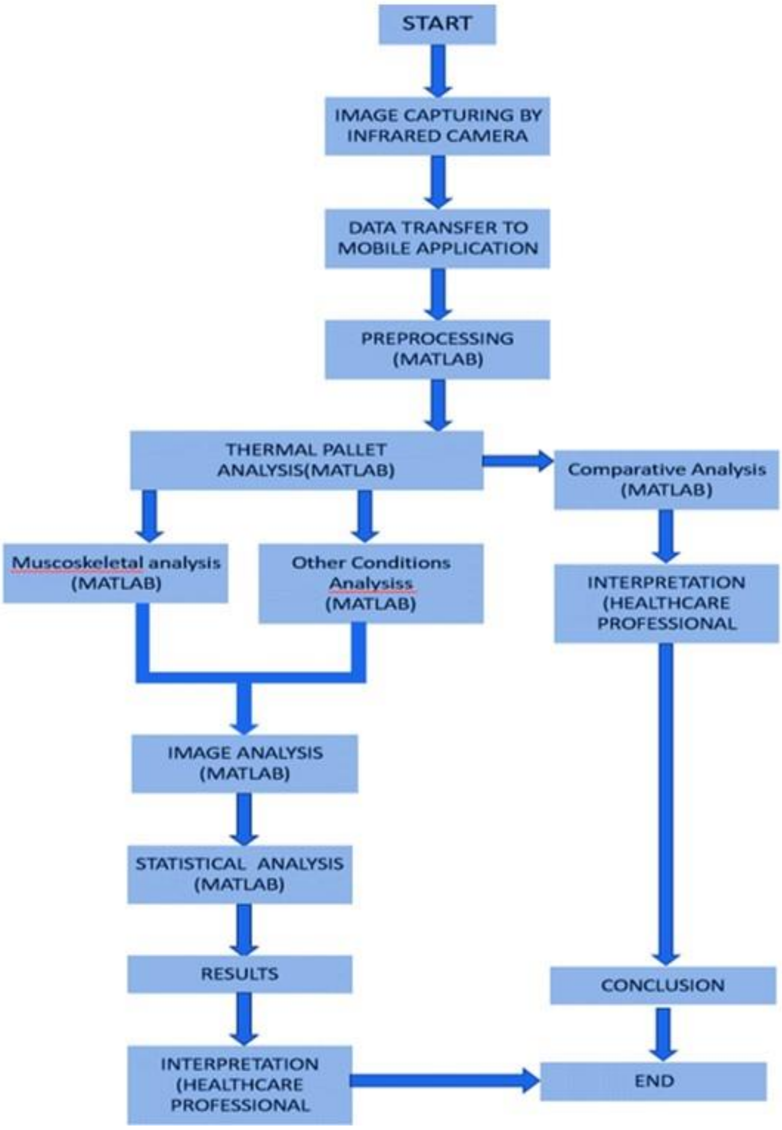

Figure 2: Musculoskeletal Analysis Procedure: Flowchart outlining the complete musculoskeletal analysis process, from infrared image capture to healthcare professional interpretation.

Image Analysis

Custom algorithms were meticulously developed in MATLAB to automate the analysis of thermal images obtained before and after therapy sessions. These algorithms were specifically designed to enhance the identification of thermal anomalies and quantify temperature changes in musculoskeletal regions. Sophisticated image processing techniques were employed to precisely locate and segment the areas of interest within the thermal images. The thermal palette is a way to represent temperature variations using color. Infrared cameras typically use various Thermal palettes where white often represents higher temperature and black color represents lower temperature Initially as shown in Figure 3. The images were pre-processed to enhance contrast and reduce noise, ensuring optimal clarity for subsequent analysis.

Subsequently, the musculoskeletal regions were delineated using advanced segmentation algorithms, which effectively separated the target areas from surrounding tissues or background. This segmentation process involved the application of thresholding, edge detection, and morphological operations to accurately define the boundaries of the regions displaying thermal anomalies.

Once the regions of interest were identified, the algorithms extracted temperature data from the thermal images for quantitative analysis. Temperature values were measured within these regions both before and after therapy, allowing for direct comparison and assessment of temperature changes over time. Statistical methods, such as mean temperature calculation and temperature distribution analysis, were employed to quantify the extent of thermal alterations associated with the therapy. Additionally, heatmaps and temperature profiles were generated to visualize the spatial distribution of temperature changes across the musculoskeletal regions. Overall, the developed algorithms provided robust tools for objective assessment and interpretation of thermal imaging data, facilitating comprehensive analysis of the therapeutic effects on musculoskeletal conditions.

