APPLICATIONS IN MEDICAL RECOVERY USING THE CRYO-SOUND MECHATRONIC SYSTEM

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Abstract - The innovative electromedical mechatronic system based on cryogenics and ultrasound SMCRM contributes significantly to ensuring the health of patients through the treatment of orthopedic and rheumatological injuries, and can be used successfully in medical recovery, especially in physical therapy. SMCRM is a device that is based on the synergy between the two therapeutic techniques known as cryotherapy and ultrasound therapy. These two techniques stimulate each other, avoiding possible complications due to the heat effect of ultrasound in acute and subacute trauma. SCMRM is equipped with a cold generation system, an ultrasound system and an IT command, control and regulation interface.

Keywords: Mechatronic system, Ultrasound, Medical recovery, Physical therapy.

1. Introduction

Medical recovery is a complex field of activity. Medical recovery treatments aim to restore the functional capacity lost by a person following a trauma caused by various causes.

The purpose of SMCRM is to improve and restore functional capacity and quality of life for people with physical disabilities, disabilities/handicaps, the object being to restore optimal function in the context of the presence of various physical injuries. SMCRM was designed for use in orthopedics; rheumatology; sports medicine; aesthetic medicine, as well as other similar fields that require a decrease in muscle spasm, an increase in tissue elasticity, etc.

The simultaneous use of cryogenics and ultrasound allows the treatment of patients with acute pathologies, with trauma and inflammatory conditions accelerating the recovery time.

2. The Application of Ultrasound Therapy in Medical Processes

Definition: ultrasound is a mechanical pendular vibration with a frequency between 500 kHz-3000 kHz. Physiotherapy devices provide ultrasound with a frequency between 800 kHz and 1000 kHz [1].

Ultrasound treatment produces a micro-massage on the tissues, ensuring a deep penetration of anti-inflammatory substances in the form of gel, depending on the dose can make warming of the treated tissues. This treatment is successfully used in sports and rheumatic medical recovery has a relaxing effect and stimulates blood circulation through local heating and micro-massage effects. Following the ultrasound therapy, the extensibility of the tendons increases 5-6 times, and if after the application of ultrasound physical exercises are done, the mobility of the joints will increase [2].

The use of ultrasound for therapeutic purposes is mainly aimed at inflammatory and degenerative diseases of the joints, spine and muscles. The effects of ultrasound can be mechanical; thermal; cavitation; diffusion ie vasodilators; analgesics; decrease muscle spasms and increase the elasticity of rigid tissues [3]. SMCRM ultrasonic physiotherapy requires the use of waves (ultrasound) at a frequency that can vary between (1 ÷ 3) MHz which means the emission of these ultrasounds in two types: continuous emission or pulse emission (interrupted).

The biological effects of ultrasound on living tissues depend on the intensity applied. These ultrasounds have an additional component compared to most types of energy, namely it is not only radiation energy but also has a thermal component, respectively that thermal energy released will help increase the temperature in the target tissue and thus generate a double benefit for medical recovery.

Effects of ultrasound application [4]:

- The physiological effects of ultrasound are: analgesics (pain relievers), muscle relaxants and hyperemia to improve blood circulation on the applied area.
- The analgesic effect is achieved through the central nervous system, through the participation of a series of mechanisms, similar to the action of low-frequency currents on the human body.

- The muscle relaxant effect is explained by the vibratory action of ultrasound on the muscular and tendon proprioceptors.

- The hyperemic effect, accompanied by the resorptive and vasculotrophic ones, takes place through the vasodilation of the arterioles and capillaries, with the consequent activation of the locoregional blood circulation, through the participation of the vegetative nervous system.

3. The Application of Cryogenic Therapy in Medical Processes

Cryotherapy consists of short exposures of the skin to freezing temperatures or close to freezing temperatures and is used primarily to reduce musculoskeletal symptoms, for analgesic purposes, to reduce inflammation and slow down local metabolic processes [5].

Cryotherapy is the general or local use of low temperatures in the medical field to treat various joint or muscle injuries.

Its purpose is to:

- decrease cell growth and reproduction (cell metabolism),
- promote cell survival,
- decrease the inflammatory process,
- reduce pain and fight spasms,
- promote vasoconstriction.

