RESEARCH ARTICLE

The Thermal and Nonthermal Effects of High and Low Doses of Pulsed Short Wave Therapy (PSWT)

Maryam M. Al-Mandeel¹ & Tim Watson²*

¹Faculty of Allied Health Sciences, Physical Therapy Department, Kuwait University, Kuwait
²School of Health & Emergency Professions, University of Hertfordshire, Hatfield, Hertfordshire, UK

Abstract

Background and Purpose. The study aimed to investigate the thermal and non-thermal effects of pulsed short wave therapy (PSWT) using high and low dose of PSWT together with placebo and control conditions in healthy subjects. Method. A single-blind, crossover design was employed with 31 subjects who all participated in three conditions: High PSWT (PD 200 μsec, PRR 800 Hz, MP 24 W, 10 minutes), Low PSWT (PD 100 μsec, PRR 200 Hz, MP 3 W, 10 minutes), and Placebo PSWT (PD 20 μsec, PRR 50 Hz, MP 0.05 W, 10 minutes). Fourteen subjects additionally participated in a Control condition (no treatment, 10 minutes). Measurements of skin temperature, blood flow, heart rate, and core temperature were taken before, during, and after the application of PSWT. Data were analyzed using a repeated measures analysis of variance (ANOVA) model with a Bonferroni post-hoc comparison. Results. A significant increase in blood volume and skin temperature with both the high- and low-dose applications during the treatment period was demonstrated. There were significant differences between time periods and between treated and untreated limbs compared with the control condition. The blood flow changes during the low-dose application were not significantly different from placebo. Some subjects were unable to detect significant changes in skin temperature. Conclusion. Significant physiological changes associated with the application of PSWT have been demonstrated, challenging the notion of a lack of effect of this therapy. The study also demonstrated a measurable increase in skin temperature, which was not associated with thermal sensory perception; thus, skin sensation may not be clinically reliable for detecting real changes in temperature. Subjects with a wide age range of ages were deliberately recruited; however, these results may not extrapolate to a patient population who could react differently to the same intervention. Further studies in the clinical environment are therefore needed.

Keywords
Pulsed shortwave therapy; blood flow; skin temperature; physiological effects; healthy humans

*Correspondence
Tim Watson, School of Health & Emergency Professions, University of Hertfordshire, Hatfield, Hertfordshire AL10 9AB, UK.
Email: t.watson@herts.ac.uk

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Introduction

Surveys have shown that Pulsed Short Wave Therapy (PSWT) is one of the more commonly used electrotherapy modalities among physiotherapists (Al-Mandeel and Watson, 2006; Shields, 2003, Kitchen and Partridge, 1996; Pope et al., 1995). A recent audit (Al-Mandeel and Watson, 2006) demonstrated its use in some 11% of outpatient treatments in the UK. PSWT involves the delivery of high-frequency electromagnetic...
energy in an intermittent mode, which is employed to modify tissue behavior and is accepted as clinically useful in conditions such as soft tissue injuries (both traumatic and operative), arthropathies (osteoarthritis, rheumatoid arthritis), nerve regeneration, and pain reduction despite the lack of literature that supports its efficacy in some of these areas.

It is thought that PSWT works by increasing blood flow, decreasing joint pain and stiffness, reducing inflammation, accelerating wound healing, and aiding the faster resolution of oedema (Kloth and Ziskin, 1996; Al Mandeel and Watson, 2008). These effects have only been examined in a limited number of studies, several of which are of low methodological quality and for which several critical ‘dose’ parameters are not fully reported. The mechanism of action of PSWT has generated significant debate with some arguing that temperature change is the main factor responsible for all the reactions observed, and that PSWT achieves its physiological actions through heating the tissues and increasing the blood supply to the heated area (Ward, 1980; Lehmann and DeLateur, 1990). Alternatively, there are those who expound the non-thermal effects of PSWT through restoration of cells’ membrane potential, an interaction that is believed to occur at both molecular and ionic levels (Hayne, 1984; Cleary, 1996, Adey, 1988; Al-Mandeel and Watson, 2008).

