applied sciences

MDPI

Article

Effect of Compression Tights on Skin Temperature in Women with Lipedema

Jose Luis Sanchez-Jimenez [1], Jose Ignacio Priego-Quesada [1,2,*], María José Gisbert-Ruiz [3], Rosa M. Cibrian-Ortiz de Anda [2], Pedro Perez-Soriano [1,2] and Inmaculada Aparicio [1]

[1] Research Group in Sports Biomechanics (GIBD), Department of Physical Education and Sports, University of Valencia, St. Gascó Oliag, 3, 46010 Valencia, Spain
[2] Research Group in Medical Physics (GIFIME), Department of Physiology, University of Valencia, Ave Blasco Ibáñez, 15, 46010 Valencia, Spain
[3] Textile Technological Institute (AITEX), Plaça Emili Sala, 1, 03801 Alcoi, Spain
* Correspondence: j.ignacio.priego@uv.es

Abstract: The aim was to analyze the effect of compression tights on skin temperature in women with lipedema and to assess the effect of different knitting on skin temperature. Twenty-four women with lipedema (Grade I = 25%; Grade II = 75%) were divided into three groups according to the compression tights prototype assigned: control (n = 9), Flat (n = 7) and circular (n = 8). The participants performed a gait test two times, separated by 15 days: before wearing the tights of the study and after the treatment (15 days employing compression tights). Skin temperature was measured using infrared thermography before and after the gait test on both days, and six regions of interest were determined in the anterior and posterior leg. The skin temperature decreased in the different regions of interest after exercise in all the groups (e.g., anterior thigh (IC95% (−1.1, −0.7 °C) $p < 0.001$), but no differences were observed in skin temperature between groups before and after walking ($p > 0.05$). The use of compressing tights for 15 days does not alter skin temperature in women with lipedema before and after walking. The absence of differences in skin temperature between tights in the different assessments allows for obtaining the benefits of wearing compression tights during exercise without negative thermal effects.

Keywords: compressive garments; infrared thermography; exercise; gait

check for updates

Citation: Sanchez-Jimenez, J.L.; Priego-Quesada, J.I.; Gisbert-Ruiz, M.J.; Cibrian-Ortiz de Anda, R.M.; Perez-Soriano, P.; Aparicio, I. Effect of Compression Tights on Skin Temperature in Women with Lipedema. *Appl. Sci.* **2023**, *13*, 1133. https://doi.org/10.3390/app13021133

Academic Editor: Jongsung Lee

Received: 29 November 2022
Revised: 3 January 2023
Accepted: 12 January 2023
Published: 14 January 2023

1. Introduction

Lipedema is a chronic disorder of adipose tissue characterized by a symmetrical increase in limb size that affects mainly the female population and lower limbs [1,2]. Moreover, lipedema causes pain, bruising, tenderness, and lower self-esteem due to aesthetic deformity, which reduces the quality of life [3,4]. Lipedema is also associated with edema formation, which is related to a dysregulation of the veno-arterial reflex and capillary leak [1]. The lipedema diagnosis is complicated due to the lack of knowledge about its physiopathology and its similarity with other pathologies, such as obesity and lymphedema [1,2], delaying this diagnosis and its specific treatment [1]. Lymphedema is produced by a dysfunction of the lymphatic system, which impairs lymphatic drainage, and it may be caused by a genetic origin or acquired from other diseases [5]. In this sense, lymphedema manifestations are asymmetrical with the absence of pain or bruising as opposed to lipedema, which is symmetrical on the limbs with the presence of pain and presents a chronic progression [6].

Compressive therapy is part of lipedema conservative treatment that is effective in the reduction of pain, edema, and disorder progression [7–9]. The level of compression and type of knitting are the main aspects to keep in mind in garment development [10,11]. The increased thickness of flat knitting tights allows the adjustment to big deformities, which is recommended for advanced lipedema [10,11]. However, circular knitting tights are seamless and more aesthetical due to the thinner material [12]. In addition, the use of the adequate size of compression tights is necessary to achieve good compression values and the beneficial effects of this treatment [7].

It is recommended for people with lipedema to wear compression tights for many hours of the day to increase the beneficial effects of the treatment [7]. However, this long exposure could increase skin temperature due to the thermal insulation of the garment and sweat production [13,14], reducing thermal comfort [13]. Infrared thermography is a non-invasive image technique that allows skin temperature assessment without contact [15,16]. Although this tool has been employed in the assessment of different diseases such as breast cancer [17] or diabetic foot [18] and in the assessment of compressive garments [19], there is a lack of studies on lipedema assessment or the effect of compression garments in this population. However, the effect of compression garments on skin temperature has been previously studied in endurance athletes observing an increase after exercise [19] due to the thermal insulation properties of the compression garments [14], which increases skin temperature and can increase heat stress [19]. For this reason, it is interesting to assess the effect of compression garments in a population with lipedema after daily exercises, such as walking, to ensure that the garments used do not provoke high skin temperatures, which compromise optimal thermoregulation. Moreover, previous studies with other disorders, such as obesity or lymphedema, can provide some basis to expect results in the lipedema population because it has been shown that the percentage of adipose tissue reduces skin temperature [20]. In relation to lymphedema, regions with edema show higher skin temperature [21], and the skin temperature is elevated according to the severity of the lymphedema [22]. However, regions with tissue fibrosis obtain lower skin temperatures than those without skin pathologies [22].

Therefore, the aims of the study were to analyze the effect of compression tights on skin temperature in women with lipedema and to assess the effect of circular and flat knitting prototype compression tights on skin temperature in women with lipedema. It was hypothesized that the use of compression tights would increase skin temperature at rest and after exercise. Furthermore, flat knitting tights could increase skin temperature more than circular knitting tights due to the higher thickness.

2. Materials and Methods

2.1. Participants

Twenty-four volunteer women with lipedema participated in this study. The participants were recruited through a doctor specialized in lipedema and local associations, and all of them were diagnosed by rehabilitation doctors, lymphedema unit doctors, or vascular specialists, as well as the lipedema unit. Participants were divided into three groups: control group (n = 9), flat knitting group (n = 7), and circular knitting group (n = 8) (Table 1). Participants were randomly divided in order to avoid differences in the characteristics between groups. Inclusion criteria included: (1) age between 25 and 65 years; (2) grade I or grade II of lipedema (the criteria to determinate the grade of lipedema followed in the hospitals was based on the changes in skin surface and palpation to analyze the size of the nodules and reversibility of the edema [1]); (3) gait without impairments; (4) have not received therapeutic treatment in the last two weeks; (5) have not suffered any injury in the last three months; (6) without pregnancy; (7) use of compression tights at least eight hours along the day (flat and circular knitting group) (not having used compression garments for the treatment of lipedema in the last 3 months (control group)); and (8) have a diagnostic of lipedema conducted in a hospital. These institutions base their diagnosis on the following criteria: family clinical history, analysis of the period of lipedema onset, inspection and palpation to identify the main manifestations of lipedema (tissue tenderness, tightness feeling, hematoma formation, symmetrical and bilateral accumulation of adipose tissue, bruising and worsening of symptoms along the day) [1]. The exclusion criteria established was suffering a disease or disorder that affects peripheral circulation. All participants signed their written informed consent, and they reported previously about the development of the study. The study was performed in agreement with the Declaration of Helsinki, and it was approved by the ethics committee of the University of Valencia (register code 1487160).