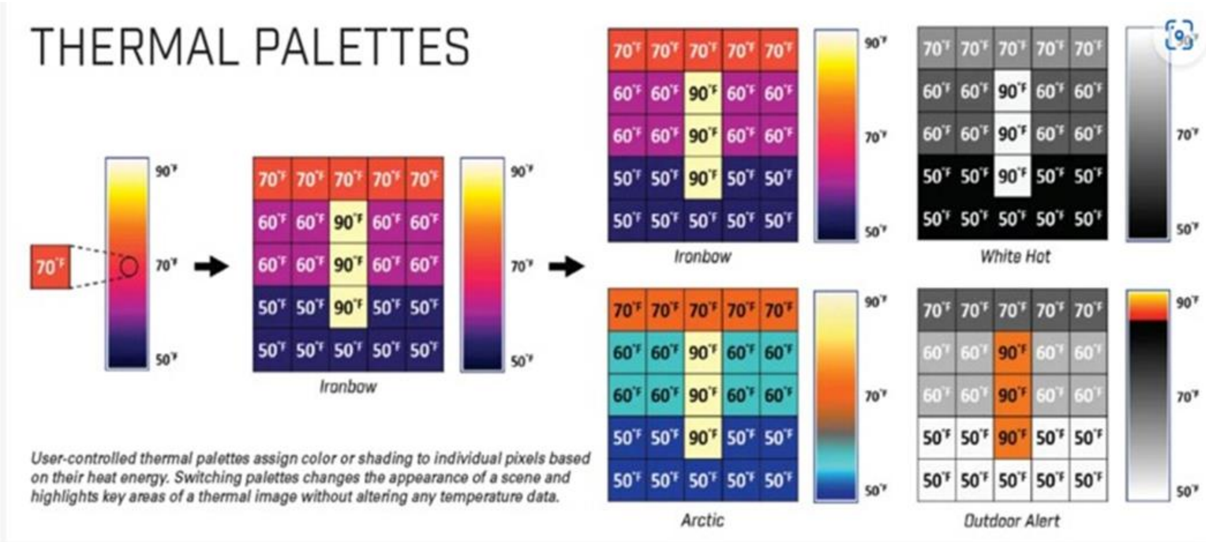

Figure 3: A thermal palette is a way to represent temperature variations using colour. Infrared cameras (eg.FLIR) typically use various Thermal palettes where white often represents higher temperature and black colour represents lower temperature.

Statistical Analysis

Utilizing MATLAB, a histogram analysis was employed to assess the significance of temperature changes observed between the pre and post-therapy images as shown in Figure 4 and Figure 5. Histograms were generated to visualize the distribution of temperature values within the identified regions of interest before and after therapy. Thermography assesses the structural damage or behavior of what is under the surface by measuring the distribution of surface temperature [5]. By plotting the frequency of temperature values against temperature bins, the histograms provided an intuitive representation of the temperature distribution and any shifts in temperature patterns following therapy.

Statistical tests, such as paired t-tests or non-parametric Wilcoxon signed-rank tests, can be conducted using the temperature data extracted from the histograms to determine histogram the significance of temperature changes.

These tests evaluated whether there were statistically significant differences in temperature distributions between the pre and post-therapy images. The results of the statistical tests were interpreted to assess the efficacy of massage therapy in modulating thermal anomalies.

Additionally, effect size measures, such as Cohen's d or eta-squared, may have been calculated based on the histogram data to quantify the magnitude of temperature changes observed between the pre and post-therapy conditions. These effect size measures provided insights into the practical significance of the observed temperature alterations, further informing the evaluation of therapy effectiveness.