Given that the mechanism of action for this modality is an area of dispute; many trials have focused on PSWT effectiveness without attempting to identify the mechanism of action. One problem with the majority of these trials is that they have focused on the maximum output of PSWT machines and neglected other commonly employed treatment power ranges. Maximum power output is associated with a definite increase in skin temperature (SkT) (Bricknell and Watson, 1995; Garret et al., 2000, Murray and Kitchen, 2000), but is an output that is rarely used in the clinical environment (Al-Mandeel and Watson, 2006). Therapists often prefer to use the minimum level of energy possible to achieve the desired physiological responses, as it is associated with minimal side effects (Low and Reed, 2000). Given these considerations, it is unlikely that therapists will employ the maximum setting of PSWT in the clinical environment and, hence, although these studies are informative, they may be of limited value to physiotherapists in informing their clinical decisions.

The non-thermal effects of PSWT on blood volume (BVol) and SkT remain inconclusive from the literature and, therefore, further investigation is warranted. The trial aimed to investigate both the thermal and the non-thermal effects produced by PSWT with a single-blind trial on healthy subjects using a high dose (mean power (MP) 24 W) and a low dose (MP 3 W). The physiological responses were compared to a placebo dose (MP 0.05 W) and a control group. These doses have been shown to be consistent with those in current clinical use (Al-Mandeel and Watson, 2006).

**Methodology**

**PSWT device**

Experimentation was carried out using a Megapulse Senior machine (EMS Physio Ltd, Wantage, UK). The Megapulse Senior is a therapeutic apparatus that can deliver shortwave in both continuous and pulsed modes. In the pulsed mode the device can deliver pulses, which are adjustable in duration (PD) (20–400 msec) and pulse repetition rate (PRR) (50–800 Hz) enabling the operator to vary the output. Although the peak output is fixed at 150 W, the mean power output can be varied by manipulating the other pulse parameters. The machine was fully checked and calibrated prior to the study commencement.

**Procedure**

In all the experimental conditions, the PSWT was applied for 10 minutes. The treatment duration was based on the finding of a questionnaire, which showed that 10 minutes is the most common treatment duration employed by therapists in the UK; therefore, making the trial outcome clinically relevant (Al-Mandeel and Watson, 2006).

**Sample size calculation**

A sample size calculation was employed during the recruitment process in order to establish the required sample size for the tests. In this type of calculation, the final sample is calculated based on the results obtained after data have been collected from the initial subjects in the study. In the current study after collecting 17 full sets of data, the preliminary results were used to calculate the total number of subjects needed using specialized software (www.calculators.stat.ulca.edu/powercalc). Based on the standard deviation (SD), effect size, significance level <0.05, and a power of 0.8,
the number of subjects needed was determined to be 31.

**Sample recruitment and allocation to experimental groups**

The study design was approved by the Ethics Committee for Radiography and Physiotherapy at the University of Hertfordshire. Thirty-one asymptomatic subjects were recruited for the research, which employed a single blind within subject (repeated measures) design. The sample included 7 males and 24 females recruited from the university students and staff. Subjects were randomly assigned to experimental groups using a randomization table.

All 31 subjects attended for three sessions representing high, low, and placebo conditions. Those who were able to attend for a fourth session \((n = 14)\) took part in the control group (Figure 1). The high dose was administered using peak power (PP) of 150 W, pulse duration (PD) of 200 μsec, and pulse repetition rate of (PRR) 800 Hz, giving a mean power (MP) of 24 W, for 10 minutes. The low dose was applied on PP 150 W, PD 100 μsec, PRR 200 Hz giving an MP of 3 W for 10 minutes. The placebo PSWT was accomplished with PP 150 W, PD 20 msec, PRR 50 Hz for 10 minutes. These parameters represented the lowest output for the Megapulse machine and resulted in a MP of 0.05 W, which was not expected to bring about physiological changes in an asymptomatic population. The subjects in the control group were required to rest on the plinth for 10 minutes where measurements are taken and no treatment was administered.

The dose used for the experiment was based on proposed treatment plans suggested by physiotherapists on theoretical cases given to them in a questionnaire (Al-Mandeel and Watson, 2006).

