Thermal Vasodilation Using a Portable Infrared Thermal Blanket in Decompensated Heart Failure

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SUMMARY

Adjuvant and non-pharmacological therapies, such as heat, for the treatment of heart failure patients have been proposed. Positive results have been obtained in clinically stable patients, but no studies of the use of thermal therapy in patients with decompensated heart failure (DHF) have been reported. An open randomized clinical trial was designed in patients with DHF and controls. We studied 38 patients with a mean age of 56.9 years. A total of 86.8% were men, and 71% had nonischemic myocardopathy. All participants were using dobutamine, and the median brain natriuretic peptide (BNP) level was 1396 pg/mL. An infrared thermal blanket heated the patients, who were divided into 2 groups: group T (thermal therapy) and group C (control). Group T underwent vasodilation using the thermal blanket at 50°C for 40 minutes in addition to drug treatment. The cardiac index increased by 24.1% \( (P = 0.009) \), and systemic vascular resistance decreased by 16.0% \( (P < 0.024) \) after thermal therapy. Heat as a vasodilator increased the cardiac index and lowered systemic vascular resistance in DHF patients. These data suggest thermal therapy as a therapeutic approach for the adjuvant treatment of DHF patients. \( \text{Int Heart J 2014; 55: 433-439} \)

Key words: Thermal therapy, Hyperthermia, Hemodynamics, Catheterization, Swan-Ganz

Heart failure (HF) is the final pathway of most heart diseases, and these patients exhibit high rates of hospitalization and mortality. \( ^4 \) Patients in advanced stages of the disease require hospitalization at some point. Hospitalization for decompensated heart failure (DHF) is urgent and requires immediate medical treatment.

Activation of the neurohormonal system occurs during decompensation with increased systemic vascular resistance, increased pulmonary capillary pressure, and reduced cardiac output. \( ^3 \) Patients at this stage present symptoms such as low cardiac output and systemic and pulmonary vasodilatation, which may lead to hypotension, poor peripheral perfusion, decreased levels of consciousness, generalized edema, and dyspnea.

Most patients respond properly to treatment when the clinical and hemodynamic profile of decompensation is used. \( ^3 \) However, a subgroup of patients depends on inotropic drugs despite medication adjustment. The assessment of perfusion and congestion through clinical observation is impaired. Therefore, hemodynamic data using objective measures must be obtained. This subgroup is refractory to treatment. \( ^4,5 \)

The use of a pulmonary artery catheter (eg, Swan-Ganz) may be indicated for the treatment of hospitalized DHF patients in select and difficult cases. \( ^1 \) This intervention may aid objective and timely treatment measures and guide medication management using the hemodynamic data obtained. Adjuvant and non-pharmacological measures, such as heat, have been proposed for HF patients. \( ^1,4,5 \) Heat increases blood flow via nitric oxide production, which increases endothelial nitric oxide synthase (eNOS) activity. Heat activates CD34+ progenitor endothelial cells, which promote angiogenesis, improving cardiac perfusion and decreasing the systemic vascular resistance. \( ^10 \)

Thermal vasodilation, or thermotherapy, was used initially to treat patients with functional class III or IV HF. The first studies were performed using hot immersion baths, \( ^2,5 \) but this method was improved using sauna sessions with infrared radiation. However, no studies of heat treatment have been performed in decompensated patients in advanced HF using intravenous drugs. Patients at this stage require inotropes, are confined to bed, and cannot undergo sauna sessions or immersion baths. These patients require rest and may easily get worse with changes in decubitus or the need for transfer to perform exams or complementary therapies. However, a method to warm the patient at the bedside could be developed, such as a handheld device that emits heat waves without the need for patient mobilization. Therefore, this study proposes the use of a thermal blanket to generate heat using direct infrared radiation.

No data have demonstrated the efficacy of thermotherapy during the acute HF phase, and it is important to analyze the
effects of thermotherapy on the hemodynamic conditions of these patients during decompensation. The present study evaluated the acute hemodynamic effects of heat using a thermal blanket in patients with refractory DHF using intravenous vasodepressor drugs. The increased cardiac index and reduced systemic vascular resistance were evaluated as outcomes.