The decrease of the temperature in the deep tissue increases the density of the tissue, thus potentiating the mechanical effect induced by ultrasound. Thus, SMCRM is equipped with a system for generating cold up to -10^{0}C, a system for obtaining ultrasound that can vary between (1 ÷ 3) MHz, and an IT interface for command, control and regulation.

Simultaneously with cold therapy up to -10^{0}C, an ultrasonic wave from 1 MHz and one at 3 MHz is performed. The working interface with a 10'' touch screen will allow you to monitor the delivery parameters of both therapies and manage the treatment throughout it.

• Traditional cryotherapy procedures

- Among the traditional methods of cryotherapy, we list cold compresses, cold bags, cold water baths, cooling sprays, and ice cube massage[4].

- Cold compresses are indicated in inflammatory or painful processes. These compresses are soaked in cold water, and to maintain the optimum temperature, they must be changed every 5 minutes.

- Cold bag therapy is support for cold therapy in healing swelling, sprains and injuries. In this therapy, smeared bags filled with ice are applied to the surface of interest. This therapy lasts an average of 5 minutes.

- Cold water baths - last between 10 and 30 seconds, and the water has a temperature below 10^{0}C.

- Cryotherapy sprays provide a cooling effect that helps relieve pain and inflammation by diffusing cold particles. This therapy is used for stretches, dislocations, sprains, contusions or sports trauma.

- Massage with ice cubes consists in rubbing the skin with pieces of ice for deep cooling of the tissues. This therapy is indicated for post-traumatic, rheumatic, inflammatory conditions, and muscle contractions and usually lasts between 5 and 10 minutes.

• Benefits of cryotherapy

- Promotes blood circulation: Cryotherapy enriches the blood with high levels of oxygen and helps in the delivery of vital nutrients throughout the body. The link between low blood oxygen levels and susceptibility to various diseases and a deficient immune system has been shown.

- Improving the immune system: With the promotion of blood circulation, nutritional and oxygenation levels will increase, stimulating the immune system quickly. Thus, hormonal imbalances will be normalized, this being one of the most important benefits of cryotherapy.

- Improving energy and strength: When the body enters an alert state by improving the immune system, one of the most common effects of therapy described in the literature is to increase energy levels and consistent strength.

- Adjuvant in the recovery of sports pathologies: While physical therapy is the standard way of recovering from sports injuries, more and more high-performance athletes are turning their attention to cryotherapy for a sharp reduction in pain and a faster recovery process.

- Effective method of reducing pain: While the skin will cool to about (8 ÷ 10) ^{0}C, the basic body temperature will remain, in principle, the same during the cryotherapy treatment and will show a slight decrease at the end of the session. This cooling therapy will promote the stimulation of the release of endorphins, which will promote analgesia. Cryotherapy used to relieve pain has become popular since the 1970s when it was shown to be useful in combating rheumatic pain.

- Decreases the time required for recovery: Cryotherapy has received increased attention from sports due to its anti-inflammatory and analgesic benefits.

- Increases concentration: sports performance depends and is largely correlated with cognitive abilities, including concentration and memory. Better focus on goals increases productivity.

- Fighting insomnia and better sleep: Poor sleep will compromise melatonin production, suppress the immune system and lead to insulin resistance. Insomnia or poor sleep contribute to a variety of medical conditions, including digestive disorders, weight problems or infections, and even cancer or diabetes.

- General well-being: has been shown to be effective in combating stress, muscle or joint pain, even in diseases such as eczema or psoriasis.

4. Using the Software to Monitor the Parameters of the SMCRM System

The SMCRM system includes two applications:

A. Using the Access program, a database structure was created that is installed on the laptop, which includes the following fields:

- the start date of the treatment;
- patient data: name, surname, age, address;
- general health (chronic diseases);
- indications for treatment;
- type of treatment (cryogenics, ultrasound, both).

In the database, if necessary, the following changes can be made, as represented in the logic diagram in figure 1:

- New data can be added to the database, such as a new person;
- Existing data in the database can be edited, such as changing people's data;
- Information can be deleted, for example, if a person no longer exists;
- You can share data with other people through reports, e-mails, an intranet or the internet.

