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Review

Infrared Thermography as a Non-Invasive Tool in Musculoskeletal Disease Rehabilitation—The Control Variables in Applicability—A Systematic Review

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Abstract: In recent years, the usefulness of infrared thermography (IRT) as a valuable supplementary imaging method in medical diagnostics, as well as for assessing the effects of the treatment of musculoskeletal injuries, has been increasingly confirmed. At the same time, great importance is attached to the standards of thermographic research, the fulfillment of which determines the correct methodology and interpretation of the results. This article discusses the medical applications of infrared thermography in musculoskeletal system diseases, with particular emphasis on its usefulness in assessing the therapeutic effects of physical treatments used in rehabilitation. The literature from the last decade that is available in the Medline and Web of Science databases has been reviewed. Among the physiotherapeutic methods used, the following were selected that directly affect the musculoskeletal system: cryotherapy, laser therapy, electrotherapy, diathermy, and massage. The article summarizes all the guidelines and recommendations for IR imaging in medicine and rehabilitation.

Keywords: musculoskeletal system; rehabilitation; thermography

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1. Introduction

Recently, there has been radical progress in diagnostic technologies; on the other hand, applications based on already known technologies are constantly emerging in the world of medicine and rehabilitation. There are various diagnostic imaging methods used for the assessment of muscosceletal disorders (MSDs), both for diagnosis and monitoring, namely plain radiographs (X-rays, XR), dual-energy X-ray absorptiometry (DXA), ultrasonography, arthroscopy, computed tomography (CT), or magnetic resonance imaging (MRI), all of which image the morphological structures. In recent years, more and more efforts have been made to investigate the causes of MSDs and take preventive action. Considerable support is provided by supplementary tests assessing the neuromuscular function, not only the structure, including electromyography [1] and infrared thermography [2]. Imaging may be used to confirm a clinical diagnosis, or its verification when there is clinical doubt [3].

The musculoskeletal system is structurally diverse, comprising bones, muscles, joints, cartilage, ligaments, tendons, and bursae. Each of these structures can be temporarily or permanently damaged or affected by many disorders. Musculoskeletal diseases and injuries are among the most disabling diseases affecting humans and have become a major public health problem worldwide, while being a leading cause of work disability, sickness absenteeism from work, and loss of productivity [4]. According to the World Health Organization (WHO), about 1.71 billion people worldwide suffer from musculoskeletal disorders that result in severe and prolonged pain [5,6].

Musculoskeletal conditions include acute and chronic diseases that affect joints (osteoarthritis, chronic polyarthritis, rheumatoid arthritis, psoriatic arthritis, gout, and ankylosing spondylitis), bones (osteoporosis, osteopenia, and osteomalacia osteonecrosis), muscles (dystrophy, myasthenia gravis, and sarcopenia, tendonitis), and the spine (low back and neck pain), as well as multiple body areas or systems with symptoms (regional and widespread pain disorders, inflammatory diseases, connective tissue diseases, and vasculitis) affecting the musculoskeletal system.

In patients with MSDs, an accurate differential diagnosis is a key to selecting appropriate treatments; moreover, monitoring of treatment effects, apart from subjective patient assessment, should also be based on objective diagnostic methods that are affordable and do not burden the patient. Research conducted in recent years has shown that infrared thermography (IRT) is useful in medical diagnostics, and also in the case of MSDs [7]. One of the arguments in favor of conducting research on the use of IRT to diagnose MSDs may be the possibility of lowering the costs of diagnosis and treatment, and minimizing radiation harmful to patients. Thermography can be useful in early diagnosis and for monitoring the effectiveness of rehabilitation because of its high sensitivity in several situations: to assess pain during muscle injuries, inflammation in injuries and in degenerative and rheumatic changes, occupational disorders, ischemic areas, excessive friction in dentures, joint overload, asymmetry of muscle tone and activity, and various motor diseases.

In this article, the authors discuss the medical applications of IRT for musculoskeletal system diseases, with particular emphasis on its usefulness in assessing the therapeutic effects of physical procedures used in rehabilitation. The authors provide guidelines and recommendations for those interested.

2. Technical Fundamentals of IRT

Infrared thermography is a touch-free imaging technique that has the ability to map the isotherms of the surface of a selected area or an entire object, owing to the detection and registration of infrared emissions [8]. Importantly, in contrast to other imaging techniques in medicine, IRT is a completely passive (non-invasive and non-radiating) technique. The possibility of creating an image on the screen plane of the temperature distribution of a body with a temperature higher than absolute zero, as observed from a certain distance, results from several laws of physics, which are the basis for the operation of thermal imaging cameras: Stefan-Boltzmann's law; Wien's law; Planck's law; and Kirchhoff's law. Those interested in these processes are referred to theoretical studies [9–11] for the details.

All living objects consist of matter in random motion, containing heat from kinetic energy and having surface temperatures above absolute zero (0 K; −273.15 °C). They emit electromagnetic radiation characterized by two features: its wavelength (λ) and intensity (Q). Both the intensity and the wavelength at which the radiation is most intense depend on the surface temperature of the emitting body. Thus, objects with a certain temperature emit radiation of different wavelengths.

Though the spectral range of visibility changes from person to person, the human eye is sensitive to a fraction of the electromagnetic spectrum, ranging approximately from 400 to 760 nm [12], but it cannot detect the IR radiation emitted by human skin. The infrared emissions from human skin at 27 °C lie within the wavelength range of 2–20 μm, and they peak around 10 μm. Based on Plank's law, roughly 90% of the infrared radiation emitted by humans is of a longer wavelength (8–15 μm) [13]. For medical applications, a very narrow wavelength band corresponding to the range 8–12 μm, termed as body infrared rays, is in general use [14].