**METHODS**

This study was a unicentric open randomized clinical study of DHF patients and controls conducted between October 2007 and April 2013. Patients were studied in a single day, and the acute effect of heat before and after the intervention was evaluated. Heat was generated using a thermal blanket with infrared radiation. Hemodynamic measurements were assessed using the invasive Swan-Ganz catheter.

**Population:** Patients with DHF from the Emergency Unit of the Heart Institute (Instituto do Coração - Incor), Clinics Hospital, Faculty of Medicine, University of São Paulo were selected to continue treatment according to the following inclusion and exclusion criteria. The patients were receiving continuous intravenous inotropic drugs and were refractory to conventional treatment after the attempted removal of vasodepressor drugs without success. All patients were using at least one oral vasodilator at the maximum tolerated dose. The diuretic of choice for congestion was intravenous furosemide, which was present in 100% of the assessed patients (mean dose of 59.6 mg/day).

**Inclusion criteria**
- Age > 18 years;
- Left ventricle ejection fraction (LVEF) < 40%, as confirmed via echocardiography using the method of Simpson or Teichholz;
- Use of intravenous positive inotropic drugs (dopamine or milrinone) for at least 5 days;
- Use of one or more oral vasodilator drugs (captopril/enalapril/losartan/hydralazine/isosorbide mononitrate).

**Exclusion criteria**
- Heat intolerance;
- Decubitus intolerance < 45 degrees;
- Fever, defined as a body temperature above 37.8°C;
- Duration of antibiotic;
- Allergy to the thermal blanket;
- Presence of decubitus ulcer;
- Large-caliber varices;
- Marked edema of the lower limbs;
- Cardiac pacemaker or implantable cardioverter defibrillator (ICD);
- Technical difficulty obtaining deep venous access.

The patients were divided into 2 groups: group T (thermotherapy) and group C (control). The first 8 patients were allocated to group T for safety analysis and validation of the proposed method. Thereafter, patients were randomly allocated to the groups. The T group underwent thermal vasodilation using a handheld device at bedside (ie, the thermal blanket) at a temperature of 50°C for 40 minutes during drug clinical treatment. Patients in group C received drug treatment, and the thermal blanket was positioned in the same manner as in group T but without heat for 40 minutes.

**Cardiac catheterization:** Measurements were obtained via the Swan-Ganz catheter following established recommendations. A cardiac output module (DX-AJDEC-0) compatible with a Dixtal® DX 2023 monitor was used for Swan-Ganz catheter measurements using the thermodilution method. Patients were monitored continuously using an electrocardiogram, pulse oximetry and blood pressure, which was measured automatically every 5 minutes using an arm cuff during the invasive procedure. A heart monitor continuously recorded ambient and patient temperatures via the catheter during the procedure. Hemodynamic measurements were performed during the pre- and post-intervention periods, with a 40-minute interval based on the randomization. Mean arterial pressure, pulmonary capillary pressure, cardiac index, and systemic vascular resistance measurements were analyzed.

**Thermal blanket:** An Aesthetics infrared (Bio Term Manufature and Commerce of Thermal Products LTD) thermal blanket was used for heating (Figure 1). The thermal blanket generates heat via 44 infrared pads that emit waves from 4 to 14 microns in a single zone of resistance and are coated with 100% waterproof nylon, which prevents the penetration of liquids and secretions to the inside. The blanket is inexpensive and easy to maintain and clean. A digital control regulated the temperature, which could reach 50°C. Physicians and a multidisciplinary team performed the intervention, which was discontinued at any time if hemodynamic instability was observed. The temperature was set 5 minutes before the start of the intervention to reach 50°C throughout the procedure. The thermal blanket includes a thermostat to automatically turn the equipment off if the temperature sensor of the digital controller stopped functioning. A digital thermometer was also placed in the blanket to ensure the proposed temperature. A cotton sheet was placed between the patient and the thermal blanket to prevent burns. The patients were asked about symptoms or discomfort during the procedure, and patients could discontinue the proceedings at any time.

