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Original Article

A Thermographic Comparison of Irreversible Electroporation and Radiofrequency Ablation

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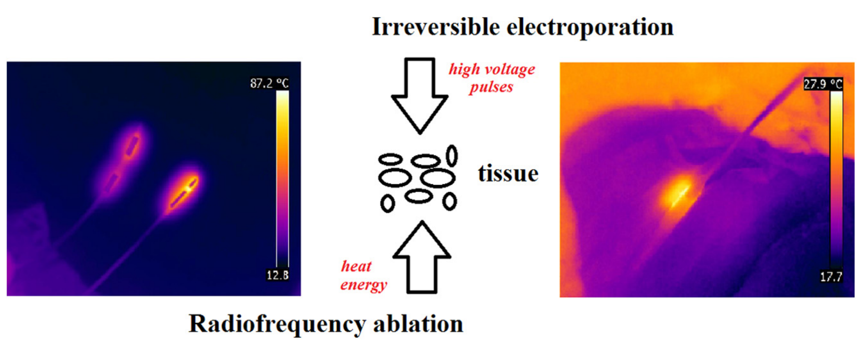
Graphical abstract



Abstract

Radiofrequency ablation and irreversible electroporation are both interventional procedures used in treating cancer diseases generally and may be used in treatment of liver cancer. The two differ in terms of their action and thermal effects. The present study examined thermal effects of radiofrequency ablation and modified irreversible electroporation ex vivo in porcine liver. Standard radiofrequency ablation was used during the experiments, as was a unique, experimental high-voltage generator of the research team's own construction coupled with a newly designed balloon electrode catheter for irreversible electroporation. The tested balloon catheter was newly designed for application in the biliary tract. The temperature of porcine liver tissue was monitored without contact by infrared camera. The results show significantly different temperature of tissue around electrodes for radiofrequency ablation and irreversible electroporation. The data obtained from radiofrequency ablation with maximum tested output power of 10 watts show a symmetrical area of tissue near active electrodes with temperature increased by more than 30 °C. Irreversible electroporation methods showed temperature increasing approximately by 5 °C. To summarize, the thermal research showed that the difference between standard RFA and innovated IRE with the balloon catheter lies not just in the differing mechanism of action, as is well known, but also in its thermal effects. There was documented that tissue temperature was much higher for RFA than for IRE, particularly for the maximum tested output parameters. The applicability of the newly designed balloon catheters was confirmed.

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1. Introduction

There exist several possible mini-invasive methods which can substitute for conventional surgical resection of tissue. These ablative methods are mainly used in cases where conventional surgical operations cannot be performed or when they are not effective. These methods are carried out under control facilitated by imaging methods and without the need for open surgery. Such approaches include radiofrequency ablation (RFA) and irreversible electroporation (IRE) [1–3]. Although these two methods are similar to one another in some respects, they are completely different in others. Their common aspects include that both are frequently used in treating oncological diseases and both utilize the effects of electric fields on living tissue [4].

Radiofrequency ablation leads to tissue destruction through thermal effects in the area of the active electrodes. This is caused by the presence of a high-intensity electric field (high-frequency alternating current, which produces frictional heating of affected tissue) [5]. RFA's destruction of tissue in the area of the active electrodes does not occur selectively. The process of thermal ablation via RFA also is influenced by heat losses due to thermal energy dispersal in flowing liquids, such as the cooling effect due to blood flowing through nearby blood vessels [6].

Irreversible electroporation is a newer method used in ablation of parenchymal organs. It works on a principle that is non-thermal. IRE's essence lies in the application of very short pulses of electrical current by means of a high voltage applied using needle electrodes placed into the target tissue. The electric field to which the tissue is exposed produces a non-physiological transmembrane voltage and induces instability of polarized lipid bilayers inside cell membranes. This has the effect of creating pores in the cell membrane with diameter on the order of nanometers. These transmembrane pores are formed either reversibly or irreversibly (irreversible electroporation, or IRE). Reversible electroporation may be used to transport substances which would otherwise not have been capable of intracellular uptake due to their chemical or physical properties. The application of IRE, in contrast, causes permanent defects in the cell membrane and subsequent disruption of homeostasis kills the cell [5]. An advantage is that this IRE effect occurs only in relation to the cell membranes (e.g., in the case of tumor cells) while the connective and fibrous tissues comprising the extracellular matrix are not destroyed. Due to this preservation of the extracellular matrix and of collagen in luminal structures, the cellular population regenerates.

This mechanism is relatively safe and does not lead to destruction of vascular structures, biliary tract, and histologically similar tissues. This makes it possible to remove unwanted tissues in places which are adjacent to arteries, veins, or bile ducts. It is not possible to perform RFA at such sites. In the case of IRE, and in contrast to RFA, flowing blood is not an obstacle in the sense of its causing thermal energy convection losses. When and where IRE is used, lesions heal without scars in most cases.

Although the possibility for thermal ablation of tumors involving bile ducts has been shown in several studies, the heat sink effect of vessels in the hepatic hilum make ablation zones difficult to assess [7]. Because it is less influenced by adjacent vascular bundles, inasmuch as IRE does not depend upon heating for ablation, the new IRE technology is advantageous for intraluminal ablation in the peripheral region of the liver.

The aim of the present study was to compare thermal effects during intraluminal RFA and IRE using ex vivo models in porcine liver tissue. This article provides information about the possibility for alternative methods in applying IRE intended for ablation of liver tissue (bile ducts) while also using newly designed balloon catheters. The thermal effects of the experiments were evaluated using contactless temperature measurement by infrared camera.

Contactless infrared thermography (IRT) is a noninvasive tool for measuring surface temperature. The physical principle of this method lies in detecting an electromagnetic wave of a defined wavelength corresponding with surface temperature according to the description of gray body irradiation. The main advantages of this diagnostic method include low operating costs, speed of the examination, and its being a safe method for both the patient and medical staff. Because of these benefits, IRT has found application in various medical fields [8]. This method is able to detect the areas with different temperature due to change of blood perfusion, inflammation, cancer, and other characteristics [9,10].

The experiments were unique inasmuch as they tested the IRE instrumentation employing newly designed and constructed balloon catheters with three electrodes and an original high-energy current generator of the research team's own design.

The basic questions investigated in this study are the following: Is it generally possible to use an infrared camera to monitor heating during RFA and IRE experiments? What tissue temperature will be reached using RFA and IRE? What is the character of the temperature distribution in the close vicinity of the proposed balloon catheter? Will there be a difference between the final tissue temperatures when RFA or IRE are used at comparable output power?

2. Materials and methods

2.1. Infrared thermal imaging

Measurements were made ex vivo. Fresh porcine liver was used as a model tissue at room temperature. To preserve homo-