The human body's surface temperature can be calculated based on the total radiant power per surface area M (Wm^{-2}). The principle of the operation of thermal imaging cameras is to measure and convert the energy of the radiation emitted by the body into a temperature value.

The total amount of energy consists of the object's emissions, the emissions reflected from the source of the environment, and the emissions from the atmosphere. The detectors of an IR camera convert the incoming power of the electromagnetic rays emitted by the body into electronic video signals that are sequentially amplified and transmitted to monitors. Thermal images generated by IR cameras are called thermograms, where each image pixel corresponds to a digital value proportional to the amount of received energy. By reason of the achieved time resolutions of 30 frames per second (fps), it is possible to analyze dynamic changes in temperature. To calculate the surface temperature correctly based on the emitted radiation, it is necessary to know the emissivity of the object [15]. Regarding the spectral region, human skin is a black-body radiator with an emissivity factor of 0.97–0.99 [16] and is therefore a perfect emitter of infrared radiation at room temperature.

The skin microcirculatory flow determines infrared irradiation from the human surface and, in that way, also skin temperature (Tsk). There is a complex relationship between skin, the metabolism of internal tissues, and the functions of local blood vessels. The skin and skeletal muscles have a relatively low resting metabolism, therefore postganglionic neurons of the sympathetic nervous system (SNS) extend to the target organs, and also to the blood vessels and the sweat glands with the peripheral nerves or blood vessels playing a dominant role in regulating the flow in its microcirculation. For this reason, SNS is the most important way by which human body temperature is regulated through thermoregulatory mechanisms of heat exchange between organs, tissues, and skin [17]. The skin is an effectively controlled "heat radiator" system, and 60% of the total heat loss of the naked human being occurs as infrared radiation [18]. Tsk of different areas of the body is related to the area of anatomical variation in the area of subcutaneous tissue and skin, as well as innervation and blood supply.

3. Standardization in Thermographic Research

Continuous progress in the field of thermovision based on establishing measurement standards for thermography, the development of computer technologies, and the design of sensitive detectors makes the analysis of thermal temperature distributions on selected surfaces of various objects applicable in more and more different fields of science and technology, including medicine and rehabilitation. Due to the very different technical capabilities of cameras, the individual differences in temperatures of selected areas, and the diversity of research objectives, it is necessary to standardize the technique of thermal imaging in medicine. General, basic guidelines for thermographic research were introduced in 2002 and then, in 2015–2016, detailed guidelines for research in the area of neuromuscular-skeletal, dental, and systemic diseases were defined [19]. In 2017, a consensus was reached and TISEM (Thermographic Imaging in Sports and Exercise and Medicine checklist) was developed, based on Moreira et al. [20].

The temperature distribution of the human body surface is influenced by many factors, which translates directly into the results of thermographic tests; therefore, the impact of any stimuli interfering with the measurements should be minimized and the rules for the proper conduct of the experiment should be followed and described in detail in the methodology of thermal imaging studies. There are many conditions for the technical and interpretative correctness of thermal imaging studies (environmental, individual, and technical). The most important are the research room's conditions, the patient preparation and pre-examination acclimatization period, the adjustment equipment, and the subject of the size and position of the regions of interest (ROI).

The detailed conditions for carrying out thermographic measurements for medical purposes are determined by the standards that have been developed by thermographic associations such as the American Academy of Thermology (AAT), the European Thermological Society, and the Polish Society of Thermographic Diagnostics in Medicine.

Based on the guidelines of these societies and the experiences of researchers, the requirements for thermo-imaging standards in medicine have been compiled below, taking into account factors influencing the recorded results:

1. Concerning the examination room where the thermovision measurements are carried out: it should allow for the convenient and correct placement of the measuring devices and the visualization of the entire examined area and it should not be smaller than 6 m^2 and it should be without unnecessary equipment; it should have a stable temperature and a relative humidity system; air-conditioning equipment should be located so that draughts are not directed at the patient and that overall air speed is kept as low as possible; airflow should be inferior to 2 m/s and the illumination should have protections to avoid incident lightning over the subject; laboratory windows have to be shut (to prevent solar radiation).
2. Concerning the environmental conditions: a range of temperatures from 18 °C to 25 °C should be adjustable; the selection of the ambient temperature in which the research is conducted depends on the type and purpose of the tests (recommendation for the examination of the extremities: a warmer ambient temperature of 22–24 °C; large body surfaces examinations within 25–27 °C; lower temperatures enable better diagnosis of inflammatory changes (20 °C)); for medical examinations, it is recommended to keep the room humidity at the level of 45–55%.
3. Concerning the patients: the intrinsic factors that should be taken into account during the implementation and interpretation of the research results are sex, age, anthropometric measurements, body composition, circadian and infradian rhythms, hair density, skin emissivity, medical history, metabolic rate, skin blood flow, genetics, and emotions; those that should be avoided are factors that alter metabolism (smoking, drinking sparkling water and/or hot coffee and tea; a heavy meal a minimum of two hours prior to the investigation; alcohol or drug consumption; and physiotherapy or sports on the image-collection day); also on the day of the examination, the patient must not apply any cosmetics to the tested body surface; the patient should report any infections and any medications taken; the subject's acclimatization or equilibration period should be 15–20 min, while during this process the body surface that will be recorded must be uncovered; to minimize thermal reflections, the person under testing should be as far as possible from all equipment and walls; physical activity during all testing procedures should be kept to a minimum; the analyzed area of the body must not be touched; the examined person should not have any jewelry and should avoid crossing legs or holding arms close to or on the body; seating should be abstained from, to prevent marks that can result in skin temperature changes.
4. Concerning the technical determinants of measurements: in medicine, cameras with a tunable focal length (zoom) are most often used, with a minimum focusing distance of approx. 0.5 m, a row's field of view 25° × 19°, and an angle of divergence equal to or less than 1 mrad; an optimized temperature range (approximately 20–50 °C) will maximize the sensitivity of the sensor; a larger number of pixels (resolution) means more thermal information; it is important to control the calibration; the distance between the camera and the analyzed object should not be less than 1–1.5 m; in the selection of the ROI, the body region must be perpendicular to the lens of the infrared camera; when setting an ROI manually, including random pixels from the background or from the borders to the ROI in the analysis should be avoided [11,19,21–23].