Table 1. Sociodemographic characteristics of the sample.

Characteristics	Total Sample (n = 24)	Control Group (n = 9)	Flat Knitting Group (n = 7)	Circular Knitting Group (n = 8)	*p* Value
Age (years)	41.1 ± 9.6	39.3 ± 6.8	42.3 ± 11.2	42.0 ± 11.4	>0.05
Body mass (kg)	69.3 ± 11.8	76.1 ± 11.5	62.7 ± 10.6	68.2 ± 10.3	>0.05
Height (cm)	154.5 ± 32.4	163.6 ± 3.3	157.4 ± 5.5	141.4 ± 7.0	>0.05
BMI (kg/m^2)	26.9 ± 4.5	28.5 ± 4.9	25.4 ± 4.9	26.5 ± 4.5	>0.05
Grade	I = 25% II = 75%	I = 22% II = 78%	I = 14% II = 86%	I = 25% II = 75%	>0.05
Compressive experience (hours/day)	10.71 ± 2.39	0 ± 0	9.9 ± 3.2	11.9 ± 1.5	>0.05

The *p*-value of parametric variables was calculated by one-factor ANOVA. The case of non-parametric variables was calculated through Kruskal–Wallis test and by chi-squared test for nominal variables such as "Grade". The control group was not considered in the analysis of the variable "compressive tights use".

2.2. Protocol

The study was formed by two tests: the first one was before wearing the compression tights of the study, and the second one was performed after fifteen days [23] of wearing the compression tights assigned (a minimum of eight hours along the day) (Figure 1). The flat knitting group was provided with flat compression tights, the control group did not receive any compression tights, and the remaining group received circular compression tights. The assignment of the prototype of compression tights was randomized, and they did not know their experimental group, so it was single-blind. Participants were instructed to maintain their lifestyle during the fifteen days between tests, and these instructions reminded the authors every five days to ensure their compliance.

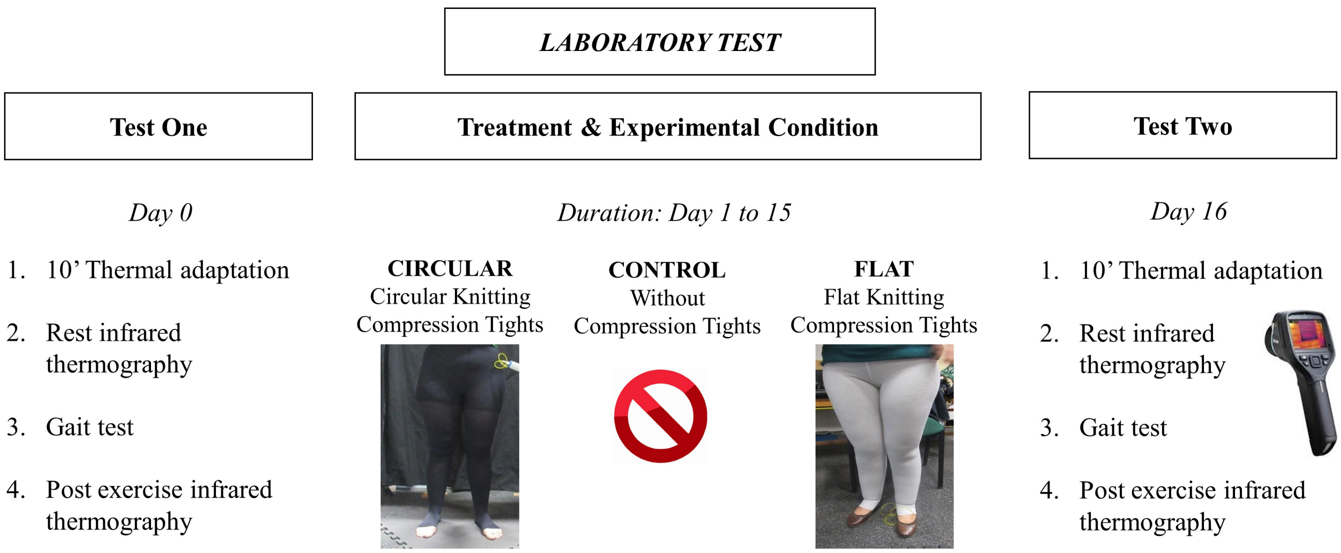

Figure 1. Study experimental design: periods and test protocol.

In both tests, participants performed a walking displacement of 10 m walkway ten times, such as in previous studies (Figure 2) [24,25]. The photocell system (Chronojump Boscosystem), located at the beginning and at the end of the displacement, was employed to monitor the velocity. Participants were recommended to walk at a self-selected speed according to 11 points (fairly light) in Borg's scale of perceived exertion. The velocity recorded in test one was the base/guideline to test two. The average speeds in Test 1 were

1.3 ± 0.2 m/s (control), 1.3 ± 1.2 m/s (flat), and 1.3 ± 0.1 m/s (circular). The average speeds in Test 2 were 1.3 ± 0.2 m/s (control), 1.3 ± 1.1 m/s (flat), and 1.3 ± 0.1 m/s (circular). The different tests and conditions did not present differences between them ($p > 0.05$). They received feedback continuously about their velocity to maintain a maximum of 5% variation in the velocity in all the repetitions [26]. Skin temperature was measured each day at rest (before the gait test) and after exercise (after the gait test). Compression tights were removed before the thermal room adaptation period in pre-exercise measurement and immediately after finishing the gait test in the post-exercise moment for skin temperature assessment. Then, 10 min and 1 min took place between compression tight removing and thermal images in pre-exercise and post-exercise measurements, respectively. No changes were observed in adipose tissue between both days, according to the measurements of the leg perimeters conducted.

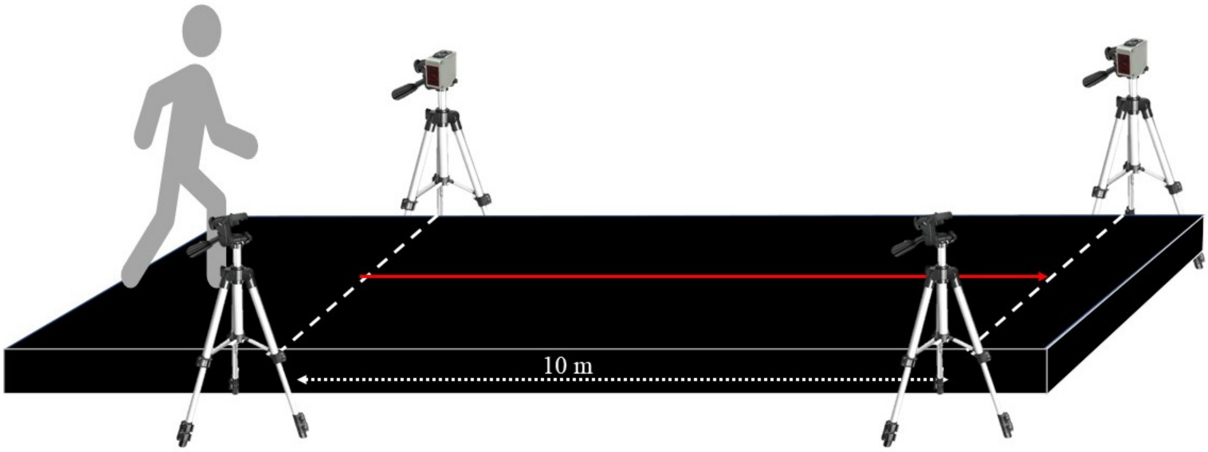

Figure 2. Gait test on walkway delimited by photo cellules.