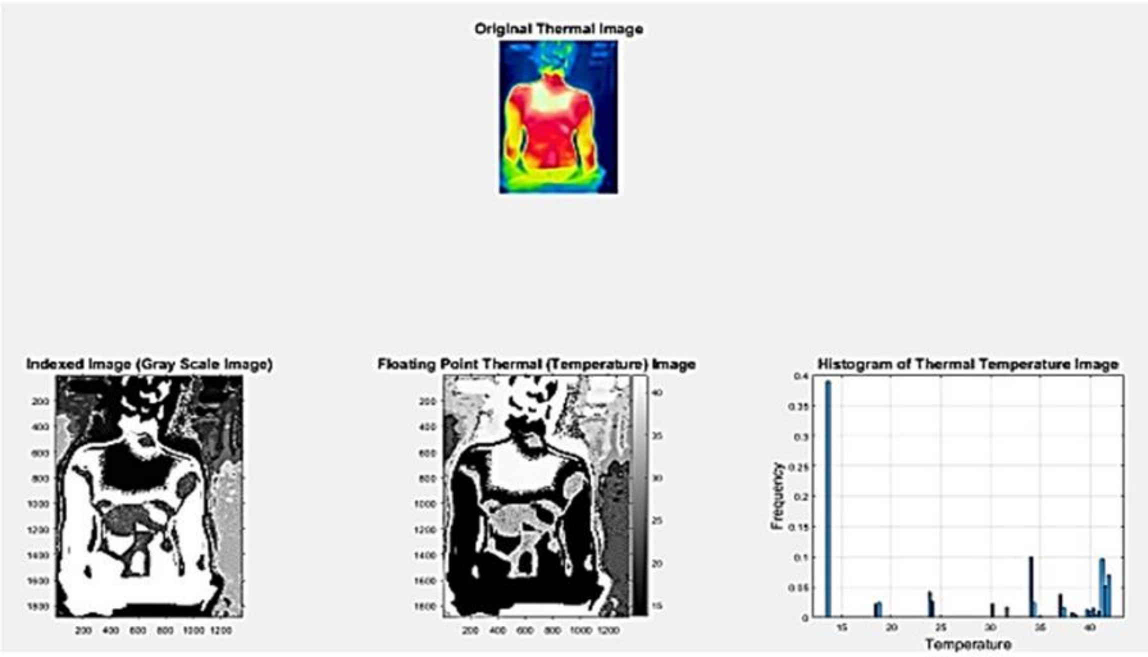

Figure 4: shows infrared images of a participant Before the therapy. The top panels use a rainbow colour scale to represent relative temperature variations, with a colour bar indicating the speci c temperature range. The bottom panels display the same images in grayscale.