It should be remembered that for the correct execution and the thermogram, it is required to enter a number of settings into the thermal imaging camera related to the external conditions of thermal imaging.

The standardization protocols for thermovision testing are constantly improving, and also in the field of medical research. The latter's guidelines for measuring devices and the methodology of the measurements themselves were included in the report of the International Organization for Standardization in 2017, ISO 18251-1:2017 [24], entitled Medical electrical equipment—deployment, implementation and operational guidelines for identifying febrile humans using a screening thermograph, which is considered to be one of the best conductors for estimating the temperature of the tested object [25]. The American Society for Testing and Materials (ASTM) also made a significant contribution to the development and standardization of thermographic research, developing standards for testing systems and thermographic devices, and proposing methods for determining the basic parameters of thermal imaging cameras [26–31].

Thermography is used in sports, medicine, and rehabilitation, both in the terms of research on adults and children, and in physiological and pathological conditions. IRT is increasingly applicable in medicine, as well as in rehabilitation, especially in fields related to musculoskeletal dysfunctions. Thermal detectors for medical applications need to be safe, easy to use, and inexpensive. It is fast, and simultaneous large-area monitoring is possible. In medical applications, thermal analysis mainly refers to the local skin temperatures, measured at fixed points/areas on the surface of the body, as well as to the mean skin temperature over the entire body surface, which can be estimated by calculating a weighted average of a series of local skin temperatures related to the surfaces that characterize it [32].

Thermovision is used in a dozen or more fields of medicine. Those most frequently described in the literature are vascular disorders, surgeries, rheumatology, neurological disorders, gynecology, traumatology, dermatology, ophthalmology, laryngology, endocrinal disorders, and musculoskeletal disorders, including, in particular, the assessment of skin temperature changes for the diagnosis, localization, and assessment of the extent and intensity of inflammation in the examined tissue, based on the phenomenon of high thermo-emission as a result of local increased blood supply and tissue metabolism. Thermal imaging can detect joint inflammation in patients with arthritis. Arthritis has been diagnosed for centuries with the underlying symptoms of inflammation (pain, swelling, redness, and loss of function). An increase in temperature around the affected joint indicates exacerbation of inflammation. It is now known that the results of thermographic analysis strongly correlate with both the severity of the inflammation in the joints and the results of scintigraphy, which was confirmed both in human studies and in an animal model. It was found that infrared imaging can be used as a complementary method, especially in the early stages of the disease, as it can provide information on the dynamics of the pathophysiological processes in the joints [33,34]. The correlation between thermographic images and the severity of the degenerative changes has also been documented [35].

The diagnostic potential of thermography is also indicated in spine pain of various origins including root pain [36], complex regional pain syndrome [37,38], and fibromyalgia [39]. In non-specific MSD, a relationship between the Tsk changes and pain intensity was found [40].

Schmitt and Guillot assessed the usefulness of thermography in muscle injuries in athletes. They found that thermal images are helpful in assessing the severity of an injury, especially in the acute phase, in monitoring its evolution, and in prognosticating healing and recovery [41].

Correlation was confirmed between the clinical, intraoperative, and thermal images in the case of supraspinatus and Achilles tendon [42]. It has been proved that in the case of scoliosis there is thermal asymmetry, mainly in the areas of the upper back, thigh, and back shank, and the high positive correlations of the angle of trunk rotation with the size of the thermal asymmetry occurs [43].

A clear and relatively wide area of interest of researchers related to rehabilitation and the use of objective tools for the assessment of therapeutic effects is the use of IRT in the assessment of the effectiveness of physiotherapeutic treatments.

4. Materials and Methods

4.1. Study Design

Among the physiotherapeutic methods used, the following were selected that directly affect the musculoskeletal system: cryotherapy, laser therapy, electrotherapy, diathermy, and massage.

4.2. Search Strategies

In this review, relevant articles were searched for in electronic databases, including the National Library of Medicine (MEDLINE) and the Web of Science. The search process used the Boolean operator AND/OR in the combinations of the following keywords: thermovision or thermography and 1. cryotherapy, 2. laser therapy, laser treatment, 3. electrotherapy, 4. diathermy, and 5. massage.

4.3. Article Protocol Selection

Articles were included for review if they met the following inclusion criteria: (1) published in English with publication date from 2012 to February 2022, (2) original studies about selected physiotherapeutic methods monitored by thermal imaging, (3) fully accessed articles, of which a copy could be obtained by the authors, and (4) studies involving humans. Articles were excluded if the main results were not in line with the purpose of this literature review. The complete search process is illustrated in the PRISMA (preferred reporting items for systematic reviews and meta-analyses) flow chart (Figure 1). The search results are presented in the individual subchapters of the manuscript. The summary is provided in Table 1.

Data synthesis and analysis were performed based on a narrative summary of the results of the included studies.