2.3. Compression Tights

Two prototypes of compression tights were delivered and tested for the study by Textile Technology Institute (AITEX); in this sense, the contours and lengths of the leg of each participant were measured by the same researcher according to the RAL-GZ 387 standard [27] in order assign the appropriate size for them. Flat knitting compression tights are formed from the following materials: 65% viscose, 26% polyamide, and 9% elastane. Circular knitting compression tights are compounded by 60% polyamide and 40% elastane. The pressure generated by the garments was measured by AITEX using a certified system, a Salzmann MST MK IV (MST MK V, Swisslastic Ag St, Gallen, Swiss). The Salzmann device consists of a thin plastic sleeve (0.04 m wide, 0.0005 m thick) with four to six paired electrical contact points (depending on the length of the probe) [28]. Therefore, the garments were located in standard wooden legs according to RAL-GZ 387/1 measures that simulate the leg where the sensors of this system measure the pressure [28]. The pressure is measured in mmHg. Figure 3 shows the values of compression (mmHg) generated by the compression tights assessed in the different locations. In relation to the thermal properties of the compression tights, water vapor resistance and thermal resistance were measured according to the normative ISO 11092:2014. Textiles, physiological effects, and measurement of thermal and water vapor resistance were tested under steady-state conditions (sweating-guarded hotplate test). The thermal resistance was measured in $m^2 \cdot K/W$, and the water vapor resistance was measured in $m^2 \cdot Pa/W$. The thermal resistance of flat knitting compression tights and circular knitting compression tights was 0.120 $m^2 \cdot K/W$ and 0.090 $m^2 \cdot K/W$, respectively. The water vapor resistance is 11.88 $m^2 \cdot Pa/W$ in flat knitting compression tights and 2.88 $m^2 \cdot Pa/W$ in circular knitting compression tights.

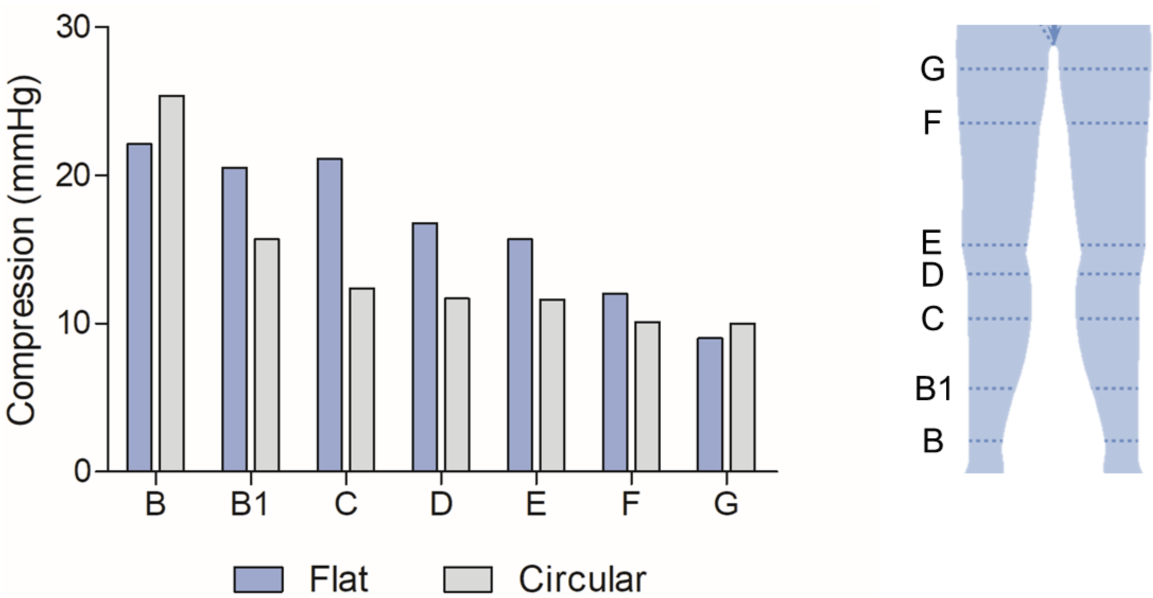

Figure 3. Average compression values of the prototypes measured in the system MST MK V, Swisslastic Ag St, Gallen, Swiss. Reference points of each measurement point extracted from [12].

2.4. Data Collection

Skin temperature was assessed employing an infrared camera (Flir E60bx, FLIR Systems Inc., Wilsonville, EEUU) with a resolution of 320 × 240 pixels, with noise equivalent temperature difference (NETD) <0.05 °C and measurement uncertainty of ±2 °C or 2%. The camera was checked before starting the experimental phase using a blackbody (BX-500 IR Infrared Calibrator, CEM, Shenzen, China) with a target emissivity of 0.95 and resolution of 0.1 °C. The blackbody presents a measurement uncertainty of ±0.8 °C and stability of ±0.1 °C at a temperature between 50 and 100 °C. Therefore, adjusting the blackbody to a temperature of 50 °C, the cameras registered 50.0 ± 0.6 °C.

During the measurements, the camera was situated perpendicularly to the regions of interest (ROI) assessed, and it was always located at the same distance (1 m) [16]. The infrared camera was turned on 10 min before the measurement for electronic stabilization [16]. At the same time, the participants conducted a thermal room adaptation of 10 min in a stand position [29]. Room temperature and relative humidity were monitored using a digital thermo-hygrometer (TFA Dostmann, Wertheim-Reicholzheim, Germany), obtaining the following environmental temperature and relative humidity: 21.1 ± 0.7 °C; 46.5 ± 7.2% (Test 1) and 20.2 ± 1.1 °C; 35.6 ± 6.8% (Test 2). No differences in environmental conditions were observed between tests ($p > 0.05$). All images were collected in an area without sunlight, 5 m away from electronic equipment, electric light, and people. The reflected temperature was measured according to the standard method ISO 18434-1, 2008. All the images were taken at the same time of the day.

Six ROIs were determined in each lower limb in the study according to the anatomical points shown in Figure 4: (1) anterior thigh, (2) posterior thigh, (3) knee, (4) popliteal fossa, (5) anterior leg and (6) posterior leg. Mean skin temperature and maximum skin temperature were obtained for each ROI using thermographic software (ThermaCam Researcher Pro 2.10, FLIR Systems, Wilsonville, Oregon, EEUU). The same researcher carried out the entire thermographic analysis to ensure consistency. Images were processed using a skin emissivity factor of 0.98. Variations in skin temperature (difference between post and pre-test) were calculated for mean and maximum skin temperature.

