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Mini Review

Diagnosis of Cold Weather Injuries Using Ultrasonic Testing

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Abstract

This article discusses the limitations in common methods used in diagnosing cold injuries and hence, suggests the use of ultrasonic method in detecting such signs. The proposed method is based on registering a change in the propagation speed of ultrasonic vibrations in the tissue of the tested biological object. Such a change is caused by the resulting change in the physical properties of the object under study in case of cold injury symptoms. Accordingly, the developed ultrasonic device is capable of detecting the degree of frostbites quickly and non-invasively, through detecting the intra-tissular pressure, whose dependence on the propagation speed of ultrasound is conducted.

Introduction

Cold weather injuries occur as a result of human body exposure to cold weather, which can impair human performance and can be life-threatening. Frost injuries and illnesses usually affect military personnel, athletes involved in winter sports, residents of the northern regions, reindeer herders, etc. Today, despite the development of modern methods of invasive and functional diagnostics, the issues of determining the degree and predicting the outcome of a frostbite in the early periods of injury still remain controversial [1,2]. It is not difficult to diagnose systemic cold injury based on core body temperature or the patient's state of consciousness. However, it can be difficult initially to determine the extent of the injury or to distinguish Freezing Cold Injuries (FCI) from Non-Freezing Cold Injuries (NFCI). Deep tissue damage often becomes fully apparent after a few weeks. Moreover, due to individual pathogenetic factors, two types of local cold injuries can coexist in the same patient or even in one limb, which also complicates the diagnosis [3]. The solution of this problem in case of cold injury will allow to carry out treatment at the earliest possible time after injury which is very important given the relatively high reversibility of the pathophysiological process with frostbite.

Common Diagnostic Techniques used to Detect Frostbites

For early diagnosis of the depth of frostbite, several instrumental methods are used to clarify the maximum degree of frostbite. Gamma scintigraphy is a well-known radionuclide method, which consists in the intravascular injection of an orthotropic drug, i.e., pyrophosphate, labeled 99TC [4]. The assessment of the degree of frostbite is carried out according to the degree of accumulation of the drug in soft tissues and bones. The negative aspects of the method include: the use of a radioactive preparation, the significant duration of one study (up to 3.5 hours), the need for expensive equipment, the insufficient early terms for determining the depth of tissue damage (on the 2nd or even on the 3rd day after injury). Another method for early diagnosis of the degree of frostbite is angiography, which is based on the intra-arterial injection of a contrast agent, followed by radiography of the arterial vascular bed of the tissue [5]. The negative side of the method is the lack of a well-defined angiographic semiotics of various degrees of frostbite and the risk of manipulation and post-manipulation complications, i.e., bleeding and infection, which are due to the significant invasiveness of the method.

The third method that helps in diagnosing the degree of frostbite is the method of infrared remote thermography, which registers infrared radiation of tissues and the intensity of this radiation makes it possible to judge the degree of vascular disorders occurring in tissues [6,7]. This method is visual, non-invasive and evaluates the degree of vascular disorders in digital characteristics in the form of a temperature difference between the area under study and any inspected tissue area. However, this method of diagnosing the degree of frostbite is considered expensive and according to many cytopathologists in the country, is not very suitable for the purpose of early prediction of the depth of tissue damage, especially in the pre-reactive and early reactive periods of frostbite, because the high value of the temperature gradient in chilled living tissues does not allow us to speak convincingly for the degree of frostbite expected in the future.

Another known method for diagnosing acute frostbite is by pricking the affected surface with a sharp tip. Diagnosis is carried out by the nature of the discharge and the time of clot formation. However, this method is invasive and retains the risk of developing infectious complications [1]. However, there is a method for early prediction of the depth of frostbitten tissue by skin electro thermometry, which consists in a three-fold measurement of tissue temperature performed 5, 10 and 15 minutes after intra-arterial administration of a complex of vasodilators. If the skin temperature does not change this indicates a deep lesion but if the temperature rises, then this indicates the presence of blood circulation in the segment [8]. This method is quite complex, invasive and not suitable for those surgeons who do not know the technique of intra-arterial punctures. This method also requires multiple temperature measurements at one point, takes quite a long time and does not have clear criteria for predicting specific degrees of frostbite.