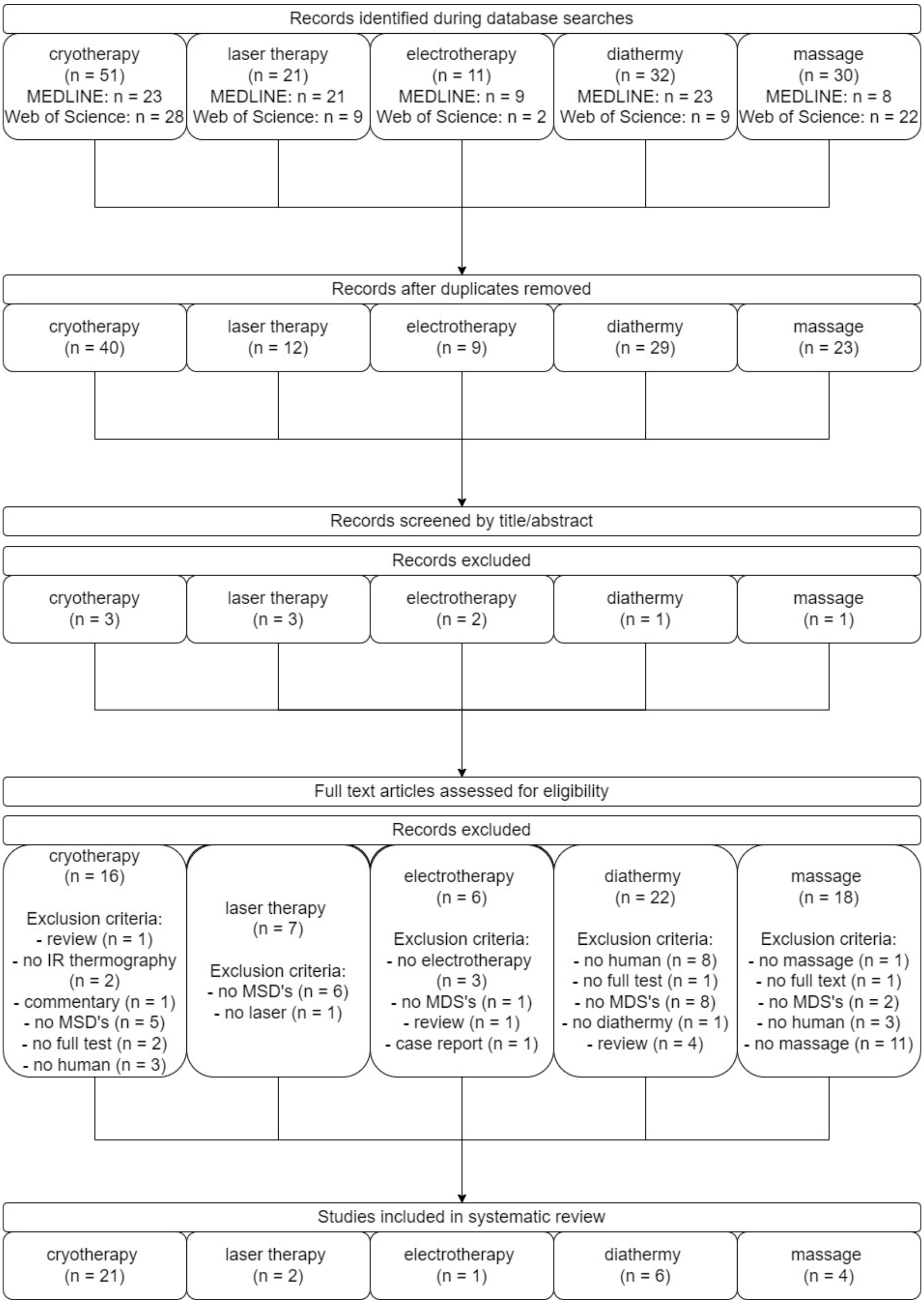

Figure 1. PRISMA (preferred reporting items for systematic reviews and meta-analyses) flow chart.

Table 1. Summary of found articles by adopted criteria.

Ref.	Sample (F/M)	Procedure	Aim of the Study	Treatment Procedure	IR Observation Period	ROI	Camera Type and Specyfication
				Cryotherapy			
[44]	$n = 30$ (15/15)	LC: 1. ethyl chloride spraying 2. ice block rubbing 3. cold pack	Comparing the effects of 3 cryotherapeutic modalities on facial skin temperature	Temperature/time 1. nd/nd 2. −20 °C/nd 3. −6 °C/10 min	20 and 5 min before LC, every 30 s from the end of LC up to 10 min thereafter; and every 5 min from 10 to 60 min after LC	center of the muscle belly of the right masseter	HotShot LT IR thermometer resolution: 0.1 °C accuracy: ±2%
[45]	$n = 47$ (39/8)	LC: 1. liquid nitrogen vapors 2. cold air	Thermovisual comparison of mean temperature of hand surface changes after local cryotherapy	Temperature/time 1. −160 °C/3 min 2. −30 °C/3 min	1, 5, 15, 30, 45, 60, 120, and 180 min after LC	hand	Flir ThermaCAM SC 2000 nd
[46]	$n = 22$ (5/17)	WBC	Studying skin temperature response, taking into account individual features of the patients and external factors	Temperature/time 1. −60 °C/30 s 2. −120 °C/3 min	pre-, post-WBC	all body	AGEMA Type 470, Flir Thermovision Camera A40 emissivity: 0.97–0.98
[47]	$n = 18$ (nd)	LC: ice bag or bags containing a mixture of ice and water (760 g of ice and 240 g of water)	Comparing variations in surface temperature of the quadriceps muscle at three different times during exposure to two forms of cryotherapy	Temperature/time nd/15 min	pre-, post-LC and 15, 30 min after	right and left quadriceps	Therma CAME 320; detector size: 320 × 240 pixels sensitivity: −0.10 °C to 25 °C precision: ±2 °C
[48]	$n = 30$ (0/30)	WBC	Evaluating the complex hemodynamic physiological reactions that occur in response to WBC exposure in healthy subjects	Temperature/time −120 °C/3 min	pre-, post-WBC and 3, 6 h after	all body	Flir P640 nd
[49]	$n = 480$ (240/240)	WBC	Examining the temperature, blood pressure, and heart rate changes after whole-body	Temperature/time −60 °C/1–3 min −100 °C/1–3 min	pre-WBC and 5, 30 min after	upper and lower extremities	ThermoVision A20 M nd