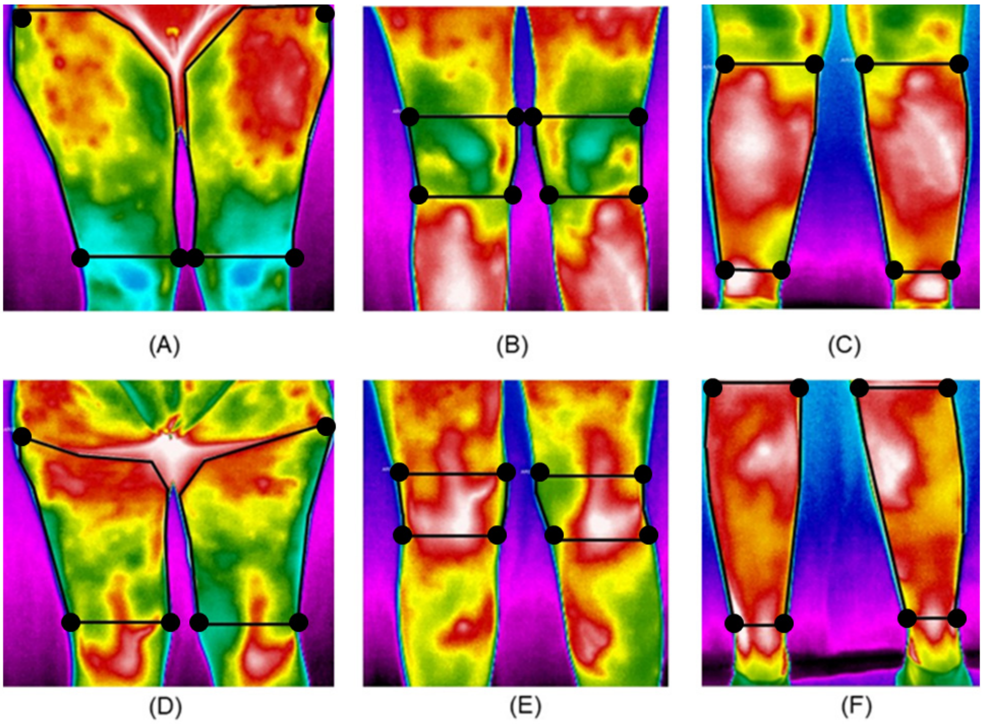

Figure 4. ROI's delimitation in the lower limb: (**A**) anterior thigh; (**B**) knee; (**C**) anterior leg; (**D**) posterior thigh; (**E**) popliteal fossa; (**F**) posterior leg.

2.5. Data Analysis

Statistical analysis was performed employing SPSS 23.0 (IBM Corp, Armonk, NY, USA). The normality of data distribution was confirmed using the Shapiro–Wilk test ($p > 0.05$). Repeated measures ANOVA with Bonferroni for multiple comparisons were applied for skin temperature assessment (mean and maximum values) with three factors: test (first test (beginning of the study) and second test (fifteen days later)), moment (pre-gait and post-gait test) and the side (left and right lower limb). These factors were established as intra-subject factors, and the group was selected as an inter-subject factor. The same analysis but without the factor of the moment was performed for variations in mean and maximum skin temperature. The significance level was set at $p < 0.05$. Data are shown as mean ± standard deviation with 95% confidence intervals of the difference between comparisons (CI95%).

3. Results

3.1. Mean Skin Temperature

Table 2 shows the data of mean skin temperature measured at the first and second tests. A significant effect in the different ROIs ($p > 0.05$) was not found when the interaction between test, moment, and type of compression tights was analyzed.

A main effect of the evaluation was identified. The values of skin temperature assessed were lower in the second evaluation than the first evaluation in the following ROIs: knees (IC95% (−1.01, −0.10 °C) $p = 0.02$), popliteal fossa (IC95% (−0.90, −0.17 °C) $p = 0.06$), and posterior leg (IC95% (−1.12, −0.20 °C) $p = 0.01$). The moment also had a main effect on the mean skin temperature ($p < 0.05$), and the values of skin temperature obtained were lower after exercise than before exercise in the following ROIs: anterior thigh (IC95% (−1.1, −0.7 °C) $p < 0.001$), knees (IC95% (−1.0, −0.6 °C) $p < 0.001$), anterior leg (IC95% (−0.7, 0.3 °C) $p = 0.4$), posterior thigh (IC95% (−1.4, −0.9 °C) $p < 0.001$), popliteal fossa (IC95% (−1.1, −0.6 °C) $p < 0.001$) and posterior leg (IC95% (−0.8, −0.3 °C) $p < 0.001$).

Table 2. Mean and maximum skin temperature values of the first and second tests.

	ROI	Test One								Test Two							
		Pre-Exercise				Post-Exercise				Pre-Exercise				Post-Exercise			
		Control	Circular	Flat	*p*	Control	Circular	Flat	*p*	Control	Circular	Flat	*p*	Control	Circular	Flat	*p*
Mean Tsk (°C)	Anterior Thigh	29.1 ± 1.3	29.0 ± 0.9	28.6 ± 1.2	1.00	28.0 ± 1.4	28.0 ± 1.0	27.9 ± 0.9	1.00	28.5 ± 1.5	28.8 ± 1.5	28.3 ± 1.3	1.00	27.7 ± 1.3	27.9 ± 1.1	27.3 ± 0.7	1.00
	Knee	28.7 ± 1.0	28.6 ± 1.3	28.6 ± 1.3	1.00	27.9 ± 1.1	28.0 ± 1.0	27.7 ± 1.2	1.00	28.3 ± 1.3	28.2 ± 1.7	27.8 ± 1.2	1.00	27.4 ± 1.3	27.6 ± 1.2	27.0 ± 0.9	1.00
	Anterior Leg	29.1 ± 1.0	29.3 ± 1.2	29.0 ± 1.5	1.00	28.7 ± 1.2	29.0 ± 1.1	28.6 ± 1.5	1.00	28.8 ± 1.3	29.0 ± 1.0	28.3 ± 1.5	>0.9	29.7 ± 4.5	28.5 ± 1.0	27.8 ± 1.5	>0.6
	Posterior Thigh	29.2 ± 1.4	29.2 ± 1.1	29.2 ± 1.5	1.00	28.1 ± 1.3	28.3 ± 1.0	28.3 ± 1.1	1.00	28.9 ± 1.4	29.4 ± 1.4	28.8 ± 1.6	1.00	27.4 ± 1.4	28.1 ± 0.9	27.6 ± 0.8	>0.5
	Popliteal Fossa	29.7 ± 0.8	30.2 ± 1.0	29.9 ± 1.1	>0.7	28.9 ± 0.8	29.3 ± 1.0	29.0 ± 0.8	>0.8	29.2 ± 1.0	29.7 ± 1.0	29.2 ± 1.2	1.00	28.0 ± 1.0	29.2 ± 0.6	28.5 ± 0.9	# 0.046
	Posterior Leg	28.7 ± 0.8	28.7 ± 1.2	28.6 ± 1.3	1.00	28.1 ± 1.1	28.4 ± 0.8	28.1 ± 1.0	1.00	28.2 ± 1.2	28.2 ± 1.2	27.8 ± 1.5	1.00	27.5 ± 1.3	27.8 ± 0.8	27.0 ± 1.5	>0.6
Maximum Tsk (°C) (°C)(°C) Temperature	Anterior Thigh	31.7 ± 1.6	31.9 ± 1.1	31.3 ± 1.4	1	30.6 ± 2.0	31.0 ± 1.1	30.6 ± 0.7	1	31.2 ± 1.9	31.4 ± 1.8	31.2 ± 1.4	1	30.4 ± 2.1	30.9 ± 1.4	29.6 ± 0.8	>0.3
	Knee	30.9 ± 1.6	30.9 ± 1.5	30.6 ± 1.3	1	30.2 ± 1.6	30.7 ± 1.2	30.1 ± 1.4	1	30.7 ± 1.8	30.7 ± 1.8	30.2 ± 0.8	1	30.3 ± 1.8	30.3 ± 1.7	29.4 ± 1.0	>0.7
	Anterior Leg	32.1 ± 1.2	31.9 ± 1.0	32.0 ± 1.3	1	32.5 ± 1.4	32.2 ± 1.0	32.3 ± 1.2	1	32.1 ± 1.4	31.7 ± 1.3	31.6 ± 1.3	1	32.2 ± 1.5	31.8 ± 1.5	31.5 ± 1.3	>0.9
	Posterior Thigh	31.5 ± 1.7	31.8 ± 1.0	31.6 ± 1.5	1	30.7 ± 1.7	31.2 ± 1.0	30.9 ± 1.6	1	31.4 ± 1.5	31.8 ± 1.2	31.2 ± 1.7	1	30.5 ± 1.7	30.7 ± 1.2	30.4 ± 1.2	1
	Popliteal Fossa	32.3 ± 1.2	32.8 ± 0.9	32.4 ± 1.1	1	32.2 ± 1.1	32.6 ± 0.9	32.3 ± 0.9	>0.9	32.0 ± 1.0	32.6 ± 0.9	32.0 ± 1.1	>0.7	31.7 ± 1.3	32.6 ± 0.8	31.8 ± 1.0	>0.2
	Posterior Leg	30.9 ± 0.9	31.2 ± 1.1	31.2 ± 1.1	1	31.3 ± 1.1	31.7 ± 1.0	31.6 ± 1.3	1	30.8 ± 1.1	30.8 ± 1.5	30.8 ± 1.6	1	30.6 ± 1.6	31.1 ± 1.5	30.8 ± 1.7	1