**Intervention:** Patients who met the inclusion criteria freely signed an informed consent. This study was registered under number 0653/08 and approved by the Research Ethics Committee of the Heart Institute and the Research Grants Committee of the Faculty of Medicine, University of São Paulo. The
Statistical analysis: The classification variables are presented in the Table as absolute (n) and relative (%) frequencies. The association between variables was evaluated using Fisher’s exact test or the likelihood ratio. The normality of the quantitative variables was evaluated using the Kolmogorov-Smirnov test. The quantitative variables are presented descriptively in tables and graphs as the mean and standard deviation (SD). The means of the variables were evaluated using analysis of variance for repeated measures (ANOVA). The measured values were compared using Student’s t test. A P < 0.05 was considered statistically significant.20)

Sample and randomization: The sample was calculated21) in 25 patients with an 80% power based on data presented in 2008.22) Twenty one and 23 patients were required to detect an increase in the cardiac index from 2.18 ± 0.81 to 3.29 ± 1.57 L/minute/m² and a reduction in systemic vascular resistance from 2151 ± 578 to 1631 ± 699 dynes/second/cm², respectively. This subject number was determined because the present study was an initial project with this type of intervention. No parameters were reported in the literature to allow calculations for the evaluation of clinically relevant outcomes in the decompensated stage of HF. Patients were randomized in exchangeable blocks of 4 into 2 groups: the thermotherapy (group T) and control (group C). The sequence of randomization was built using random distribution in blocks through tables of numbers with the aid of a computerized system. The sequence was closed in individually numbered and sealed opaque envelopes.23) A person who did not participate in the study performed the assembly process and sealed the envelopes. These envelopes were opened at bedside minutes before the intervention.

### Table. Patient Characteristics Divided Per Group

<table>
<thead>
<tr>
<th>Variable</th>
<th>Control (n = 25)</th>
<th>Thermotherapy (n = 23)</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (years)</td>
<td>54.4 ± 11.2</td>
<td>59.4 ± 9.3</td>
<td>0.150</td>
</tr>
<tr>
<td>Sex</td>
<td></td>
<td></td>
<td>0.979</td>
</tr>
<tr>
<td>Male, n (%)</td>
<td>13 (86.7)</td>
<td>20 (86.9)</td>
<td></td>
</tr>
<tr>
<td>Female, n (%)</td>
<td>2 (13.3)</td>
<td>3 (13.1)</td>
<td></td>
</tr>
<tr>
<td>Ethnicity</td>
<td></td>
<td></td>
<td>0.399</td>
</tr>
<tr>
<td>White, n (%)</td>
<td>9 (60.0)</td>
<td>12 (52.2)</td>
<td></td>
</tr>
<tr>
<td>Other, n (%)</td>
<td>6 (40.0)</td>
<td>11 (47.8)</td>
<td></td>
</tr>
<tr>
<td>Etiology</td>
<td></td>
<td></td>
<td>0.602</td>
</tr>
<tr>
<td>Ischemic, n (%)</td>
<td>5 (33.3)</td>
<td>6 (26.1)</td>
<td></td>
</tr>
<tr>
<td>Non-ischemic, n (%)</td>
<td>10 (66.7)</td>
<td>17 (73.9)</td>
<td></td>
</tr>
<tr>
<td>VAD (days)</td>
<td>14 ± 10.6</td>
<td>18.6 ± 13.5</td>
<td>0.418</td>
</tr>
<tr>
<td>Dobutamine, n (mcg/kg/minute)</td>
<td>15 (7.75 ± 4.22)</td>
<td>23 (10.79 ± 3.85)</td>
<td>1.000</td>
</tr>
<tr>
<td>Milrinone, n (mcg/kg/minute)</td>
<td>0</td>
<td>1 (0.375)</td>
<td></td>
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<tr>
<td>Hemodynamic variables</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>HR (bpm)</td>
<td>82.5 ± 17.2</td>
<td>85.7 ± 16.0</td>
<td>0.441</td>
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<tr>
<td>SBP (mmHg)</td>
<td>93.1 ± 13.8</td>
<td>97.4 ± 10.3</td>
<td>0.507</td>
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<tr>
<td>MAP (mmHg)</td>
<td>73.4 ± 11.1</td>
<td>76.3 ± 9.2</td>
<td>0.390</td>
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<tr>
<td>DBP (mmHg)</td>
<td>63.1 ± 10.8</td>
<td>65.6 ± 9.3</td>
<td>0.805</td>
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<tr>
<td>PCP (mmHg)</td>
<td>25.4 ± 8.7</td>
<td>31.2 ± 8.2</td>
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</tr>
<tr>
<td>CI (L/minute/m²)</td>
<td>3.18 ± 0.68</td>
<td>2.94 ± 0.75</td>
<td>0.638</td>
</tr>
<tr>
<td>SVR (dynes/second/cm²⁻⁵)</td>
<td>1479.1 ± 444.5</td>
<td>1707.0 ± 573.6</td>
<td>0.675</td>
</tr>
</tbody>
</table>