			cryotherapy in healthy subjects to determine the safety conditions of the treatment	−120 °C/1–3 min −140 °C/1–3 min			
[50]	n = 15 (0/15)	LC: cold water immersion	Investigating acute effects of normobaric hypoxia on hand-temperature responses during and after cold-water hand immersion test	Temperature/time 8 °C/30 min	pre-, post- LC and 1, 2, 3, 4, 5, 10, and 15 min after	hand	Flir T365 spatial resolution: 1.36 mrad spectral range: 7.5–13 μm detector size: 320 × 240 pixels
[51]	n = 24 (12/12)	WBC	Assessing the distribution and dynamics of temperature changes on the surface of selected body parts after systemic cryostimulation	Temperature/time −130 °C/3 min	pre-, post-WBC and in 1st, 5th, and 10th day of treatment	upper and lower extremities	Flir Therma CAM TM Sc500 nd
[52]	n = 60 (0/60)	WBC	Assessing the impact of cryotherapy on changes of surface body temperature and efficiency of thermoregulatory processes in relation to the intensity of cryogenic stimuli	Temperature/time 1. −110 °C/3 min 2. −120 °C/3 min 3. −140 °C/3 min	pre- WBC and 5 and 30 min after	regions of trunk, lower limbs and upper limbs	ThermoVision A20 M Researcher spectral range: 7.5–13 μm spatial resolution: 2.7 mrad automatic emissivity correction
[53]	n = 10 (2/8)	LC: cold pack	Evaluating the impact of the exposure duration of local cryotherapy on the skin temperature of the thigh and of the knee	Temperature/time Nd/5 and 10 min	every 30 s for 20 min after LC	skin of the thigh and of the knee	VarioCAM® hr head accuracy: ±2% spectral range: 7.5–14 μm detector size: 640 × 480 pixels
[54]	n = 36 (0/36)	LC: 1. cold water immersion 2. ice massage	Evaluating the effectiveness of LC in supporting recovery and preventing delayed-onset muscle soreness after maximum anaerobic physical effort	Temperature/time 1. 8 °C/3 min 2. nd/3 min	pre-, post-LC and 30 min after	front and back surface of lower limbs	Flir A325 thermal sensitivity: −20 °C to 350 °C accuracy: ±2% or ±2 °C sensitivity: <0.05 °C infrared spectral band: 7.5–13 μm refresh rate: 60 Hz

							detector size: 320 × 240 pixels
[55]	*n* = 15 (5/10)	WBC	Exploring the use of a new WBC technology based on forced convection (frontal unilateral wind) through the measurement of skin temperature	Temperature/time 1. −20 °C/30 s 2. −40 °C/3 min	pre-, post-WBC and within 20 min after	all body	VarioCAM® hr head; Thermal sensitivity: −40 °C to 1200 °C accuracy: ±2% detector size: 640 × 480 pixels spectral range: 7.5–14 µm
[56]	*n* = 20 (0/20)	WBC LC: liquid nitrogen vapors	Verifying whether local cryotherapy improves thermal diagnosis, similar to whole-body cryotherapy in spinal diseases	Temperature/time WBC: −110 °C/3 min LC: −160 °C/3 min	pre-, post-cryotherapy	spinal region (Th5/Th6-L5/S1)	Thermovision Camera E60 emissivity: 0.97–0.98
[57]	*n* = 10 (5/5)	PBC WBC	Observing the differences between PBC and WBC treatments, based on the analysis of skin temperature distribution	Temperature/time −140 °C/3 min	pre-, post-cryotherapy	all body	Flir Thermal SC620 nd
[58]	*n* = 40 (0/40)	WBC	Evaluating changes in the distribution of body surface temperature under the influence of WBC, classical massage, and hot stone massage	Temperature/time −120 °C/3 min	pre-WBC and up to 10 min after	12 areas in whole body	Thermo Vision A20M Sensitivity: 0.12 °C, temperature range: −20 °C to 900 °C detector size: 160 × 120 pixels frequency: 50/60 Hz
[59]	*n* = 22 (22/0)	LC: cold pack	Searching for associations between skin surface temperature and pressure pain tolerance thresholds of healthy individuals undergoing cryotherapy and thermotherapy	Temperature/time nd/20 min	pre-, post-LC and 20 min after	right knee	Flir E4; nd
[60]	*n* = 21 (0/21)	LC: wetted ice	Investigating differences in the cooling ability of different cryotherapy modalities in	Temperature/time nd/20 min	post- and 5 times during LC and 20 min after	anterior thigh	Flir A40M; emissivity: 0.97–0.98