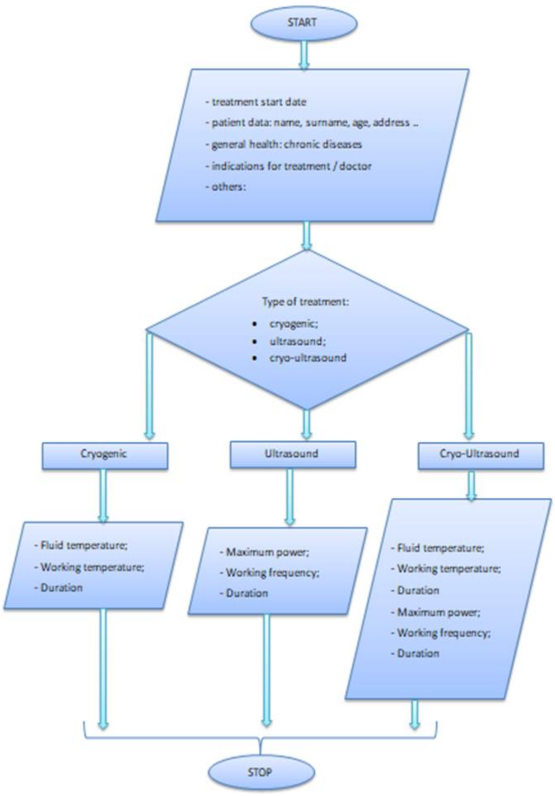

Figure 1: The logical diagram of the SMCRM system

B. Using the Python program, an IT software application was created which is installed on the "Medical Recovery Device" - SMCRM, as follows:

The software application consists of selection screens specific to each working mode as shown in figures 2 - 7 below.

Figure 2: SMCRM software application

- The current value of the temperature and a selectable threshold are displayed in the Crio screen in figure 3.

Figure 3: Crio SMCRM screen display

- A random number generator was used to simulate the temperature, as shown in Figure 4.

Figure 4: SMCRM temperature setting

- In the Ultrasound screen in figure 5 are included a Start/Stop Timer button and two buttons for selection (disjunction) of the two frequencies.

Figure 5: SMCRM ultrasound screen display

- Enter the H Min Sec values, in the appropriate range for each field, and press START TIMER.

- A soft timer is launched which decreases per second.

- During the timer duration, the three buttons are hidden so that switching to another page is not allowed.

- The timer can be switched off by pressing the STOP Timer button (see figure 6).

Figure 6: Display STOP TIMER, SMCRM

When the timer is interrupted or expires normally, the 3 bottom buttons are displayed on the eraser again (see figure 7).

Figure 7: SMCRM main screen display

- The CRIO or Ultrasound screen contains the elements of both screens.
- A confirmation message is displayed when the application is closed.
- If YES, the application closes.

5. Characteristics and technical data of the SMCRM – Mechatronic System

The research carried out aims to achieve by INCDMTM a mechatronic ultrasound system that will be used in physiotherapy [7] that will have the following characteristics:

- Three levels of intensity
- Timer (5-20 min)
- Maximum ultrasound output power: 3 W/cm^2

Technical data of the device:
Acoustic frequency: 1 MHz ± 10%, ± 3 MHz 10%
Output power:
- 0.5W-10.0W, when the load factor ≥ 80% for 5 cm2
- 0.5W-15.0W, when the load factor ≤ 70% for 5cm2
- 0.1W-3.0W, when the load factor ≤ 80% for 1cm2
- 0.1W-3.0W, when the load factor ≤ 70% for 1cm2

Effective intensity (max.):
- 1.0 W / cm2 ± 20% (1 MHz)
- 3.0 W / cm2 ± 20% (3 MHz)

Environmental conditions for use:
- Ambient temperature: -10^0 ~ 40^0 C
- Relative humidity: 30% - 85%
- Atmospheric pressure: 800-1060 hPa.

6. Research and Development Objectives of SMCRM

The SMCRM mechatronic system is based on the achievement of low temperatures and ultrasound, being built from three main modules: the cryogenic module, the ultrasound module and the IT control module. The SMCRM system is shown in Figure 8.