p = Difference between means; # = differences between circular group and control group; Tsk: skin temperature.

The mean skin temperature at the rest of the two tests was compared. The flat knitting group was the only group that reduced the skin temperature at rest after the treatment (popliteal fossa IC95% (−1.42, −0.03 °C) p = 0.042). Mean skin temperature after the exercise of the two tests was compared. The mean skin temperature after exercise of the posterior thigh in the control group (IC95% (−1.33, −0.015) p= 0.045), popliteal fossa of the control group (IC95% (−1.47, −0.19) p = 0.013) and the posterior leg of flat knitting group (IC95% (−1.87, −0.19) p = 0.019) was lower in the second evaluation than in the first evaluation.

3.2. Maximum Skin Temperature

Table 2 shows the data of maximum skin temperature measured in the different tests, moments, and types of compression tights. No differences were observed in the different ROIs ($p > 0.05$) in the interaction between tests, moment, and type of compression tights.

The moment (pre-exercise or post-exercise) had a primary effect on maximum skin temperature. A lower maximum skin temperature was measured after exercise than before exercise in the anterior thigh (IC95% (−1.25, −0.69 °C) $p < 0.001$), knee (IC95% (−0.74, −0.25 °C) $p < 0.001$) and posterior thigh (IC95% (−1.16, −0.52 °C) $p < 0.001$).

3.3. Mean Skin Temperature Variation

No differences were observed between groups in both tests ($p > 0.05$). Moreover, considering the main effect of evaluation, only the posterior thigh (IC95% (0.01, 0.60 °C) p = 0.042) presented a higher mean skin temperature variation at the second evaluation (Figure 5), while no differences were observed in the other ROIs ($p > 0.05$): anterior thigh (IC95% (−0.36, 0.40 °C)), knees (IC95% (−0.40, −0.26 °C)), anterior leg (IC95% (−0.15, 0.39 °C)), popliteal fossa (IC95% (−0.33, 0.25 °C)) and posterior leg (IC95% (−0.19, 0.40 °C)).

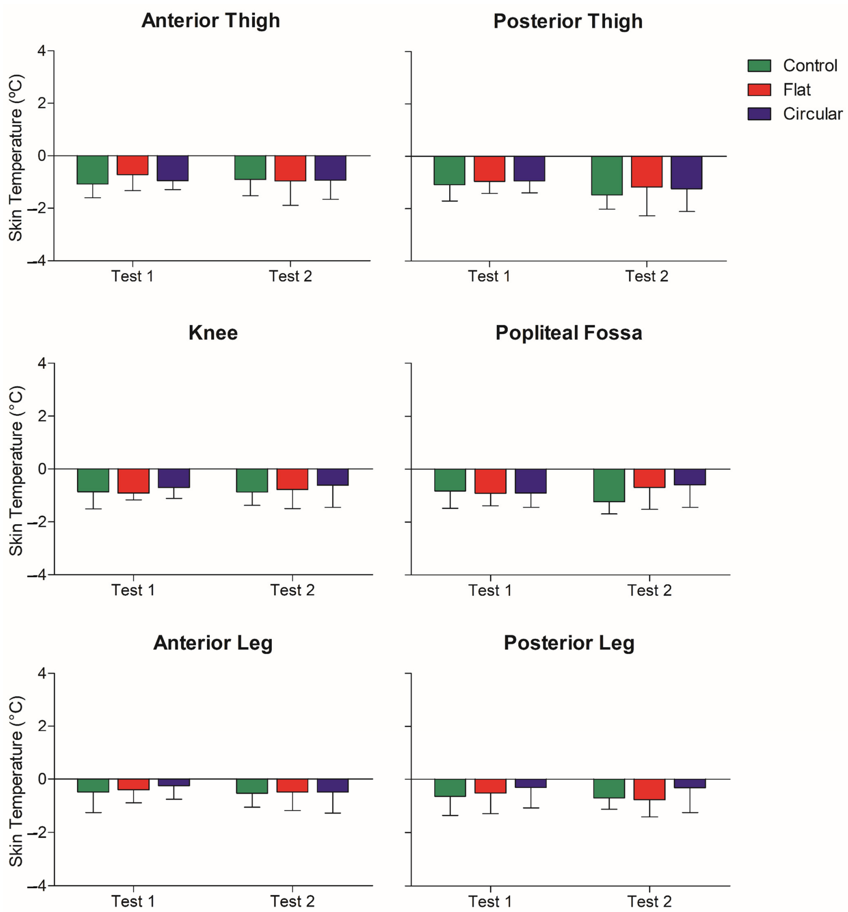

Figure 5. Skin temperature variation (Mean ± SD) for each region of interest in all groups.

3.4. Maximum Skin Temperature Variation

No differences were observed in the interaction between groups and both tests ($p > 0.05$). Furthermore, when the main effect of evaluation is considered, only the anterior leg (IC95% (−0.08, 0.62 °C) $p = 0.014$) and posterior leg (IC95% (0.08, 0.77 °C) $p = 0.018$) showed a higher maximum skin temperature variation at the second evaluation (Figure 6). Moreover, no differences were observed in the other ROIs ($p > 0.05$): anterior thigh (IC95% (−0.39, 0.55 °C)), knees (IC95% (−0.28, 0.30 °C)), posterior thigh (IC95% (−0.15, 0.61 °C)) and the popliteal fossa (IC95% (−0.26, 0.36 °C)).