		(500 g ice + 500 mL water) crushed ice CryoCuff®	a rugby union population in an attempt to describe optimum cooling protocols				
[61]	n = 16 (16/0)	LC: ice bag watered ice (500 g of ice in 500 mL of water) wetted ice (500 g ice and 500 mL water)	Comparing the effects of different cryotherapeutic preparations	Temperature/time nd/20 min	pre-, post-LC and 5, 10, 15, and 20 min after	anterior thigh	Flir A325sc accuracy: 0.07 °C emissivity: 0.98
[62]	n = 10 (3/7)	LC: GameReady GRPro 2.1	Evaluating changes in temperature in response to a cold stress test after a strength-fatiguing exercise protocol	Temperature/time 0–3 °C/3 min	pre-, post-LC	anterior thigh	Flir E60bx detector size: 320 × 240 pixels accuracy: ±2%, NETD: <0.05 °C
[63]	n = 14 (4/10)	LC: Game Ready GRPro 2.1	Determining the reproducibility of lower limbs skin temperature after cold stress test using the Game Ready system	Temperature/time 0–3°C/3 min	pre-, post-LC and 30, 60, 120, and 180 s after	lower limbs skin	Flir E-60bx; detector size: 320 × 240 pixels NETD: <0.05 °C resolution: 1.36 mrad accuracy: ±2%
[64]	n = 23 (11/12)	LC: 1. liquid nitrogen vapors 2. ice bag 3. cold air	Evaluating the dynamics of temperature changes in the knee joint area in response to different kinds of local cryotherapy	Temperature/time 1.: −160 °C/3 min 2.: −30 °C/3 min 3.: 0 °C/3 min	pre-, post-LC and 1–5 min after (with frequency 1 min) and 5–90 min (with frequency 5 min)	knee joint	Flir A655s NETD: <0.05 °C detector size: 640 × 480 pixels accuracy: ±2% frequency: 50/200 Hz temperature range: −40 °C to 150 °C, emissivity: 0.98
Laser therapy							
[65]	n = 41 (17/24)	LLLT	Evaluating the usefulness of thermography as a prognostic tool in the treatment	λ = 808 nm; power: 400 mW;	pre-treatment and 2 and 4 weeks after	the pressure ulcer	VIGOcam v50 camera; resolution: 1 mrad detector size:

			of stage III and IV pressure ulcers	frequency: 5000 Hz time: 5–20 min			384 × 288 pixels NETD: 0.07 °C emissivity: 0.950 frequency: 60 Hz
[66]	n = 14 (0/14)	LLLT	Verifying the influence of PMB on muscle fatigue and the temperature of the biceps brachii	λ = 808 nm; power: 100 mW/point; energy of 3 Joules/point Time:nd	pre-, post-treatment and 5, 10, and 15 min after	biceps brachii muscle	FLIR S65 emissivity: 0.98
Electrotherapy							
[67]	n = 45 (25/20)	NMES	Verifying whether unilateral application of NMES can result in local and cross-education thermal effects	400 µs, 8 Hz time: 12 min	pre-, post-treatment and 10 and 20 min after	anterior region of both thigh	Flir E60 detector size: 320 × 240 poixels NETD: < 0.05 °C frequency: 60 Hz
Diathermy							
[68]	n = 60 (26/34)	ESW	Detecting thermal conditions in the region of tested muscles to assess the effects of the radial ESW stimulation	pressure of 1.5 bar; frequency of 5 pulses per s [Hz] 1500 shots	pre-, post-treatment	carpal flexor muscles	MobIR M8 m detector size: 160 × 120 pixels spectral range: 8–14 µm thermal sensivity: ≤100 mk temperature range: −20 °C to 250 °C accuracy: ± 2% or ± 2 °C
[69]	n = 40 (40/0)	short- and microwave diathermy	Evaluating the behavior of temperature and arterial blood flow after the application	1. 27.12 MHz 240 W 2. 2.45 GHz 200 W time: 20 min	pre-treatment and 10, 20, 30, and 40 min after	lower limb	Flir T300; accuracy: 0.05 °C emissivity: 0.98
[70]	n = 10 (4/6)	TT	Determining if TT, administered in two modes, affects the intramuscular blood flow, perfusion of skin microcirculation, and skin temperature	resistive and capacitive TT time: 8 min	pre-, post-treatment	volar forearm	Voltcraft Infrared IR 500-8S; nd

[71]	*n* = 32 (0/32)	TT	Analyzing the acute effect of TT on latent myofascial trigger points on skin temperature, ankle range of motion, and pain in professional basketball players	0.5 MHz radiofrequency signals at a variable power with a maximum of 300 W time: 25 min	pre-treatment and 15 and 30 min after	medial gastrocnemius	Flir E6 nd
[72]	*n* = 26 (26/0)	SWD	Evaluating local and general temperature changes after treatment with SWD	1 MHz; 300 m wavelength; 11 m short-wave diathermy time: 8 min	pre-, post-treatment	area of the right knee joint	Flir ThermaCAM P640 detector size: 640 × 480 pixels temperature range: −200 to 9000 °C
[73]	*n* = 18 (0/18)	three capacitive technique of SWD	Analyzing which capacitive technique arrangement of SWD is the most effective in skin temperature change	27.12 MHz; contra-, coplanar and longitudinal arrangement time: 20 min	pre-treatment and over 25 min after	anterior aspect of the thigh	Flir A325sc ccuracy: ±2% detector size: 320 × 240 pixels
				Massage			
[74]	*n* = 12 (10/2)	RM	Determining whether RM triggers measurable changes of body surface temperature and of heart rate variability	10 RM sessions once or twice week time: 30 min	pre-treatment and 5 and 10 min after	dorsal region	Goratec Technology AVIO TVS 700 nd
[75]	*n* = 35 (35/0)	classical massage	Determining the relationship between classical sports massage of the hand and the forearm and the surface temperature of upper limb muscles	nd	pre-, post-treatment	upper limbs	Flir A 325 nd
[58]	*n* = 40 (0/40)	classical massage; hot stone massage	Evaluating changes in the distribution of body surface temperature under the influence of WBC, classical massage, and hot stone massage	temperature of hot stone: 60 °C; 19 stones in different size time: 30 min	pre-, post-treatment	12 areas in the whole body	Thermo Vision A20M; temperaturę sensitivity: 0.12 °C temperature range: –20 °C to 900 °C, detector size: 160 × 120 pixels

