Recent trends in Radiofrequency thermal ablation in the treatment of malignant Tumors

Essay
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INTRODUCTION
AND
AIM OF THE WORK

INTRODUCTION

Radiofrequency ablation (RFA) is emerging as a new therapeutic method for management of solid tumors. That works by converting electro magnetic energy into thermal injury within the target tissue and is generated by a high frequency, alternating, and electric current passing around the tip of a specialized probe to a large grounding pad through heating is produced when ions in the tissue attempt to follow the changing directions of the current ***(McGhana and Dodd, ٢٠٠١).***

One of the biggest foibles in radio-frequency treatment today is targeting of the lesion. Targeting can be performed with ultrasonography (US), CT, or MR imaging, and ablation may be delivered by means of open surgery, percutaneous access, or laparoscopy. The guidance system is chosen largely on the basis of operator preference and local experience. US is still accepted as a preferable modality for guidance or monitoring during radio-frequency ablation over CT or MR imaging ***(Meloni, et al., ٢٠٠٦).***

٢٠٠٦

Primary and secondary malignant hepatic tumors are some of the most common tumors worldwide. Chemotherapy and radiation therapy are ineffective treatment methods and surgical resection is considered the only potentially curative method. Recent results from multiple investigations indicate that several minimally invasive treatment techniques are very effective for treating primary and secondary hepatic tumors and that they may replace surgical resection in the near future ***(McGhana and Dodd, ٢٠٠١).***

Minimally invasive thermal destruction rather than surgical excision of early stage primary breast tumors may be appreciate in carefully selected patients. Radiofrequency thermal ablation (RFA) may be an alternative treatment option to lumpectomy in patients with co morbid conditions. The procedure is cheaper and much less invasive to surgery ***(Gazelle, et al., ٢٠٠١).***

Radiofrequency thermal ablation (RFA) has emerged as the safest, easiest and most predictable technology used for thermal ablation in the liver, kidney, heart, prostate, breast, brain, lymph nodes, nerve ganglia and soft tissue ***(Meloni, et al., ٢٠٠٦).***

AIM OF THE WORK

This research was made for the better understanding of the general aspects of radiofrequency thermal ablation of malignant tumors; as well as the controversies regarding the different treatment options. This understanding will be important in developing safe, effective and possibly curative therapy for malignant tumors.

CHAPTER ١:

GENERAL ASPECTS OF RADIOFREQUENCY THERMAL ABLATION.

- *Definition of the energy used for RFA*
- *Evolution of RF-based therapies*
- *Mechanism of Radiofrequency*
- *The Radiofrequency ablation devices*
- *RFA electrodes: design and working principles*
- *Commercial RF generators: design and working principles*
- *Size and geometry of hepatic RFA lesions*
- *Patho-physiologic process of thermal coagulation necrosis*
- *Morphologic features of RFA-induced lesions*
- *Applications of imaging modalities in RFA*

DEFINITION OF THE ENERGY USED FOR RFA

Radiofrequency (RF) is an electromagnetic wave frequency between audio and infrared that ranges from approximately $١٠^{٤}$ to ٣X $١٠^{١٢}$ Hz.

RFA can be defined as destruction of biological tissues by using electricity from an un-modulated, sinusoidal wave, alternating current (AC) at an electromagnetic frequency that falls well into the range characteristic of radio broadcasting signals (e.g., ٣٠–٣٠٠ KHz for long wave, ٣٠٠–٣٠٠٠ KHz for medium wave, and ٣–٣٠ MHz for short wave), i.e., high enough (>٢٠ KHz) to cause molecular frictional heating without stimulating neuromuscular reaction and electrolysis and low enough (<٢٠ MHz) to confine energy transmission to a more controllable tissue mass without generating excessive radiation ***(Ni et al., ٢٠٠٥).***

AC stronger than ١٠٠ mA at a lower frequency of ٥٠ Hz household mains electricity) is known to cause fatal electrocution and ventricular fibrillation. The RF energy is non-ionizing and believed to be free of health hazards if used properly.