Measurements of BVol, SkT, Pulse Rate (PulsR), and Core Temperature (CorT) were taken in three periods; a baseline (10-minute measurement period prior to intervention), treatment (10 minutes during the intervention), and recovery (post-intervention for 10 minutes). Skinfold thickness (SKF), height, and weight were measured for all subjects. SKF was measured from triceps, suprailium, abdomen in females and from chest, triceps, and subscapular area in males using Lafayette callipers (Model 01127, Bissell Healthcare Company). The measurements were taken three times by the same researcher and the mean was used for analysis (Jackson and Pollack, 1985; Lehmann et al., 1988).

At the first attendance, subjects read an information sheet and this was followed by a briefing on the procedure and time to enquire about any issues of concern. Treatment contraindications were checked, and a consent form was signed by all the subjects. Subjects were excluded from the study if their SKF was above 40 mm for two main reasons. First, because of the possible effects that a thick layer of adipose fat may have on PSWT penetration (Ward, 1980; Hand, 1990) and, consequently, the physiological effects brought about by the treatment may be significantly compromised (although this may not be integral to current clinical practice). Second, the body fat calculation for subjects with an SKF above 40 mm have been found to be less reliable (Jackson and Pollock, 1987; Kwok et al., 2001) as reliability decreases with obesity when using the skin caliper technique (Scherf et al., 1986).

At the beginning of each session subjects were asked about the nature of their activities in the 2 hours prior to attending the laboratory to note any activities that may affect the data collected. All treatments were delivered using a drum (monode) electrode applied 1.5 cm from the anterior aspect of the right knee. The patient was positioned in a half lying position with a roll under the knee to bring it into 30° of flexion.

Subjects were asked to attend for three appointments with at least 2 days in between the sessions to allow the effects of previous treatment to recede; hence, washing out any latent effect of the PSWT treatment (Cleary, 1996). Subjects were asked to attend at the same time for the three sessions to minimize the effect of CorT variation on the outcome (Houdas and Ring, 1982; Guyton and Hall, 2000). All subjects were asked to

**Figure 1** Schematic representation of the experimental groups
refrain from smoking, drinking coffee, and exercise at least 1 hour before the trial to minimize their effect on circulatory system as a result of the changes in metabolism (Drust et al., 2003). They were asked not to exercise because of the possibility that fluid may shift between tissues and increase SKF reading, thereby confounding the results (Jackson and Pollock, 1987).

All the testing procedures were conducted in a research laboratory with a room temperature between 23°C and 26°C. Both the room humidity and temperature were monitored and recorded before and after each experimental session (Thermo Hygrometer, RS 212-124).

Subjects attended 15 minutes before the start of the experiment to acclimatize to the laboratory temperature and to allow their vital signs to stabilize. Although the treatment was applied to subjects’ right knee to ensure consistency, outcome measures were taken from both limbs to enable comparison.

Data acquisition system

The physiological data (BVol and SkT) were collected using MP100 (Biopac Systems, Santa Barbara, CA, USA). Sampling rate for this experiment was set to 200 samples/second based on extensive pilot work.

Recording of blood volume

BVol was measured using TSD 100B photoplysmography (PPG) transducer (Biopac Systems). The processor provided real-time continuous estimate of the BVol in the superficial microvasculature. The PPG probe was placed 2 cm medial to the tibial tuberosity along the knee joint line and was secured in place using a V elcro strap. BVol was monitored continuously for the duration of the experiment (pre-, during, and post-treatment). The potential heating of the PPG transducer and signal interference was excluded in the pilot work.

Recording of skin temperature

SkT was measured using SKT 100B amplifier module (sensitivity <83 m°C) connected to a TSD 102D rapid response thermistor (Biopac Systems). The temperature probe was attached 2 cm lateral to the tibial tuberosity along the knee joint line. The probe was secured in place using a non-allergic tape. SkT was measured pre- and post-treatment for 10 minutes each. During the treatment the temperature probe was removed because heating of the probe was demonstrated during pilot work. Reliability of the probe reattachment was also established during pilot studies.