							frequency: 50/60 Hz
[76]	*n* = 40 (40/0)	isometric and classic massage	Determining the relationship between isometric and classic massage and the chosen parameters of the quadriceps femoris muscles	nd time: 12 min	pre-, post-treatment	anterior part of the thigh	Flir A 325; nd

Legend: LC—local cryotherapy, WBC—whole-body cryotherapy, PBC—partial-body cryotherapy, NETD—noise equivalent temperature difference, LLLT—low-level laser therapy, PMB—photobiomodulation, NMES—neuromuscular electrostimulation, ESW—extracorporeal shock wave, TT—Tecar therapy, SWD—short-wave diathermy treatment, RM—rhythmical massage, nd—no data available in publication.

5. The Use of Thermovision to Assess the Effects of Chosen Physiotherapy Treatments

5.1. Cryotherapy

Of the 51 papers found (PubMed n = 23, Web of Science n = 28), a total of 21 works were analyzed after applying the inclusion and exclusion criteria and the exclusion of copies. A total of 963 people (including 379 women, 566 men, and 18 non-identified subjects) took part in the study. The larger sample was composed of 480 subjects [49]; the smallest sample was 10 [53,57,62]. Most studies used local cryotherapy (LC) (n = 12) [44,45,47,50,53,54,59–64]; less often, whole body cryotherapy was used (n = 7) [46,48,49,51,52,55,58]. One study used both WBC and LC (using liquid nitrogen vapor) [56], and one used WBC and PBC [57].

In the case of local cryotherapy, thermovision was used primarily to compare the effects of various cooling factors on the change in the temperature of the facial skin [44], the surface of the hand [45], quadriceps surface [47], and the front of the thigh [61] and knee joint [64]. In one of the studies found, thermography was used to assess the effect of exposure to one coolant (gel pack) depending on the duration of the procedure (5 min vs. 10 min) [53].

In the Adamczyk et al. paper [54], thermovision was used to compare the assessment of the effectiveness of ice massage and immersion in cold water in the context of using it as a method of supporting post-workout regeneration. Thermovision has also made it possible to describe the optimal cooling protocols of the anterior thigh in the rugby player population [60]. On the other hand, Muñoz-Alcamí [62], using thermography, assessed changes in skin temperature in the anterior part of the thigh in response to a cold stress test after fatigue protocols during physical exercise.

Vargas et al. [59] examined the influence of cold and thermotherapy on pain tolerance, and Keramidas et al. [50] the influence of normobaric hypoxia on hand temperature reactions after a cold-water immersion test. One study demonstrated the reproducibility of the skin temperature of the lower extremities after the cold-endurance test [63].

In the case of whole body cryotherapy (WBC), thermography was used to analyze the distribution and dynamics of the temperature changes on the surface of both the whole body [46,48,55] and the individual regions of the body [49,51,52,58]. Four studies focused on analyzing the body's response to WBC exposure [46,48,51,52], and one assessed changes in the temperature distribution of the body surface under the influence of WBC, classic massage, and hot stone massage [58]. Thermovision made it possible to determine the safety conditions of the WBC procedure [49]. One study used thermography to validate the new WBC technology [55].

Polidori et al. [57] used thermography to compare whole-body temperature distribution between WBC and PBC, while Cholewka et al. [56], focusing on the spinal region of Th5/Th6-L5/S1, verified whether PBC improves thermal diagnostics in spinal diseases in a manner comparable to WBC.

Cryotherapy (cryostimulation) is a physical procedure that exposes the body to low or extremely low temperatures. Treatments are divided into whole-body cryotherapy (WBC), partial-body cryotherapy (PBC), and local cryotherapy (LC) [77]. In WBC and PBC, patients are exposed to extremely low temperatures (−110 °C to −160 °C) for a maximum of 3 min in a specially designed chamber (cryo-chamber) or cabin (cryo-cabin). In the PBC chamber (also called a cryosauna) the patient's head and neck are not exposed to the cold [78].

Cryotherapy is used in medicine, health, and sports, and its type depends on the desired effect. Exposure to cold causes strong fluctuations in skin temperature and leads to the stimulation of skin thermoreceptors, and thus to the stimulation of the thermoregulation center in the hypothalamus [79]. In local cryotherapy, a small area of the body is exposed to cold [64]. Cooling factors include liquid nitrogen vapors, ice bags, cold air [64], frozen gel bags [59], wetted ice, crushed ice [60], watered ice [61], cold-water immersion [50], ethyl chloride spraying, ice-block rubbing [44], or special systems [60,63].

5.2. Laser Therapy

Of the 31 papers found (PubMed $n = 12$, Web of Science $n = 19$), a total of two works were analyzed after applying the inclusion and exclusion criteria and the exclusion of copies. A total of 55 people (including 17 women and 38 men) took part in the study. Both studies used low-level laser therapy (LLLT).