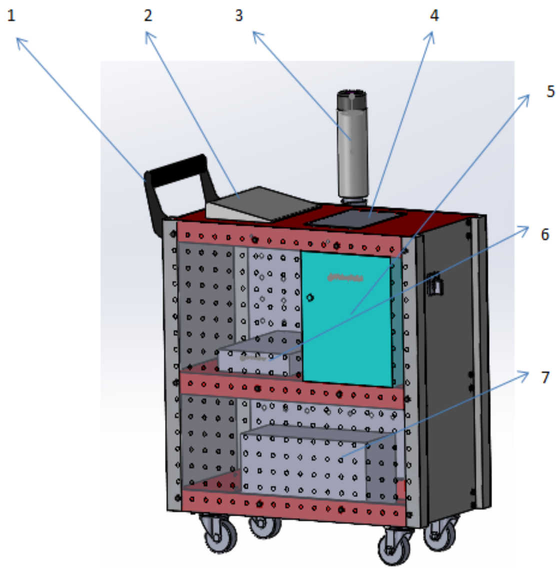

Figure 8: SMCRM system

Regarding the SMCRM structure, an original solution has been adopted which involves: the SMCRM support subassembly (1) which will include all the equipment necessary to perform the function for which it is designed, namely: Ultrasound display (2); Cryo-ultrasound subassembly (3); IT command and control display (4); Electrical panel (5); Power supply (6); Refrigerating unit (7).

The refrigerating unit (7) is composed of a compressor, evaporator and condenser, which cools the fluid inside and inside the hose in the range -20^0C to + 10^0 C. The hose head (3), which comes into contact with the patient's skin, will take the temperature from the evaporator which will be measured and adjusted with the help of the temperature sensor, as needed.

The adjustment is done in 2 ways:

- directly on the display screen
- via Wireless Display.

The cryo-ultrasound assembly in figure 9 consists of the evaporator (8) having the structure of the Cu material and dimensions calculated according to the volume required for cooling and the realization of the evaporation function for obtaining the temperature up to -10^0C and an ultrasonic sensor (9) which can achieve adjusting the ultrasound range between (1 ÷ 3) MHz.

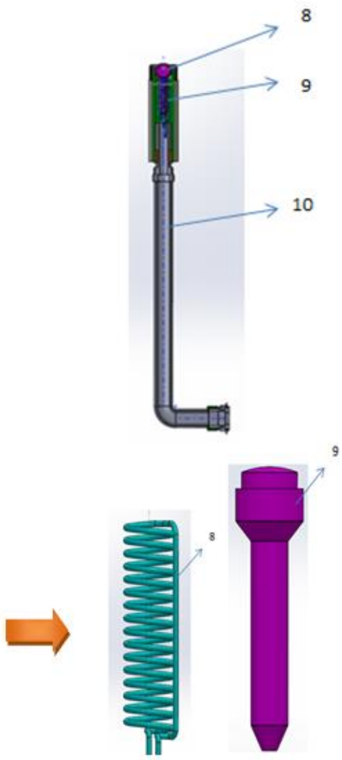

Figure 9: SMCRM cryo-ultrasound assembly

The cryogenic assembly is therefore equipped with a tight network of pipes and tubes, the first of which are arranged inside it (the cooling circuit), and the others outside, on the rear wall (condenser). The refrigerant flows through this continuous system of pipes and tubes. Depending on its location in the pipe network at some point, the refrigerant is either liquid or gaseous.

The cryogenic assembly is composed of:

- an electric compressor (7) acting on the refrigerant. It is electrically operated and transfers energy to the cryogenic system in the form of mechanical work, in exchange for the electricity used;
- a network of liquefied pipes mounted inside on the back of the compressor, usually painted black, which are part of a subassembly called a condenser;
- an internal cooling circuit, internal copper pipes through which the refrigerant flows, a circuit sometimes called a vaporizer (10);
- an expansion valve;
- coolant, also called refrigerant or refrigerant.

The design of the designed mechanical and assembly elements was made using the state-of-the-art processing equipment from the CERMISO center (Makino D200Z 5-axis processing equipment, Makino EDAF2 electrode erosion equipment). Also in the CERMISO center, metal and plastic parts were made with the help of 3D printers (JCR 1000 plastic 3D printing and Shining3D EP-M250 for metal printing).