Recording of pulse rate and core temperature

The PulsR was recorded from the right ear lobe every 2 minutes using a Tunturi unit (TPM-400, Japan). The mean of the PulsR readings for each phase (pre-/ during/post-treatment) was used for analysis. The CorT was recorded using Tympanic Thermometer (Invac Medical Systems, Model 2090, San Diego, CA, USA). The CorT was measured from the left ear at 5-minute intervals (i.e. twice during each recording period), as the CorT was not expected to vary significantly (Guyton and Hall, 2000) in a 10-minute period. The mean for the two readings during each phase was used for analysis.

Data analysis

All data were analyzed using a repeated measure analysis of variance (ANOVA) model. Normality of distribution and homogeneity of variance were examined for each variable prior to analysis. A post-hoc comparison (Bonferroni) was conducted to compare all pairs of conditions where the main findings were found to be significant in order to determine which experimental group was significantly different from the rest of the groups and under what conditions.

The factors used with ANOVA were condition, which had four levels (high dose, low dose, placebo, and control), phase, which had three levels (baseline, treatment, and recovery or post-treatment period), and side, which had two levels (treated and non-treated).

Results

Thirty-one subjects were recruited for the study. Subjects ranged in age between 19 and 48 years. A summary of the demographic data is presented in Table 1.

Blood volume results

A 4*3*2 (condition, time, side) repeated measure ANOVA revealed significant interactive effect between condition/phase/side (F(1.902, 22.828) = 2.448, p = 0.000). There was a main effect for condition (i.e. the
M. M. Al-Mandeel and T. Watson Effects of high and low doses of PSWT

The applied dose makes a significant difference to the blood flow changes observed and there were significant changes in BVol when comparing the pre/during/post data. Using the post-hoc (Bonferroni) contrast to compare the levels of the independent variables, a significant effect of different treatment conditions was demonstrated for the following combinations (high vs. control $p = 0.000$; low vs. control $p = 0.002$; high vs. low $p = 0.001$, and high vs. placebo $p = 0.032$). There was no significant difference in BVol between Low and Placebo conditions. The high dose resulted in the largest BVol changes compared with other doses. The low dose produced a BVol change, which was significantly greater than control. The high-dose BVol changes were significantly greater than those observed under low-dose conditions. Furthermore, there were significant effects between experimental phases (before/during/after) with the greatest changes demonstrated between the ‘before’ and ‘during’ phases (i.e., the changes observed during the intervention were not sustained post-intervention). There was a significant effect between treated and non-treated side, with the non-treated side changes mirroring those of the treated side, but the changes were of lower magnitude.

Figures 2 and 3 represent the summary data for all 31 subjects, showing an increase in blood volume during the intervention phase, most markedly for the high PSWT group and less so for the low and placebo conditions.

Table 1. Demographic data of the subjects (mean ± SD)

<table>
<thead>
<tr>
<th>N</th>
<th>Age (years)</th>
<th>Gender</th>
<th>Height (cm)</th>
<th>Weight (kg)</th>
<th>Body fat (%)</th>
<th>Dominant side</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Male</td>
<td>Female</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>31</td>
<td>26 ± 7.22</td>
<td>7</td>
<td>24</td>
<td>167.8 ± 8.98</td>
<td>70.15 ± 12.35</td>
<td>23.67 ± 7.08</td>
</tr>
</tbody>
</table>

Figure 2 Change in mean blood volume for the four experimental conditions in the treated limb (error bars represent the standard deviation)
groups compared with control. The responses in the untreated limb reflect the treated limb changes but tend to be of lower magnitude. The magnitude of the BVol changes in the placebo group for both the treated and untreated limbs are approximately equivalent, and suggest that these are ‘real’ changes, though not immediately attributable to the applied energy. The mean changes in BVol across the four experimental conditions are presented in Table 2.