Bilska et al. [65] demonstrated the usefulness of thermovision as a prognostic tool during treatment of stage III and IV pressure ulcers. Stamborowski et al. [66], based on thermograms, investigated the effect of photomodulation from low-level laser therapy on muscle fatigue and the temperature of the brachial biceps.

Low-level laser therapy (LLLT) energy is so low that it does not exhibit photobiological effects, but it is sufficient to elicit a stimulatory response from body tissue. The wavelength used is in the range 390–10,600 nm and the output power is up to 500 mW. LLLT does not produce thermal or ablative effects (rather a photochemical effect); therefore, it is called "soft" laser therapy or cold laser therapy [80]. LLLT has found application in promoting tissue regeneration, relieving pain, and reducing inflammation [81,82].

5.3. Electrotherapy

Of the 11 papers found (PubMed $n = 9$, Web of Science $n = 2$), a total of one work was analyzed after applying the inclusion and exclusion criteria and the exclusion of copies.

Benito-Martínez et al. [67] examined 45 people (25 women and 20 men) and used thermography to investigate the effects of applying symmetrical biphasic square currents on skin temperature.

Electrotherapy is one of the basic methods used in physiotherapy, which consists of introducing a certain amount of physical energy into the biological system. The result is physiological changes that are used for therapeutic purposes [83]. Depending on the expected effect, direct current, pulsed low-frequency, and an alternating current of medium and high frequencies are used [84]. Applied by Benito-Martínez et al. [67], neuromuscular electrical stimulation (NMES) is used both for selective muscle overtraining and swelling control, and for maintaining muscle mass and strength during longer periods of immobilization.

5.4. Diathermy

Of the 32 papers found (PubMed $n = 23$, Web of Science $n = 9$), a total of six works were analyzed after applying the inclusion and exclusion criteria and the exclusion of copies. A total of 186 people (including 96 women and 90 men) took part in the study. The larger sample was composed of 60 subjects [68], and the smallest sample was 10 [70]. In the found works, the diathermy methods included extracorporeal shock waves (ESW) [68], short-[69,72,73] and microwave diathermy [69], and Tecar therapy (TT) [70,71].

Dymarek et al. [68] used thermography to detect thermal conditions in the region of the carpal flexor muscles to assess the effects of the radial extracorporeal shock wave stimulation. In case of short- and microwave diathermy, thermography was used to evaluate the temperature behavior and arterial blood flow after lower limb administration [69] and to evaluate local and general temperature variations in the area of the right knee joint [72]. Furthermore, Benincá [73], using the three capacitive techniques of shortwave diathermy treatment (contra-, coplanar, and longitudinal arrangement), compared the effectiveness in changing skin temperature. Clijse [70], using thermography, verified whether TT administered in two modes (resistive and capacitive) floats on intramuscular blood flow, perfusion of skin microcirculation, and skin temperature. In turn, Yeste-Fabregat [71], in their research among professional basketball players, analyzed the effect of TT on latent myofascial trigger points on skin temperature, range of ankle motion, and pain.

Diathermy is a thermotherapeutic method that uses high-frequency electromagnetic currents to induce heat [85]. Diathermy includes ultrasound, shortwave, and microwave [86]. Both shortwave diathermy (SWD) and microwave diathermy (MWD) have been used in the treatment of musculoskeletal conditions [69]. In SWD, heat is generated at a deep tissue level by generating electromagnetic vibrations, which in turn lead to ion movement, deformation of molecules, and the formation of electric vortices. The treatment causes vasodilation, increases metabolism in the body, and normalizes muscle tension [72]. In addition, they can reduce pain and promote wound healing [87].

5.5. Massage

Of the 30 papers found (PubMed $n = 8$, Web of Science $n = 22$), a total of four works were analyzed after applying the inclusion and exclusion criteria and the exclusion of copies. A total of 127 people (including 85 women and 42 men) took part in the study. The larger sample was composed of 40 subjects [58,76], and the smallest sample was 12 [74]. The studies using thermography included rhythmical [74], classic [58,75,76], isometric [76], and with hot stone [58] massage.

Wälchli et al. [74], using thermography, analyzed the heat distribution after the treatment sessions. In the case of classic massage, two works by the same authors were found [75,76]. In the first one, the authors focused on determining the relationship between the classic sports massage of the hands and forearms and the temperature of the surface of the muscles of the upper limbs [75]. In the second, they focused on the relationship between isometric and classic massage and selected parameters of the quadriceps muscle of the thigh [76]. Classic massage was also the subject of the study of Gruszka et al. [58], who assessed the changes in the temperature distribution of the body surface under the influence of WBC, classic massage, and hot stone massage using thermography.

According to the Ottawa Panel definition, massage is "soft tissue and joint manipulation using the hands or a handheld device" [88]. Massage therapy improves blood and lymph flow, reduces muscle tension, lowers blood pressure, and provides relief in many diseases of the musculoskeletal system [89].

6. Conclusions

As the review shows, thermovision is an undeniably important diagnostic tool in the physiotherapeutic methods used in musculoskeletal dysfunctions. Most of the studies found concern cold-therapy treatments. Nevertheless, thermovision is becoming more and more popular among other therapeutic methods (e.g., diathermy or massage). However, there is a significant gap regarding the influence of laser therapy and electrotherapy on the distribution of temperature in the treatment area.

Thermovision makes it possible to evaluate the effectiveness of a given procedure, and it provides information on the temperature distribution of the whole body and individual areas. As a non-contact and non-invasive method, it does not affect the results of the procedure; therefore, the obtained results are reliable and authoritative.

Authors recommend the use of thermography to assess the effectiveness of physiotherapeutic procedures, in accordance with the test standards and taking into account the factors affecting the recorded results.

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