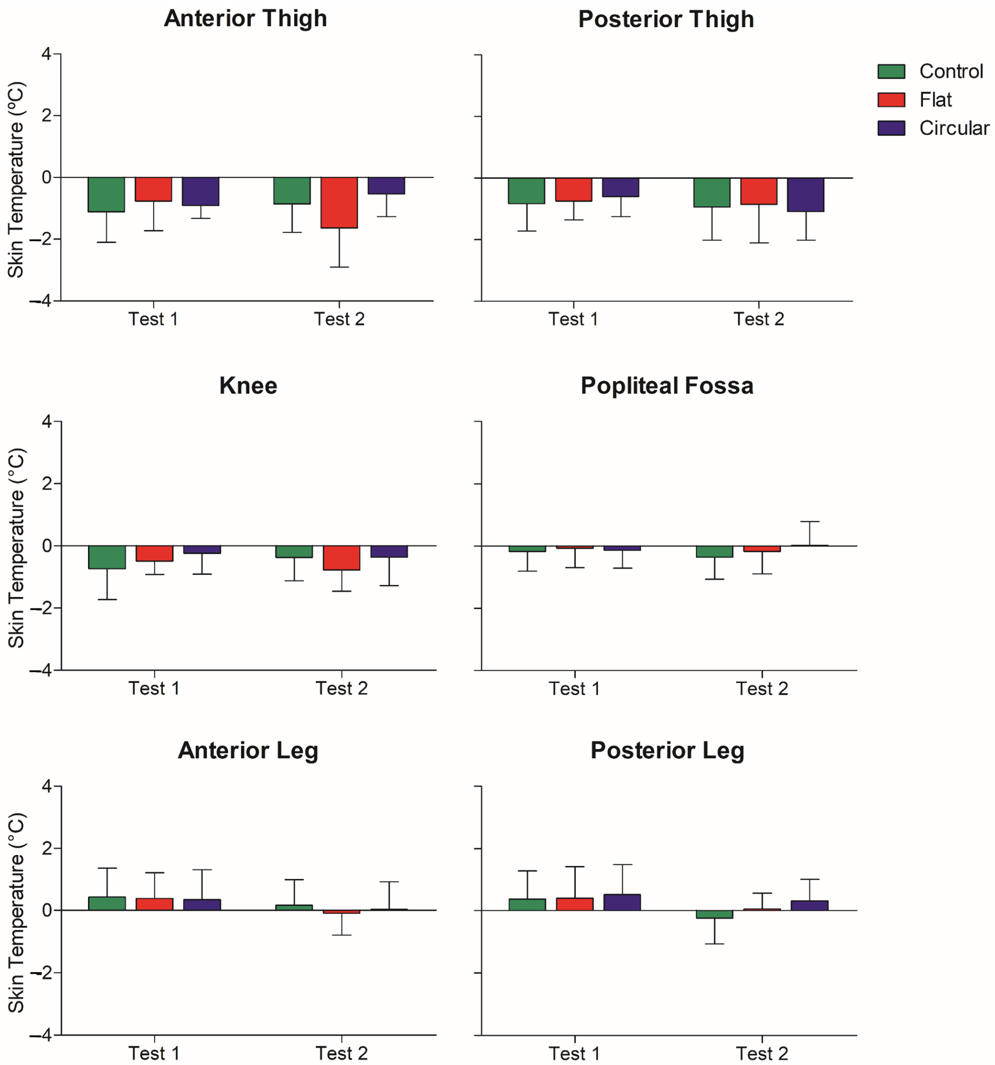

Figure 6. Maximum skin temperature Variation (Mean ± SD) for each region of interest in all groups.

4. Discussion

The objective of the study was to assess the effect of compression tights on skin temperature in women with lipedema. The main result is the absence of any effect on skin temperature after 15 days of employing different compression tights at rest and after exercise.

4.1. Skin Temperature at Rest

Lipedema is underdiagnosed due to the lack of knowledge about its physiopathology and the existing similarities among pathologies such as lymphedema and obesity [1,30]. However, there are some differences; for example, lipedema is a symmetrical increase in adipose tissue, whereas lymphedema is not symmetrical and does not raise the percentage of adipose tissue [1,30]. From the author's knowledge, although any previous study assessed skin temperature in people with lipedema, lymphedema has been assessed previously [21,22]. Kelly et al. [22] measured resting skin temperature, and they obtained the greatest values of skin temperature in women with advanced lymphedema. Furthermore, the skin temperature of the regions with nodules and fibrosis was lower than regions without it, and this fact probably was produced by a blood flow impairment in the region. On the contrary, Dębiec et al. [21] measured lower values of skin temperature in people with lymphedema, especially in those with advanced lymphedema. The controversy in the results of these studies shows the necessity of performing new studies to provide more evidence.

In this sense, in our study composed of women with lipedema, the participants of the control group did not employ compression tights before their inclusion in the study and during the study in comparison with the groups that wore compression tights along the study, which also employed compression garments before the study. However, no differences between groups were observed in rest skin temperature in the first and the second test. These results are in agreement with the results of previous studies that compared in a healthy sample the skin temperature between groups with compression garments and generic garments without compression [31,32]. In our study, the only difference observed was in the flat knitting group in the popliteal fossa ROI (p = 0.042), where the skin temperature in the second test was lower than the first test. This effect probably was a random effect because it happened only in one ROI and in one group. However, this fact could be produced by the difference in the values of compression between their compression tights and the prototypes of the study. In the development of the prototype, it was paid attention by AITEX to comfort and perspiration, and the values of compression obtained were lower than the own tights of participants that used therapeutical compression tights (Level CCL2). According to the data provided by the Technological Institute of Textile (AITEX) (Figure 3), circular knitting compression tights have the greatest declining compression in the lower leg in comparison with flat knitting compression tights (circular b1: 62%, c 49%; d 46% vs. flat b1: 93%; c: 95% d: 76%). This idea must be analyzed in other studies to identify the effect of the compression level and the percentage of compression in skin temperature.

4.2. Skin Temperature after Exercise

Regarding physical exercise, it increases the energetic demand resulting in an increase in heat production [33,34]. In this way, the human body needs some mechanisms to dissipate the heat with the aim of maintaining thermic homeostasis [33,34]. The beginning of exercise triggers the thermoregulatory response; it specifically increases the rate of sweating, which allows the decrease in skin temperature in the first minutes of the activity [35,36]. Women with lipedema decreased their mean and maximum skin temperature variation in all the ROIs except in the lower leg after walking. In this part of the leg (posterior leg and anterior leg), they increased the mean skin temperature during the first test, and they maintained it during the second test. This reduction in skin temperature may be produced by vasoconstriction in the skin [18]. The energetic demand of the musculature and the absence of heat strain are facts that prioritize the blood in the muscle and not in the skin [37]. In addition, skin impairments produced as a consequence of lipedema, such as fibrosis, can also alter skin blood flow [22]. On the other hand, skin temperature variation was calculated because it allows for detecting skin temperature differences between conditions that, in some cases, cannot be detected by the average and maximum skin temperature due to the variability between participants in their baseline value [38].

After the test, the control group obtained lower values of mean skin temperature after exercise in the hamstrings (p = 0.045) and in the popliteal fossa (p = 0.013) than in the test before de treatment. The flat compression tights group reduced skin temperature in the posterior leg in the second test in comparison with the first test (p = 0.019). In the case of the circular tights group, they experienced the same tendency, but no significant differences were observed. In this way, the differences were observed in groups that followed the treatment and in groups without compression tights. Therefore, the effect cannot be associated with wearing compression tights, and it may be produced by vasoconstriction [18] or sweating [37]. Furthermore, flat knitting compression tights produced a skin temperature reduction in the lower leg, the opposite of the hypothesis, which affirms that this knitting would increase skin blood flow and skin temperature.