**Skin temperature results**

A 4*2*2 (condition, time, side) repeated measure ANOVA was used to analyze SkT data. All interactions were significant for condition/phase ($F(2.054,24642) = 11.606$, $p = 0.000$), condition/side ($F(3,3) = 6.888$, $p = 0.001$), phase/side ($F(1,12) = 33.959$, $p = 0.000$), and condition/phase/side ($F(3,36) = 21.056$, $p = 0.000$). The Bonferroni post-hoc contrasts showed the most significant changes were in the treated limb at high dose comparing the before versus after data. The mean changes in skin temperature of the treated limb are clearly greater in the high- and low-dose conditions than in the placebo and control conditions, demonstrating minimal temperature change in the absence of significant energy introduction to the tissues.

**Table 2.** Mean change in BVol across the experimental conditions (± SD) in the treated and untreated limbs (values are reported in arbitrary unit)

<table>
<thead>
<tr>
<th>Condition</th>
<th>Treated limb blood volume (BVol) (arbitrary units)</th>
<th>Non-treated limb blood volume (BVol) (arbitrary units)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Before</td>
<td>During</td>
</tr>
<tr>
<td>High dose</td>
<td>30.70 ± 11.98</td>
<td>134.22 ± 71.30</td>
</tr>
<tr>
<td>Low dose</td>
<td>20.21 ± 9.89</td>
<td>74.56 ± 50.23</td>
</tr>
<tr>
<td>Placebo dose</td>
<td>27.10 ± 19.00</td>
<td>65.32 ± 38.74</td>
</tr>
</tbody>
</table>

Figure 3 Change in mean blood volume for the four experimental conditions in the untreated limb (error bars represent the standard deviation)
Pulse rate results

A 4*3 (condition, time) two-way ANOVA was used to examine the difference between the experimental groups. There was no significant difference when the data were analyzed by the treatment applied ($F(3,36) = 1.214, p = 0.318$) or between the experimental phases ($F(2,24) = 0.217, p = 0.807$). The mean changes in PulsR values ± SD across the four experimental conditions are displayed in Table 4.

Core temperature results

A 4*3 (condition, time) two-way ANOVA was used to examine the difference in core temperature between the experimental groups. The overall ANOVA results show a statistically significant difference between the experimental conditions ($F(3,36) = 3.928, p = 0.016$), but looking at the data in Table 4, it can be seen that any changes, while showing statistically significant differences between experimental conditions, are not of
sufficient magnitude to be clinically meaningful. The mean changes in CorT before, during, and after treatment are summarized in Table 5.

**Ambient temperature**

Using repeated measure ANOVA. There was a main effect of condition \((F(2.471,29.66) = 3.369, p = 0.039)\), and phase \((F(1,12) = 6.943, p = 0.022)\), which was not statistically significant when the post-hoc test for all the levels of the condition were examined and compared.

This means that there was a significant change in room temperature between the start and end of the experiment; however, this did not alter the outcome obtained with variables examined during the experimental conditions as confirmed by the post-hoc test.

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**Figure 5** Skin temperature (SkT) before and after treatment in the untreated limb (°C, error bars represent SD)

**Table 4.** Mean changes in pulse rate (PulsR) across the experimental conditions: mean ± SD; b.p.m., beat per minute

<table>
<thead>
<tr>
<th>Condition</th>
<th>PulsR before treatment (b.p.m.)</th>
<th>PulsR during treatment (b.p.m.)</th>
<th>PulsR after treatment (b.p.m.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>High dose</td>
<td>69.21 ± 11.69</td>
<td>68.90 ± 11.42</td>
<td>68.94 ± 10.75</td>
</tr>
<tr>
<td>Low dose</td>
<td>68.37 ± 13.93</td>
<td>69.20 ± 13.42</td>
<td>69.22 ± 13.20</td>
</tr>
<tr>
<td>Placebo</td>
<td>68.23 ± 13.69</td>
<td>68.19 ± 14.08</td>
<td>69.18 ± 14.20</td>
</tr>
<tr>
<td>Control</td>
<td>73.18 ± 9.64</td>
<td>72.55 ± 9.56</td>
<td>71.75 ± 9.41</td>
</tr>
</tbody>
</table>