VAD indicates vasoactive drug; LVD, diastolic diameter of the left ventricle; LVS, systolic diameter of the left ventricle; LVEF, ejection fraction of the left ventricle; BNP, brain natriuretic peptide; HR, heart rate; SBP, systolic blood pressure; MAP, mean arterial pressure; DBP, diastolic blood pressure; PCP, mean pulmonary capillary pressure; CI, cardiac index; and SVR, systemic vascular resistance.
RESULTS

A total of 165 patients were evaluated for eligibility. Twelve of these patients refused the study, and 105 were excluded by the exclusion criteria. Forty-eight patients were included, but 10 patients were excluded before randomization. Two patients had hypovolemia, and the cardiac output could not be measured through the Swan-Ganz catheter due to technical difficulties in 2 patients. Two patients had severe dyspnea during the procedure, which prevented continuation of the intervention, and deep venous access was not possible in 4 patients. One patient in the thermotherapy group died (Appendix).

Eight patients who underwent heat sessions for safety and method validation were evaluated initially, and 30 patients were randomized to the end of the study. A total of 38 patients were studied. The study profile is shown above (Figure 2). No differences in baseline characteristics were observed between the groups (Table).

A total of 38 patients with DHF were evaluated. Most patients were male (86.8%) with a mean age of 56.9 years, nonischemic etiology (71%), and a left ventricular ejection fraction (LVEF) of 23.4%. All patients were using dobutamine at a mean dose of 9.27 mcg/kg/minute with a mean use time of 16.3 days. An association of milrinone was observed in one patient in the thermotherapy group. The mean initial BNP was 1396 pg/mL. Atrial fibrillation was present in 28.5% of the patients. Patients exhibited an initial MAP of 74.8 mmHg, PCP of 28.3 mmHg, CI of 3.06 L/minute/m², and SVR of 1.593 dynes/second/cm⁻⁵. Hemodynamic measurements were obtained during dobutamine administration, when they were transferred from the emergency room for adjustment and continuity of treatment.

The results of the hemodynamic variable measurements are presented in Figures 3-6.

Mean arterial pressure (MAP): No significant differences were found in the behavior of the two groups post-intervention (P = 0.968). (Figure 3)

Pulmonary capillary pressure (PCP): No significant differences were found in the behavior of the two groups post-intervention (P = 0.521). (Figure 4)

Cardiac index (CI): The CI increased in group T post-intervention (P = 0.009). (Figure 5)

Systemic vascular resistance (SVR): The SVR decreased in group T post-intervention (P = 0.024). (Figure 6)

DISCUSSION

This report is the first study to include thermotherapy as a non-pharmacological method for DHF treatment in hospitalized patients at an advanced stage of the disease who were dependent on vasoactive drugs and refractory to conventional treatment. The patients exhibited low cardiac output, vasoconstriction, and prolonged use of a vasoactive drug. This type of patient does not often fit into the guidelines or published papers on HF treatment because this population is severe with high in-hospital mortality. Therefore, this work is novel due to the profile of the population studied and the use of heat as an adjuvant measure for the treatment of cardiac decompensation.