4.3. Limitations

The main limitation is the absence of healthy women to identify if exists differences in skin temperature between healthy women and women with lipedema. Another limitation is that the sample of the study (n = 24) was divided into three groups. This limitation was because it is difficult to recruit participants currently diagnosed by a doctor due to the lack of knowledge about the physiopathology of lipedema and the difficulty of distinguishing it from other diseases. This limitation also results in an age heterogeneity of the sample. Moreover, the menstrual cycle was not controlled, and it may affect skin temperature. For this reason, it is recommended in the future to collect more sample that allows for exploring other factors, such as the grade of the pathology. On the other hand, the level of compression and other intrinsic and extrinsic factors may influence the skin temperature, and it would be interesting to perform a crossover study where all the participants are under the same conditions. The duration of the treatment was not established according to previous research due to the absence of them. In this sense, 15 days could not be enough to generate an effect in the women. Finally, the sample was composed of women with grade I or grade II lipedema, and it could be interesting to include women with grade III lipedema.

5. Conclusions

The use of compression tights (over 15 days) did not alter skin temperature in women with lipedema, rejecting the hypothesis established in the study. Moreover, flat or circular knitting did not cause differences in skin temperature, and it refutes the hypothesis that the elevated thickness of flat knitting compression tights will produce a greater increase in skin temperature than circular knitting compression tights. Therefore, these compression tights could be employed during exercise, providing the benefits of this treatment to women with lipedema. Therefore, the temperature factor in women with lipedema is not conditioned to the use of compression tights.

Author Contributions: Conceptualization, all the authors; methodology, J.I.P.-Q., I.A., P.P.-S. and R.M.C.-O.d.A.; formal analysis, J.L.S.-J., J.I.P.-Q. and I.A.; investigation, J.L.S.-J. and I.A.; writing—original draft preparation, J.L.S.-J., J.I.P.-Q. and I.A.; writing—review and editing, all the authors; supervision, J.I.P.-Q., P.P.-S. and I.A.; project administration, P.P.-S. and I.A; funding acquisition, P.P.-S., M.J.G.-R. and I.A. All authors have read and agreed to the published version of the manuscript.

Funding: This research was funded by Conselleria d'Economia Sostenible, Sectors Productius, Comerç i Treball de la Generalitat Valenciana, through IVACE, and is cofounded by ERDF from the European Commission within the framework of the Operational Programme FEDER for the Comunitat Valenciana 2014–2020. Reference: IMDEEA/2020/11. TPTex 2.0: R&D of compression garments to improve health in patients with lower limb pathologies.

Institutional Review Board Statement: The study was conducted in accordance with the Declaration of Helsinki and approved by the Ethics Committee of the University of Valencia (register code 1487160).

Informed Consent Statement: Informed consent was obtained from all subjects involved in the study.

Data Availability Statement: The datasets generated and analyzed during the current study are available from the corresponding authors upon reasonable request.

Acknowledgments: We are grateful to Conselleria d'Economia Sostenible, Sectors Productius, Comerç i Treball de la Generalitat Valenciana, IVACE and the Operational Programme FEDER for the support.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Kruppa, P.; Georgiou, I.; Ghods, M.; Biermann, N.; Prantl, L.; Klein-Weigel, P. Lipedema-Pathogenesis, Diagnosis, and Treatment Options. *Dtsch. Arztebl. Int.* **2020**, *117*, 396–403. [CrossRef] [PubMed]
2. La Torre, Y.S.D.; Wadeea, R.; Rosas, V.; Herbst, K.L. Lipedema: Friend and Foe. *Horm. Mol. Biol. Clin. Investig.* **2018**, *33*, 20170076. [CrossRef] [PubMed]
3. Dudek, J.; Białaszek, W.; Gabriel, M. Quality of Life, Its Factors, and Sociodemographic Characteristics of Polish Women with Lipedema. *BMC Womens Health* **2021**, *21*, 27. [CrossRef] [PubMed]
4. Alwardat, N.; Di Renzo, L.; Alwardat, M.; Romano, L.; De Santis, G.L.; Gualtieri, P.; Carrano, E.; Nocerino, P.; De Lorenzo, A. The Effect of Lipedema on Health-Related Quality of Life and Psychological Status: A Narrative Review of the Literature. *Eat. Weight Disord.-Stud. Anorex. Bulim. Obes.* **2019**, *25*, 851–856. [CrossRef] [PubMed]
5. Grada, A.A.; Phillips, T.J. Lymphedema: Pathophysiology and Clinical Manifestations. *J. Am. Acad. Dermatol.* **2017**, *77*, 1009–1020. [CrossRef] [PubMed]
6. Shavit, E.; Wollina, U.; Alavi, A. Lipoedema Is Not Lymphoedema: A Review of Current Literature. *Int. Wound J.* **2018**, *15*, 921–928. [CrossRef]
7. Fetzer, A.; Wise, C. Living with Lipoedema: Reviewing Different Self-Management Techniques. *Br. J. Community Nurs.* **2015**, *20*, S14–S19. [CrossRef]
8. Langendoen, S.I.; Habbema, L.; Nijsten, T.E.C.; Neumann, H.A.M. Lipoedema: From Clinical Presentation to Therapy. A Review of the Literature. *Br. J. Dermatol.* **2009**, *161*, 980–986. [CrossRef]
9. Kröger, K. Lymphoedema and Lipoedema of the Extremities. *Vasa-J. Vasc. Dis.* **2008**, *37*, 39–51. [CrossRef]
10. Reich, S.; Schmeller, W.; Brauer, W.J.; Cornely, M.E.; Faerber, G.; Ludwig, M.; Lulay, G.; Miller, A.; Rapprich, S.; Richter, D.F.; et al. S1 Guidelines: Lipedema. *JDDG—J. Ger. Soc. Dermatol.* **2017**, *15*, 758–767. [CrossRef]
11. Todd, M. Diagnosis and Management of Lipoedema in the Community. *Br. J. Community Nurs.* **2016**, *21*, S6–S12. [CrossRef]
12. Doherty, D.; Morgan, P.; Moffatt, C. *Role of Hosiery in Lower Limb Lymphoedema*; MEP Ltd.: London, UK, 2006.
13. Gavin, T. Clothing and Thermoregulation During Exercise. *Sport. Med.* **2012**, *33*, 941–947. [CrossRef]
14. Duffield, R.; Portus, M. Comparison of Three Types of Full-Body Compression Garments on Throwing and Repeat-Sprint Performance in Cricket Players. *Br. J. Sports Med.* **2007**, *41*, 409–414. [CrossRef] [PubMed]
15. Hillen, B.; Pfirrmann, D.; Nägele, M.; Simon, P. Infrared Thermography in Exercise Physiology: The Dawning of Exercise Radiomics. *Sport. Med.* **2020**, *50*, 263–282. [CrossRef] [PubMed]
16. Moreira, D.G.; Costello, J.T.; Brito, C.J.; Adamczyk, J.G.; Ammer, K.; Bach, A.J.E.; Costa, C.M.A.; Eglin, C.; Fernandes, A.A.; Fernández, I.; et al. Thermographic Imaging in Sports and Exercise Medicine: A Delphi Study and Consensus Statement on the Measurement of Human Skin Temperature. *J. Therm. Biol.* **2017**, *69*, 155–162. [CrossRef]
17. Kandlikar, S.G.; Perez, I.; Raghupathi, P.A.; Gonzalez, J.L.; Dabydeen, D.; Medeiros, L.; Phatak, P. Infrared Imaging Technology for Breast Cancer Detection—Current Status, Protocols and New Directions. *Int. J. Heat Mass Transf.* **2017**, *108*, 2303–2320. [CrossRef]
18. Carbonell, L.; Priego, J.I.; Retorta, P.; Benimeli, M.; Cibrián Ortiz De Anda, R.M.; Salvador Palmer, R.; González Peña, R.J.; Galindo, C.; Pino Almero, L.; Blasco, M.C.; et al. Thermographic Quantitative Variables for Diabetic Foot Assessment: Preliminary Results. *Comput. Methods Biomech. Biomed. Eng. Imaging Vis.* **2019**, *7*, 660–666. [CrossRef]
19. Priego, J.I.; Lucas, A.G.; Gil, M.; Giménez, J.V.; Aparicio, I.; Cibrián Ortiz de Anda, R.M.; Salvador, R.; Llana, S.; Pérez, P. Effects of Graduated Compression Stockings on Skin Temperature after Running. *J. Therm. Biol.* **2015**, *52*, 130–136. [CrossRef]
20. Chudecka, M.; Lubkowska, A.; Kempińska, A. Body Surface Temperature Distribution in Relation to Body Composition in Obese Women. *J. Therm. Biol.* **2014**, *43*, 1–6. [CrossRef]
21. Dębiec, A.; Skrzek, A.; Wozniewski, M.; Malicka, I. Using Thermography in the Diagnostics of Lymphedema: Pilot Study. *Lymphat. Res. Biol.* **2020**, *18*, 247–253. [CrossRef]
22. Kelly, L.A.; Karim, M.; Sultan, A.; Al Kawsar, A.; Khair, A.; Betts, H.; Douglass, J.; Forrer, A.; Taylor, M.J. Infrared Thermal Imaging as a Novel Non-Invasive Point-of-Care Tool to Assess Filarial Lymphoedema. *J. Clin. Med.* **2021**, *10*, 2301. [CrossRef] [PubMed]
23. Zasadzka, E.; Trzmiel, T.; Kleczewska, M.; Pawlaczyk, M. Comparison of the Effectiveness of Complex Decongestive Therapy and Compression Bandaging as a Method of Treatment of Lymphedema in the Elderly. *Clin. Interv. Aging* **2018**, *13*, 929–934. [CrossRef]
24. Sanchís, R.; Blasco, C.; Encarnación, A.; Pérez, P. Changes in Plantar Pressure and Spatiotemporal Parameters during Gait in Older Adults after Two Different Training Programs. *Gait Posture* **2020**, *77*, 250–256. [CrossRef]
25. Sanchís, R.; Blasco, C.; Camacho, A.; Encarnación, A.; Pérez, P. Evaluation of Impact-Shock on Gait after the Implementation of Two Different Training Programs in Older Adults. *Clin. Biomech.* **2020**, *80*, 105131. [CrossRef]
26. Pérez, P.; Llana, S.; Encarnación-Martínez, A.; Martínez-Nova, A.; Morey-Klapsing, G. Nordic Walking Practice Might Improve Plantar Pressure Distribution. *Res. Q. Exerc. Sport* **2011**, *82*, 593–599. [CrossRef]
27. Neumann, H.; Partsch, H.; Mosti, G.; Flour, M. Classification of Compression Stockings: Report of the Meeting of the International Compression Club, Copenhagen. *Int. Angiol. J. Int. Union Angiol.* **2016**, *35*, 122–128.
28. Wardiningsih, W.; Troynikov, O. Interface Pressure Generated by Knitted Fabrics of Different Direction, Composition and Number of Layers in Sport Compression Garments. *J. Text. Inst.* **2018**, *110*, 882–890. [CrossRef]