**Table 5.** Mean changes in CorT across the experimental conditions: mean ± SD

<table>
<thead>
<tr>
<th>Condition</th>
<th>CorT before treatment (°C)</th>
<th>CorT during treatment (°C)</th>
<th>CorT after treatment (°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>High dose</td>
<td>34.76 ± 0.51</td>
<td>34.76 ± 0.39</td>
<td>34.79 ± 0.43</td>
</tr>
<tr>
<td>Low dose</td>
<td>34.81 ± 0.34</td>
<td>34.91 ± 0.29</td>
<td>35.00 ± 0.38</td>
</tr>
<tr>
<td>Placebo</td>
<td>34.86 ± 0.33</td>
<td>34.95 ± 0.35</td>
<td>34.94 ± 0.33</td>
</tr>
<tr>
<td>Control</td>
<td>34.83 ± 0.43</td>
<td>34.97 ± 0.42</td>
<td>34.92 ± 0.39</td>
</tr>
</tbody>
</table>
**Ambient humidity**

There was no main effect between conditions ($F(3,36) = 2.119, p = 0.115$), which means that there was no significant change in room humidity that could have affected the outcomes of the various variables examined.

**Discussion**

The effects of PSWT on SkT and BVol have been studied previously; however, the majority of the studies have focused on the maximum dose with a typical MP of 48 W. Furthermore, the limited reporting of substantial information needed to judge the quality of the studies and the absence of reporting of full treatment parameters, the diverse methodologies and the arbitrary choice of dosage, limit their clinical value. No published reports have been found that employed MP of 3 W or 24 W that could be used for comparison with the current study.

The study employed four dependent and two independent variables. The dependent variables were the change in SkT, BVol, PulsR, and CorT. The independent variables were the treatment dose and the side (treated or non-treated knee) considering before, during, and after treatment phases.

**Blood volume**

It has been argued that PSWT serves no physiological action other than heating the tissues and thus increasing the blood supply through the treated area (Wilson, 1974). The current study has provided evidence that there could be an increase in the circulating blood volume even with very minimal increase in SkT as was seen with the 3 W dose, which may be attributable to the ‘non-thermal’ effects — though the term non-thermal is used here in its clinical context meaning that there is no gross thermal change in the tissue. Clearly, the application of any energy to the tissues will have some thermal effect — though it may be smaller than the minimal detectable change by both therapists and patients.

Though PSWT at 3 W did not elicit a significant increase in BVol post-treatment, it did produce a considerable rise in BVol during the treatment period. The increased recording of PPG output provides an estimate of the change in BVol in the treated area. This increase could be explained by the combined result of the increase in hematocrit, and the expansion of intra-vascular volume though these functions were not assessed in the current study (Jespersen and Pedersen, 1986) as a result of a decrease in arterial system compliance (Babchenko et al., 2001). Moreover, given that the change in BVol in the vessels corresponds to the change in vessel diameter (Lindberg, 1991), it is expected that the increase in BVol noticed in both treatment conditions (high, low) is associated with local vasodilatation.

Morrissey (1966) reported that there was no statistical change in peripheral blood flow after irradiating the calf with PSWT at MP of 40 W for a period of 15 minutes. The findings of the current study challenge this, and demonstrate that there was a significant increase in BVol with 24 W, 3 W, and with the placebo condition during the treatment phase. The significant changes observed during the treatment phase were not maintained in the post-treatment period. Although the current study employed a lower MP, the increase in BVol could be attributed to the difference in methodology and sensitivity of the measuring device employed.

There was a 2.5-fold measured increase in BVol during treatment with the 24 W application and these findings carry clinical implications. In cases where swelling or hematoma are present, this dose should probably be avoided as it may exacerbate the symptoms by dilating blood vessels and, therefore, increasing the interstitial fluid volume.

The lack of statistical significance between the outcome of the low (3 W) and placebo (0.05 W) conditions means that energies as low as 3 W may be no more effective than placebo in asymptomatic subjects as the amount of applied energy is too small to achieve therapeutic results. This may not be true in the patient population as numerous studies have identified increased tissue sensitivity to applied energy in most if not all patient groups (Watson, 2008). There were increases in the blood volume in the untreated limb, though these changes were not as large nor as sustained as those observed in the treated region. It is possible that this was due to ‘overflow’ radiation from the treatment applicator, or may be a contralateral physiological response as has been demonstrated with other modalities.