The safety and feasibility of the method was demonstrated initially in a group of critically ill patients because no data exist for this scenario. Preliminary results suggested hemodynamic improvement through an increased cardiac index and
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Figure 5. CI indicates cardiac index pre- and post-intervention.

Figure 6. SVR indicates systemic vascular resistance pre- and post-intervention.

decreased systemic vascular resistance with heat. However, the clinical behavior of patients admitted for DHF in the presence of thermotherapy was not certain.

A total of 38 patients were evaluated in this study pre- and post-intervention. The hemodynamic improvement reported by patients undergoing thermotherapy was apparent. Thermal vasodilation increased the CI by 24.1% (P = 0.009) and reduced systemic vascular resistance by 16% (P = 0.024) without affecting patient mean blood pressure (group C: 73.4 ± 13.3 to 73.8 ± 12.4 mmHg; group T: 76.3 ± 11.7 to 76.7 ± 13.3 mmHg; P = 0.968) or heart rate (group C: 83.3 ± 18.6 to 86.9 ± 19.8 bpm; group T: 89.5 ± 19.0 to 95.1 ± 21.8; P = 0.355). An immediate hemodynamic effect of heat is observed due to peripheral vasodilatation, especially through the type of radiation used in this study. The choice of infrared radiation in previous studies was due to its higher heat transfer compared to other methods.

Tei, et al12,13 first described thermotherapy at the end of the 1980s. Hot immersion baths were described initially and improved in 2007 with the use of saunas with infrared radiation (eg, Waon therapy). Waon therapy uses saunas with infrared radiation unlike traditional saunas, which are heated by hot stones or electric elements. Only approximately 20% of the heat in these traditional saunas is transferred in the form of radiation. In contrast, the infrared heating elements transfer approximately 90% of their energy through infrared radiation. Tadashi Ishikawa invented these “modern” infrared heaters in 1965. The infrared radiation penetrates deep into the body, which likely underlies the greater heat effect in these treatments.

Hot immersion baths or transfer for saunas during patient hospitalization in this study would not be possible because of their hemodynamic conditions. Therefore, thermotherapy was applied using an infrared thermal blanket with the same features as infrared saunas with the benefits of portability and ease of use at bedside. This blanket generates heat directly on hospitalized patients via infrared radiation pads connected to the socket. The target temperature (50°C) was adjusted and maintained during the entire procedure using the thermostat.

The patients were monitored continuously throughout the procedure. The Swan-Ganz catheter and a digital thermometer monitored patient temperature during heat treatment. A difference of at most 1°C was found in the central body temperature of patients undergoing thermotherapy. No statistically significant changes in body temperature were observed, which may be a risk predictor for the procedure (group C: 36.9 ± 0.52 to 37.01 ± 0.48°C; group T: 37.03 ± 0.50 to 37.3 ± 0.36°C; P = 0.359).

Most studies on the use of heat in HF patients involved symptomatic patients (NYHA Class III and IV) without the need for vasoactive drugs. Kihara, et al25 studied 20 patients with congestive HF who received Waon therapy (15 minutes of sauna per day). Symptoms improved in 17 of 20 patients after 2 weeks of treatment. Kihara, et al26 subsequently followed a protocol similar to the first study and evaluated 30 patients with complex ventricular arrhythmias (> 200 ectopic ventricular beats/day). After randomization, 20 patients received Waon therapy for 5 days per week for two weeks, and 10 patients in the control group remained at rest for 45 minutes in a room at 24°C. A statistically significant reduction in the number of ventricular ectopic beats was observed in the group that received thermotherapy, which is more important data to explain patient hemodynamic improvement.