Proposed Method of Frostbite Diagnosis

Hence, we were faced with the task of creating a device for rapid diagnosis of frostbite degree. Therefore, we tried to solve the task using a method based on registering a change in the propagation speed of ultrasonic vibrations which are caused by change in the physical properties of the object under study enduring an injury. The proposed device consists of two identical channels: the first channel measures the ultrasound propagation speed in that tissue which has undergone frostbite and the second channel measures the propagation speed in tissue that has not undergone frostbite and the difference in speeds is determined. The device contains two generators of ultrasonic pulses, two ultrasonic receivers, two ultrasonic emitters, two amplifiers, two threshold devices, two reference voltage sources, two speed parameter formation units, a control and indication unit. The working principle of the ultrasonic device for diagnosing cold injuries is explained in the following functional block diagram (Figure 1).

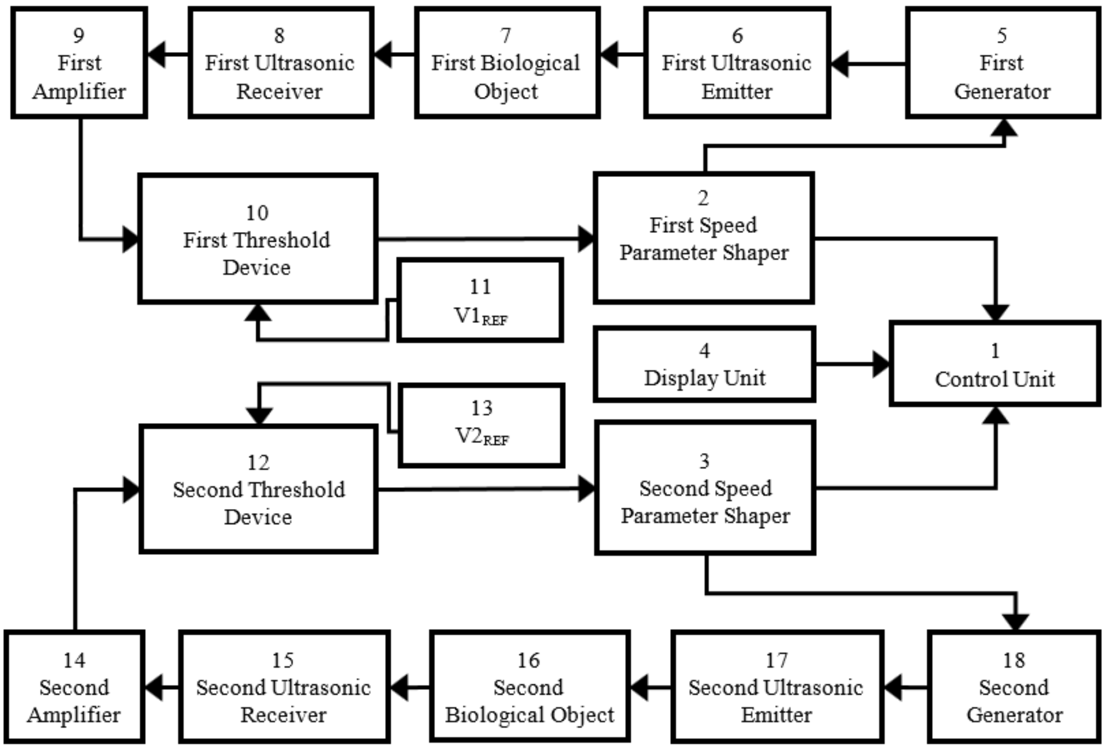

Figure 1: Functional diagram of the proposed ultrasonic device for diagnosing cold injuries.

The biological object should be placed between the ultrasonic emitter and the receiver, which are mounted on the skin. At the same time, the first and second speed parameter shapers of block 2 and block 3 generate trigger pulses for the generators of blocks 5 and 18, whose role is to emit ultrasonic waves and excite the ultrasonic emitters of blocks 6 and 17. The emitted ultrasonic pulses propagate through the biological objects (blocks 7 and 16) and are received by ultrasonic receivers 8 and 15, then are amplified by amplifiers, 9 and 14, fed to the inputs of the first and second threshold devices 10 and 12. The second input of the first threshold device (10) is supplied with voltage from the first reference voltage source (11). The second input of the second threshold device (12) is supplied with voltage from the second reference voltage source 13. As soon as the voltage at the output of the first amplifier (9) exceeds the $V1_{REF}$ voltage, the output of the first threshold device (10) switches to the state of logic 1 and by this signal, the first speed parameter shaper of block 2 fixes the propagation time of the ultrasonic pulse through the biological object (7) and calculates the ultrasound propagation speed in it. At the same time, the signal from the output of the second amplifier (14) is fed to the input of the second threshold device (12), whose other input is supplied with voltage $V2_{REF}$ from the second reference voltage source (13).

