Hyperthermia and Shock Waves: New Methods in the Treatment of Sports Injuries

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Definition of Hyperthermia

Hyperthermia is the therapeutic technique which raises a pre-established part of the body to a temperature range between 41.5°C and 45°C, and maintains it at this range, for a given period of time.

Introduction and Historical Background of Diathermy

The primary rationale for the employment of therapeutic heat in physical medicine is the inducement of blood flow (BF) increase, which is anticipated to occur with the increase of temperature in the treated region.

This rationale is so because the mechanism for healing is thought to be highly dependent upon the transport of blood-nurturing substances and removal of toxic waste products [1]. The secondary rationale is the increase of the metabolic rate of a specific tissue volume, assuming that this behavior is comparable to the increase of the overall body metabolic rate on the basis of a 13% increase per degree above the normal temperature [2].

Shortwave (27.33 MHz) and microwave (2450 MHz) diathermy, together with ultrasound therapy, have been used over the decades as major heat methods for stimulating various beneficial physiological responses, and for the relief of a variety of pathological conditions.

Despite the widespread use of these methods in routine clinical practice, it appears that the major problem has been the lack of a correct scientific approach in the design and use of diathermy apparatus for optimal results.

Interest in the interaction of electromagnetic (EM) energy with biological tissues dates back to the first man-made EM sources [1]. A. D’Arsonval, a French physiologist, found in 1892 that currents of frequency 10 KHz or greater would produce an increase of temperature without painful muscular contractions [3].

The word ‘diathermy’ was introduced by Nagelschmidt in 1907 to describe the relatively uniform heating produced in the tissue by the conversion of high frequency currents into heat [3]. Between 1900 and 1935 in fact, physicians were using high frequency currents of between 0.5 – 3 MHz and 10 MHz (long-wave diathermy: 118 cm in muscle tissue at 10 MHz) for the above purposes.

In 1928, EM radiation as high as 100 MHz (short wave diathermy: 27 cm in muscle tissue at 100 MHz) was being produced by Esau, and used clinically by Schliephake [3]. Holmann in 1939 discussed the possible application of radio-waves of 25 cm wavelength for therapeutics, and predicted that these waves could be focused to produce heating of the deep tissues without excessive heating of the skin [3, 4].

The first therapeutic application of microwaves was at the Mayo Clinic (USA) in 1946 by Krusen and Leden, and involved the exposure of test animals to 65 W of 3000 MHz radiation (microwave diathermy: 1.45 cm at 3000 MHz). Despite the fact that the average temperature rise was greater in the skin and subcutaneous fat than in the deep muscle tissue, this work launched the use of microwave diathermy for application to physical medicine [5, 6]. It must be remembered, however, that these conclusions were based on the use of microwaves in dogs, which have thinner layers of subcutaneous fat and muscle than humans.

As a result of this study and the research done at MIT (Massachusetts Institute of Technology) in 1947, the FCC (Federal Communications Commission) assigned the frequency of 2450 MHz to physical medicine based on its alleged superiority in therapeutic value.

In 1950, Schwan demonstrated that 2450 MHz was not a good choice of frequency for the following reasons [7]:

1. Excessive heating in the subcutaneous fat
2. Poor penetration of energy into the muscle tissue due to small skin depth
3. Poor control of energy absorption due to large variation in the electrical thickness of subcutaneous tissues

Schwan recommended a frequency of 900 MHz or less. Lehmann and Guy, between 1960 and 1980, verified experimentally that 900 MHz or lower frequencies could produce better heating patterns than obtained with 2450 MHz or with other natural and technological heating modalities [8, 9].
In 1972, Johnson and Guy measured the properties of short-waves and microwaves in biological media in terms of depth of penetration of each frequency in tissue with a high water content (muscle and skin) and low water content (fat and bone [10]). As a result of this study it was noted that, in the range of frequency from 1 to 10,000 MHz, the depth of penetration was inversely correlated with frequency: the higher the frequency, the lower the penetration depth; the lower the frequency, the higher the penetration depth.

From 1980 to 1990, some studies showed that ultrasound could cause an increase of temperature in exposed human tissues and for this reason it became the most widely used deep heating method in physical medicine [11–15].

Knowledge of this historic evolution is important in the elucidation of the present-day problems encountered in the medical use and biological effects of short waves, microwaves, and ultrasound. Lack of physics and engineering knowledge in medicine has produced scientific research which did not consider the fact that electrical properties and geometry of tissue, as well as wave length, are far more important than the absorption and the focusing characteristics of waves in the generation of therapeutic heating patterns.

**Benefits of Therapeutic Heating**

The responses of therapeutic heating are:

1. Increase of blood flow due to vasodilation accompanied by increase in capillary pressure [16–19]
2. Increase of cellular membrane permeability [20]
3. Increase of metabolic reaction rate [2]
4. Alteration in sensory nerve conduction [21]
5. Increase of viscous flow properties of collagenous tissues in tendon, joint capsule and scarred synovium [22–25]

Due to these effects, heating can promote tissue regeneration, oedema reduction, relaxation in muscle spasm and reduction of tendon and muscle pain.

The most important factors, mandatory for the number and intensity of biological reactions of heat, are:

1. The therapeutic temperature threshold: approximately from 41.5°C to 45°C
2. The duration of the therapeutic temperature threshold: from 3 to 30 min
3. The speed of the temperature rise: the faster it is, the better is the effect
4. The proper heating of the target volume [9, 16, 26, 27]

It must be stressed that one of the most important factors in determining the extent of the above physiological responses to heat is the blood flow rate (BFR).

Scientific studies published in the 1980s in the fields of oncology, biomechanical engineering and physical medicine, have proved that the increase of blood perfusion response is a function of temperature threshold: to produce a significant rise in blood perfusion, at least 41.5°C must be reached, and the maximum blood rate is achieved when the temperature reaches approximately 45°C [1, 28–30].

Although the mechanism regulating the blood perfusion process is complex and not easily summarized in few lines. Sekins and colleagues made possible the examination of the interplay between local temperature, muscle blood flow, specific absorption rate and temperature gradients (Figs. 1, 2). The following table may help to understand the average hyperemia values modified by the rise of temperature in a thigh muscle heated with hyperthermia prototype equipment:

<table>
<thead>
<tr>
<th>Temperature</th>
<th>Blood perfusion</th>
</tr>
</thead>
<tbody>
<tr>
<td>36°C</td>
<td>2.7 ml/min/100g</td>
</tr>
<tr>
<td>37°C approx.</td>
<td>2.7 ml/min/100g</td>
</tr>
<tr>
<td>38°C approx.</td>
<td>2.7 ml/min/100g</td>
</tr>
<tr>
<td>39°C approx.</td>
<td>2.7 ml/min/100g</td>
</tr>
<tr>
<td>40°C approx.</td>
<td>2.7 ml/min/100g</td>
</tr>
<tr>
<td>41°C approx.</td>
<td>2.7 ml/min/100g</td>
</tr>
<tr>
<td>42°C approx.</td>
<td>10 ml/min/100g</td>
</tr>
<tr>
<td>43°C approx.</td>
<td>20 ml/min/100g</td>
</tr>
<tr>
<td>44°C approx.</td>
<td>30 ml/min/100g</td>
</tr>
<tr>
<td>45°C approx.</td>
<td>40 ml/min/100g</td>
</tr>
</tbody>
</table>

**Fig. 1.** Schematic of the experimental setup used to study human muscle temperatures and blood flow rates during 915-MHz direct contact diathermy. (From [1])