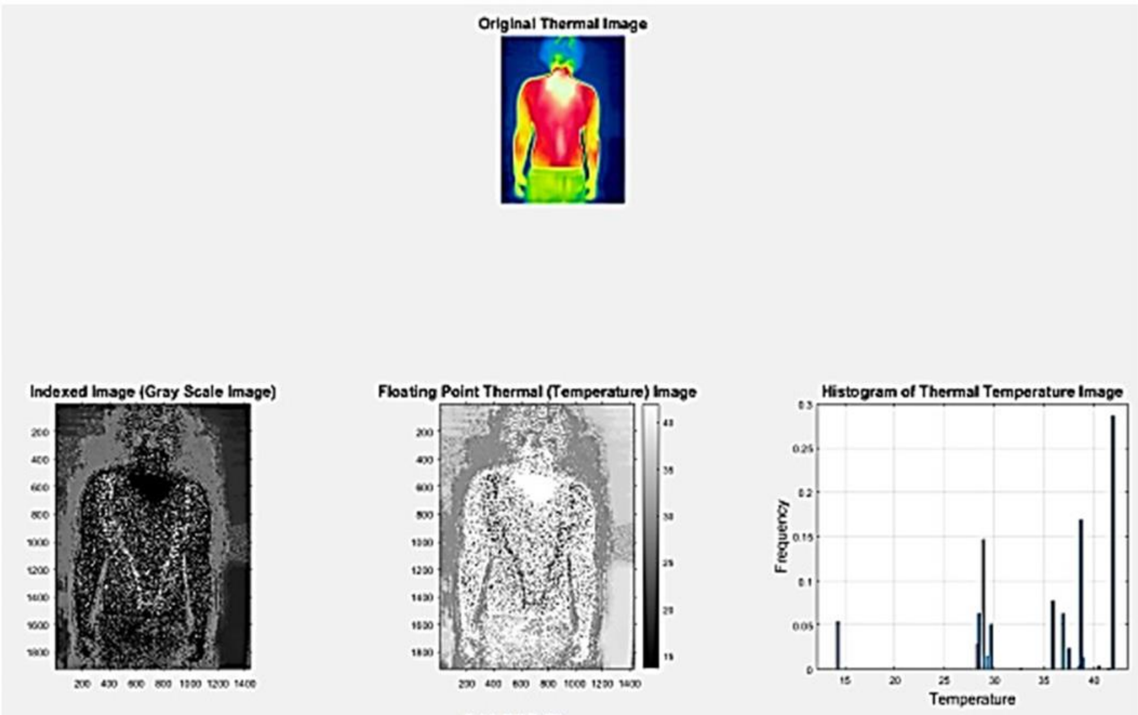

Figure 5: Infrared images of a participant After the therapy. The top panels use a rainbow colour scale to represent relative temperature variations, with a colour bar indicating the specific temperature range. The bottom panels display the same images in grayscale, where brighter areas represent warmer temperatures and darker areas represent cooler temperatures. Histogram of Thermal Temperature Image: This data visualization shows the frequency of different temperature values in the image.

Overall, the combination of histogram analysis and statistical tests in MATLAB offered a comprehensive approach to assessing the significance of temperature changes before and after therapy. This methodology provided quantitative evidence supporting the efficacy of massage therapy in mitigatingthermal anomalies associated with musculoskeletal conditions.

Ethical Considerations

Ethical considerations were diligently managed throughout the research endeavor, commencing with Institutional Review Board (IRB) approval to uphold human research standards. Informed consen tprocedures were meticulously followed, ensuring participants were fully informed about the study's objectives, procedures, and potential risks before their involvement. Robust privacy protocols were implemented to maintain confidentiality, with participant identities anonymized to protect their privacy.

Continuous monitoring and oversight mechanisms were in place to promptly address any ethical concerns or unforeseen issues that arose during the study. Adherence to the Declaration of Helsinki and institutional guidelines was paramount in upholding participant welfare and research integrity. Additionally, stringent measures were enacted to mitigate any potential discomfort or distress experienced by participants, prioritizing their well-being throughout the research process.

DECLARATIONS

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Ethical Approval

In the research described, ethical considerations were paramount throughout the study's duration.

The following details can be added to address ethical approval:

1. Institutional Review Board (IRB) Approval: Before commencing the study, approval from the Institutional Review Board was obtained to ensure compliance with ethical standards for human research. The IRB review process involved a thorough evaluation of the study protocol, including participant recruitment procedures, informed consent processes, data handling, and potential risks to participants.

2. Informed Consent Procedures: Rigorous informed consent procedures were implemented to ensure that participants were fully informed about the study's objectives, procedures, and potential risks before their

involvement. Participants were provided with detailed information about the study, including its purpose, procedures, potential benefits, and any foreseeable risks or discomforts. They were given adequate time to review the consent form and ask questions before voluntarily agreeing to participate.

3. Participant Privacy and Confidentiality: Robust privacy protocols were implemented to safeguard participant confidentiality and privacy. Participant identities were anonymized to protect their privacy, and all data collected during the study were stored securely and accessed only by authorized personnel. Any personal information collected was kept confidential and used solely for research purposes.

4. Continuous Monitoring and Oversight: Continuous monitoring and oversight mechanisms were in place throughout the study to promptly address any ethical concerns or unforeseen issues that arose. Researchers remained vigilant in monitoring participant welfare and research integrity, promptly addressing any ethical issues or deviations from the approved protocol.

5. Adherence to Ethical Guidelines: Adherence to ethical guidelines, including the Declaration of Helsinki and institutional guidelines, was paramount in upholding participant welfare and research integrity. Researchers ensured that all aspects of the study were conducted in accordance with ethical principles, including respect for participant autonomy, beneficence, non-maleficence, and justice.

By adhering to these ethical considerations and obtaining proper approval from the Institutional ReviewBoard, the researchers ensured that the study was conducted ethically and with utmost regard for participant welfare and research integrity.

Funding

Not Applicable.

Availability of Data and Materials

To access the datasets used in this study, interested parties can request access through the corresponding author. Due to privacy and ethical considerations, access to the datasets may be subject to approval by the Institutional Review Board (IRB) or other relevant regulatory bodies. Additionally, data sharing may require compliance with data protection regulations and the completion of data use agreements.

Conflict of Interest

The authors declare that there are no conflicts of interest regarding the publication of this research.

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