The switching of the second threshold device (block 12) to the state of logic 1 will occur if the input voltage exceeds the voltage $V2_{REF}$. The logical unit at the output of the second threshold device (12) gives a signal to the second speed parameter shaper (3), which fixes the propagation time of the ultrasonic pulse through the second biological object (16) and calculates the speed of ultrasound propagation in it. Likewise, the logical unit at the output of the first threshold device (10) gives a signal to the first speed parameter shaper (2), which fixes the propagation time of the ultrasonic pulse through the first biological object (7) and calculates the speed of ultrasound propagation in it. Finally, the control unit (1) compares the values of both speeds received from the first and second speed parameter shapers of block 2 and block 3 and, thus, displays the value of the degree of frostbite on the display unit.

Clinical Results of Diagnostic Tests

The device was tested in the surgical department of the regional clinical hospital of Tomsk city in Russia, where 29 patients with various degrees of frostbites were examined. The intra-tissular pressure and the difference in the speeds of ultrasound propagation were measured in tissues with and without pathophysiological condition. The diagnostic test results are presented in (Figure 2), which shows the dependence of the intra-tissular pressure on the speed of propagation of ultrasound in soft tissues. As a result of the tests an almost linear dependence of the change in the difference in the speeds of ultrasound propagation in tissues with and without pathophysiological condition from the intra-tissular pressure was obtained, which allows us to conclude that the proposed method can be used for diagnosing cold injuries.

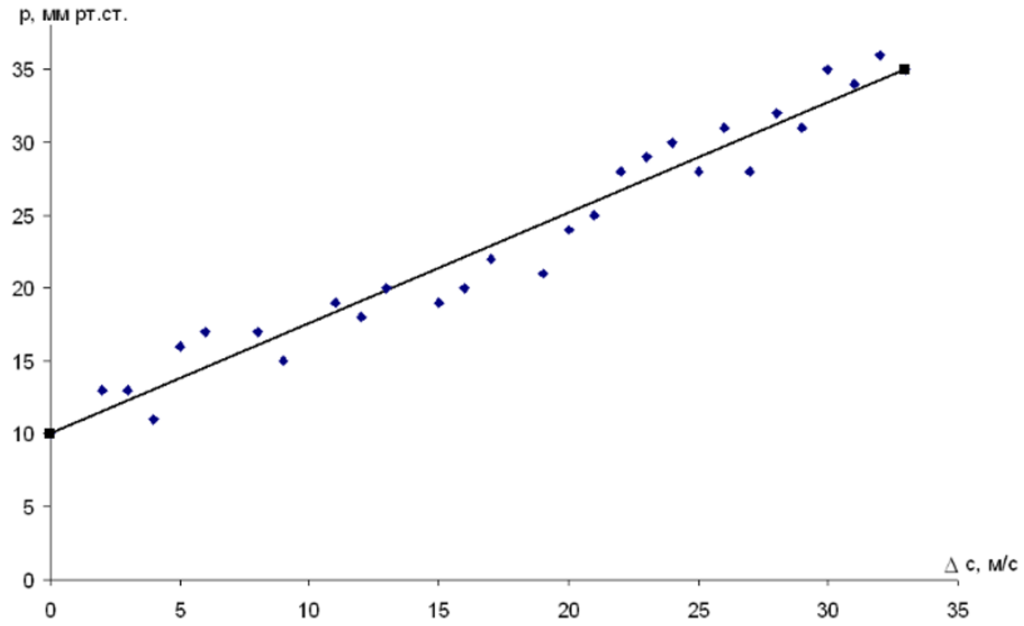

Figure 2: Dependence of intra-tissular pressure on the difference in the speeds of ultrasound propagation in tissues with and without injury condition.

Conclusion

The ultrasonic device for diagnosing cold injuries, where the propagation speed of ultrasonic fluctuations is an informative indicator has the following advantages: the ability to quickly diagnose the degree of frostbite, non-invasiveness, no contraindications for use, no additional technical devices are required, ease of use; it does not require special training of medical personnel to work with. The pathophysiological mechanism that occurs in tissues during cold injury is similar to that of crush injury and compartment syndrome. Therefore, this device can also be used in emergency medicine to diagnose cases of symptoms similar to those of cold-induced injuries.

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