29. Marins, J.C.B.; Moreira, D.G.; Cano, S.P.; Quintana, M.S.; Soares, D.D.; De Andrade Fernandes, A.; Da Silva, F.S.; Costa, C.M.A.; Dos Santos Amorim, P.R. Time Required to Stabilize Thermographic Images at Rest. *Infrared Phys. Technol.* **2014**, *65*, 30–35. [CrossRef]
30. Forner, I.; Szolnoky, G.; Forner, A.; Kemény, L. Lipedema: An Overview of Its Clinical Manifestations, Diagnosis and Treatment of the Disproportional Fatty Deposition Syndrome—Systematic Review. *Clin. Obes.* **2012**, *2*, 86–95. [CrossRef]
31. Fujii, N.; Nikawa, T.; Tsuji, B.; Kenny, G.P.; Kondo, N.; Nishiyasu, T. Wearing Graduated Compression Stockings Augments Cutaneous Vasodilation but Not Sweating during Exercise in the Heat. *Physiol. Rep.* **2017**, *5*, e13252. [CrossRef]
32. Venckunas, T.; Trinkunas, E.; Kamandulis, S.; Poderys, J.; Grunovas, A.; Brazaitis, M. Effect of Lower Body Compression Garments on Hemodynamics in Response to Running Session. *Sci. World J.* **2014**, *2014*, 353040. [CrossRef]
33. Kenefick, R.W.; Cheuvront, S.N. Physiological Adjustments to Hypohydration: Impact on Thermoregulation. *Auton. Neurosci. Basic Clin.* **2016**, *196*, 47–51. [CrossRef]
34. Kenny, G.P.; Mcginn, R. Restoration of Thermoregulation after Exercise. *J. Appl. Physiol.* **2017**, *122*, 933–944. [CrossRef]
35. De Andrade, A.; Dos Santos, P.R.; Brito, C.J.; De Moura, A.G.; Moreira, D.G.; Costa, C.M.A.; Sillero, M.; Marins, J.C.B. Measuring Skin Temperature before, during and after Exercise: A Comparison of Thermocouples and Infrared Thermography. *Physiol. Meas.* **2014**, *35*, 189–203. [CrossRef]
36. Vargas, N.T.; Chapman, C.L.; Johnson, B.D.; Gathercole, R.; Schlader, Z.J. Skin Wettedness Is an Important Contributor to Thermal Behavior during Exercise and Recovery. *Am. J. Physiol.-Regul. Integr. Comp. Physiol.* **2018**, *315*, R925–R933. [CrossRef]
37. Priego, J.I.; De la Fuente, C.; Kunzler, M.; Perez, P.; Hervás, D.; Carpes, F.P. Relationship between Skin Temperature, Electrical Manifestations of Muscle Fatigue, and Exercise-Induced Delayed Onset Muscle Soreness for Dynamic Contractions: A Preliminary Study. *Int. J. Environ. Res. Public Health* **2020**, *17*, 6817. [CrossRef]
38. Priego, J.I.; Kunzler, M.R.; Carpes, F.P. Methodological Aspects of Infrared Thermography in Human Assessment. In *Application of Infrared Thermography in Sports Science*; Springer International Publishing: Valencia, Spain, 2017; pp. 49–79. ISBN 978-3-319-47409-0.