**Skin temperature**

It has been argued that pulsing the shortwave output could eliminate the thermal effects normally associated
with its application. Bricknell and Watson (1995) have demonstrated a definite heat perception that was felt after a 7-minute exposure with MP of 10.8 W. Murray and Kitchen (2000) have shown that definite thermal sensation can be experienced if the MP was 21.19 ± 8.27 W. The distance between the treatment head and the treated area was 4 mm in Bricknell and Watson, but it was not mentioned in the Murray and Kitchen study.

The current study has examined the effect of MP 3 W and MP 24 W on SkT. Findings demonstrated that there was a mean increase of 1.9 ± 1.12°C in SkT post high dose and a mean increase of 0.34 ± 0.69°C with the low dose. The number of subjects who reported a thermal sensation was 11 (42.3%) with the high dose and 1 subject (0.3%) with the low dose. This difference in findings could be attributed to several reasons. The distance between the treatment head and the treatment area (Lehmann et al., 1969) which could either increase or decrease the amount of circulating air underneath the treatment head and as such, change the perception of thermal sensation. Another factor could be the dose employed which was the maximum setting of the PSWT with Bricknell and Watson (1995). A third factor could be the difference in the equipment employed (Diapulse in Murray and Kitchen, and Curapuls in Bricknell and Watson) in comparison to Megapulse in the current study. Each of these machines has a different PP (975 W with Diapulse, 200 W with Curapuls model 403 and 150 W with Megapulse Senior). Pilot work by the authors has showed that different PSWT machines do not behave identically even at the same apparent power settings. Moreover, it could be because different body parts have different temperature sensitivity to heat and this could be affected by the difference in somatosensory representation or the difference in vascularization (Odia and Aligogun, 1988). It is possible that the time needed to feel the developed heat on the front of the thigh could be different from the anterior knee. Findings also suggest that a significant increase in SkT could be measured even when the subject does not report a thermal sensation. The implication of this is that the reported skin sensation of heat may not be a consistently reliable source for detecting changes in thermal build up, a safety issue that needs to be taken into consideration. All participants in the current study had their thermal skin sensation tested following a standardized protocol, which was consistent with methods employed clinically.

In contrast with the literature that has shown a definite thermal sensation with MP as low as 10.8 W, Morrissey (1966) has demonstrated that with an MP of 40 W, there was no statistical significant increase in SkT. The findings of the current study have also shown non-significant statistical increase in SkT with 24 W, despite the measured temperature increase that reached 2°C. However, this increase although not statistically significant could have detrimental effects on treatment outcome with inflammatory lesions, where slight increase in temperature may exacerbate the symptoms (Hosie and Dickson, 2000).

The temperature increases demonstrated in the current study were around 2°C for the high dose and below 1°C with both the low dose and the placebo application. This increase in temperature returned to baseline or slightly above baseline after termination of PSWT only when the MP was 3 W or 0.05 W. These findings are in agreement with Tenforde (1996), who stated that with athermal exposure or when the increase in tissue temperature does not exceed 1°C, the effects were found to be reversible upon termination of the exposure. These findings imply that if the thermal effect is the aim of the treatment, a higher dose application needs to be employed (demonstrated in this study) or the time of exposure needs to be increased to allow the delivery of higher outputs of energy to the tissues (not evaluated in this study).

The increase in temperature associated with PSWT use is expected to stimulate metabolism and speed up chemical reactions (Ward, 1980). It is proposed that for each 1°C increase in tissue temperature, there could be a 13% increase in the rate of metabolic reaction (Kitchen, 2002). Research has shown that the intramuscular temperature needs to increase to at least 39°C and some say to 41°C in order to gain therapeutic effects (Noonan et al., 1993). The application of PSWT at MP 24 W was associated with a 1.9 ± 1.12°C increase in SkT and as such could be expected to increase local metabolism and speed up chemical reactions, consequently may be of therapeutic value.