Kihara, et al27 published the results of a third trial in April 2009. This study assessed 129 patients with HF (NYHA functional class III or IV), and 64 patients were treated with Waon therapy for 5 days during hospitalization and at least twice per week after discharge. The data were compiled after 5 years and analyzed. Twelve patients in the control group died, and 8 patients in the Waon group died. Over the 5 years, 31% of patients who received Waon therapy were re-hospitalized for HF or died from heart disease compared to 69% in the untreated group (P < 0.01).

Clinical, hemodynamic and laboratory parameters in patients with prolonged hospitalization lost diagnostic value in the present study from the moment the patients become refractory to conventional treatment. The BNP dose during hospitalization for prognosis assessment would be significant with a longer follow-up, which was not evaluated in this work.

Miyata, et al28 conducted a prospective multicenter study to confirm the results of thermotherapy using laboratory markers. A total of 188 patients received conventional treatment for HF for 1 week, and 112 patients received Waon therapy. A total of 76 patients were in the control group. The Waon group received the same protocol (ie, 15 minutes of sauna per day at 60°C followed by 30 minutes of rest with a blanket, 5 days per week for 2 weeks). Echocardiography and BNP dose were assessed before and after treatment and again two weeks later. A statistically significant improvement was observed in all measures in the Waon group patients after treatment.

Fujita, et al29 demonstrated a decrease in oxidative stress in patients undergoing Waon therapy. Forty patients were divided into a control group (n = 20) and a Waon therapy group.
(n = 20). Hydrogen peroxide and BNP concentrations decreased significantly in the Waon group after 4 weeks of daily sessions, but nitric oxide metabolites increased. No changes were observed in the control group.

The advanced stage of heart failure, especially the dependence on vasoactive drugs and treatment resistance, is a time when small hemodynamic changes may occur frequently and result in disease evolution in patients, which hampers treatment. The functional loss of baroreceptors that suppress sympathetic activity and inhibit vasopressin secretion prolongs decompensation even in the presence of circulatory compensation. Vasodilators, such as prostaglandins and nitric oxide, are released to compensate for the vasoconstriction. Therefore, heat would act as another vasodilator in the hemodynamic adaptation process.

Heat can be used acutely as an important adjunct therapy for clinical improvement in DHF patients. Intermitent, and not daily, sessions of heat with pharmacological treatment may be necessary to promote the expected clinical improvement at this stage. Ochiai, et al demonstrated that DHF in patients who received more than 2 oral vasodilators during hospitalization (multiple vasodilations) exhibited higher cardiac indexes and lower systemic vascular resistance compared to patients treated with only one vasodilator. These data support the use of thermotherapy as another option for vasodilatation in decompensation. Therefore, the addition of other vasodilators may effectively change the prognosis in decompensation in the presence of oral vasodilators when the usual treatments are ineffective.

In conclusion, the use of heat (ie, thermotherapy) as a vasodilator increased the cardiac index and reduced systemic vascular resistance in decompensated HF.

The data from this sample suggest that thermotherapy is a therapeutic adjuvant for the treatment of DHF patients. However, a randomized clinical trial using a larger patient sample is required to explore the potential clinical efficacy.

Limitations of the study: Some variables in this initial exploration were not analyzed. The echocardiographic variables that were not repeated after the use of heat were considered important. The BNP dose would be important in long-term follow-up studies during hospitalization for clinical outcomes.

Only a long-term randomized clinical trial with a larger sample and more clinically relevant outcomes would provide evidence of thermotherapy efficacy in DHF.

**APPENDIX**

Male patient, 60 years-old, admitted with a diagnosis of idiopathic decompensated heart failure, hospitalized at 37 days since then with dobutamine at a mean dose of 15 mcg/kg/minute and milrinone associated with a mean dose of 0.375 mcg/kg/minute. Already using oral vasodilators and diuretics without clinical improvement. Attempted withdrawal of vasoactive drugs 3 times without success, presenting hemodynamic instability. The left ventricle ejection fraction was 21%, with important diffuse hypokinesia and without thrombi. He was randomized to the thermotherapy group. On the sixth day, he suffered cardiorespiratory arrest in PEA readily assisted, and died. No necropsy was performed due to the severity of the case.

**REFERENCES**

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