7. Vaporizer Calculation Elements

One of the most important activities in the design of refrigeration systems is the calculation or choice of system components. The importance of this stage comes from the fact that the appliances designed or chosen to be part of the installation are the ones that must ensure during its operation, the low temperatures and the cooling powers necessary to make the product.

In order to make the evaporator (8) from figure 9, the volume of the Indelb BD35F cooler from figure 10 was calculated, marked with VR Indelb which will be replaced with the volume of the SMCRM vaporizer (8) resulting in the number of turns necessary to achieve the temperature of -10^{0}C.

Figure 10: Indelb BD35F cooling unit

$$V_{RIndelb} = V_1 + V_2 - V_3 cm^3 \quad (1)$$

where:
$V_{RIndelb}$ – Indelb BD35F cooler volume;
V_1 – inner volume - pipe;
V_2 – serpentine volume;
V_3 – the outer volume of the inner capillary which ensures the thermal cooling regime.

Following the calculations, the following values are obtained:

$$V_1 = 226{,}08 cm^3 \quad (2)$$

$$V_2 = 28{,}26 cm^3 \quad (3)$$

$$V_3 = 27{,}69 cm^3 \quad (4)$$

and

$$V_{RIndelb} = 226{,}65 cm^3 \quad (5)$$

Regarding the structure of SMCRM, an original solution of the cryogenic subassembly was adopted by replacing the Indelb vaporizer with the next vaporizer. It is made of Cu pipe with a diameter of Ø6mm and a capillary with a diameter of Ø1.9mm.

To calculate the number of turns required for the evaporator we will equal $V_{Rindelb}$ with $V_{Evaporator}$, as follows:

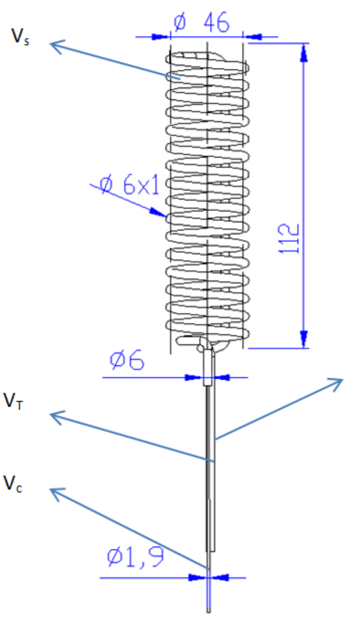

Figure 11: Evaporator (8) SMCRM

Thus:

$$V_{Evaporator} = V_T + V_c + n \cdot V_s \quad (6)$$

where:
V_T – inner volume - pipe;
V_c – inner volume - capillary;
V_s – the inner volume of a coil;
n – the number of turns required.

Following the calculations, the following values are obtained:

$$V_T = 100{,}48cm^3 \quad (7)$$

$$V_s = 7{,}25cm^3 \quad (8)$$

$$V_c = 5{,}08cm^3 \quad (9)$$

This is how it is obtained:

$$V_{Evaporator} = 105{,}56 + n \cdot 7{,}25 \quad (10)$$

Equating the two volumes, $V_{Rindelb}$ with $V_{Evaporator}$ we will determine the number of turns needed, namely:

$$V_{RIndelb} = V_{Evaporator} \quad (11)$$

$$226{,}65 = 105{,}56 + n \cdot 7{,}25 \quad (12)$$

$$n \approx 16 spire \quad (13)$$

8. SMCRM – Integration and Validation of Probe

The cryogenic subassembly was subjected to assembly and experimentation also within the CERMISO center within INCDMTM-Bucharest.

Figure 12: Evaporator

Following the tests, it is found that the value of -20ºC is obtained at the evaporator in a time of 10 minutes. This temperature will be taken over by the metal body which will help to obtain the temperature of -10ºC by adjusting it. The metal body together with the ultrasonic sensor will have contact with the skin through special gels.

9. Conclusions

The use of SMCRM mechatronic equipment facilitates the healing process with a faster recovery due to the interruption of the cycle of inactivity of the painful spasm. This device is indicated in the treatment of people who have suffered a recent trauma or in the presence of acute or subacute inflammation.

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