Findings with the high-dose application have shown an increase in SkT of around 2°C above baseline reading. Although intramuscular temperature was not measured, it is expected that with energy delivered at MP 24 W and irradiation time of 10 minutes therapeutic effects may be obtained. Lehmann et al. (1983) have demonstrated on human tissue substitutes that the specific absorption area ratio of muscle to fat heating with
inductive electrodes could reach up to 2.67 times higher. This may mean that the deep tissue temperature could have increased to a possible 4°C degree. In an efficient circulatory system it is expected that no build up of heat will develop due to the dissipation of heat by the circulating blood. The differential heating effects at the skin surface and at depth in the tissues merit further detailed research as it is important to know, rather than to assume thermal profiles in the treated tissues. At the present time, measurement of temperature changes at depth without using indwelling probes is problematic.

The findings of the current study have shown that the application of PSWT is associated with a placebo effect and this is in accordance with the findings reported in the literature (Reed et al., 1987; Foley-Nolan et al., 1990; Klaber-Moffett et al., 1996). The study has also shown that the use of a low-dose application culminates in similar findings to placebo PSWT in healthy subjects. Such findings may have implications for the choice of parameters and time of exposure as these findings imply that lower power outputs could be no better than placebo in relation to the physiological parameters investigated. However, the use of very low power outputs needs to be examined in the patient population before they are discarded clinically as they may have an effect on compromised tissue that is not apparent in ‘normal’ tissues.

In all conditions it was found that the increase in BVol and SkT was directly proportional to the amount of energy applied. The fact that the response obtained during the treatment and was lost during the post-treatment period with the low-dose application (MP 3 W) or was higher than baseline but not statistically significant with the high dose (MP 24 W), could indicate that higher energies are needed to preserve the treatment effects. Again, this response may be different in a patient as opposed to a healthy asymptomatic population. Increasing the treatment time in order to achieve longer-lasting effects may be preferable and also needs investigation. The 10-minute application in this study was directly related to the most ‘popular’ clinical uses of the modality as identified by previous research (Al-Mandeel and Watson, 2006).

The physiological measurements were taken from both limbs because work on other electromagnetic frequencies has shown a ‘cross-talk’ effect between treated and non-treated side (e.g. Tabrah et al., 1990). Findings of this study concur with the Tabrah et al. (1990) findings as the response seen in the non-treated side was found to mirror the treated side but with smaller magnitude.

Although this research was designed primarily as a laboratory based study there are considerations, which may transfer to the clinical environment. Standard clinical thermal testing of skin sensation may not be sufficiently sensitive able to be able to discriminate ‘accurate’ and ‘inaccurate’ sensory levels. The results of this research certainly demonstrated changes in skin temperature, which were not recognized as a ‘heat sensation’ by the participant even though all participants were tested for thermal skin sensation. From previous research with PSWT (Bricknell and Watson 1995) a thermal skin change of 1.0–1.5°C is typically recognized by asymptomatic subjects. Further clarification with regards the thermal sensitivity of standard clinical skin sensation tests is needed to ensure the use of these tests is sufficiently accurate to enable avoidance of tissue damage through overheating.

One of the drawbacks of laboratory testing is that testing is conducted on young healthy subjects. In the current study, the age range of the recruited subjects was deliberately wide to enable better generalization, even so, they may not transfer directly to a patient population (pathology present, comorbidity, variable tissue-energy sensitivity), and a repeated study with a patient population, using the same methodology and measurement equipment has been conducted by the authors in order to enable a differentiated response set (Al Mandeel and Watson, in preparation).

The findings of the current study may have implications with regard to the decisions that therapists need to consider when deciding on efficacy of different treatment parameters.

**Conclusion**

The effect of applying PSWT at two different treatment doses plus a placebo and a control dose was examined in 31 healthy subjects. The results demonstrated a significant increase in BVol with both 24 W and 3 W applications during the treatment period. It was demonstrated that the post-treatment effects of the intervention (carry-over effects) were not significant, possibly because of the limited amount of energy delivered to the tissues. This could be overcome by increasing the time of exposure or using higher energy output. Such issues may have implications for clinical decision-making processes by physiotherapists, though
confirmation of this data in a patient population is necessary before definitive conclusions can be reached in this regard.

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