The term ablation in the context of RFA can be comprehended as a kind of virtual surgical ablation, i.e., to devitalize a volume of tissue without removing it from the body, resulting in an effect similar to that of surgical resection ***(Ni et al., ٢٠٠٥).***

EVOLUTION OF RF-BASED THERAPIES

The use of electrical current to heat tissues for medical purposes is by no means new and can be traced back to the ١٩th century, shortly after the English physicist James C. Maxwell and the German physicist Heinrich Hertz theoretically and practically characterized electromagnetism.

At ١٩٠٠, the Croatian physicist Nikola Tesla first recognized heating of biological tissues with RF current.

The first widely accepted RF generator was produced in the early ١٩٠٠ s through the collaboration of a physicist (William T. Bovie, ١٨٨٢–١٩٥٨) and a surgeon (Harvey Cushing, ١٨٦٩–١٩٣٩) ***(Hand & Haar, ١٩٨١).***

During the development of RFA, although certain methodological or conceptual differences might exist, several historical synonyms have been used for electricity-generated heat therapies, including arsonvalization, fulguration, electro-coagulation, oscillatory desiccation, electro-cautery, electro-surgery, diathermy, electro-physiotherapy, and RF coagulation. For almost a century in clinical oncology, physicians from many disciplines have applied this technique to coagulate surface lesions ***(Ni et al., ۲۰۰۵).***

Meanwhile, the ‘‘electric scalpel,’’ an RF instrument, has allowed the safe division of tissue and by coagulating bleeding vessels. These applications use a sharp, brief RF energy delivery linearly for a bloodless incision or at a focal point for coagulative homeostasis to minimize unwanted energy dissipation into the surrounding tissues and collateral damage. Similarly, destruction of peripheral sensory nerves for control of constant pain and trans-catheter ablation of abnormal cardiac conducting pathways for the treatment of arrhythmia require more or less focused RF energy deposition ***(Husang, ۱۹۹۱).***

In contrast, interstitial RFA for the management of solid malignancies necessitates a more dispersed distribution of relatively mild RF energy to cause a more extensive sphere of tissue destruction.

In recent years, the RFA of deeply seated tumors in internal organs has been realized thanks to two important and associated technologic developments in the clinic:

- The increased sensitivity and specificity of imaging diagnosis with advanced ultrasound (US), computed tomography (CT), and magnetic resonance imaging (MRI)
- Improved guidance in and monitoring of interventional procedures with implementation of dedicated imaging modalities and endoscopic equipment. In accordance with this trend, tremendous efforts have been made mainly to re-modulate the RF technology from previously more focused to currently more volumetric energy deposition to meet the requirements of oncologic radicality for tumors of clinically relevant size ***(Ni et al., ٢٠٠٥).***

These advances have been achieved by upgrading RF generator to yield more appropriate power output (e.g., ‘‘pulsed’’ current depositions), controllable tip temperature, and impedance adaptation, by optimizing the RFA electrode configuration to improve heat generation and distribution, and by decreasing local heat loss through vascular occlusion and induced hypotension ***(Ni et al., ۲۰۰۵).***

These changes have significantly improved the efficacy of RFA and enabled ablation of larger lesions on the order of several centimeters compared with only several millimeters previously. Numerous groups and individuals have actively participated in this campaign of experimental research and instrumental optimization and jointly contributed to the current boom in RFA therapy. Notably, even a few doctoral theses have focused on RFA-related topics ***(Lee et al., ۲۰۰۳).***

Thus far, the liver is the major organ that has been studied most intensively for the management of primary and metastatic tumors. After many years of percutaneous ablation of small hepatocellular carcinomas (HCCs) in patients who had cirrhosis ***(Lee et al., ۲۰۰۳).***

Lencioni et al., demonstrated superior ٣ and ٥-year survival rates of ٨٩% and ٦١%, respectively, and concluded that RFA is more effective than surgery and should be offered as the first-line treatment for patients who have HCC ***(Lencioni et al., ٢٠٠٣).***

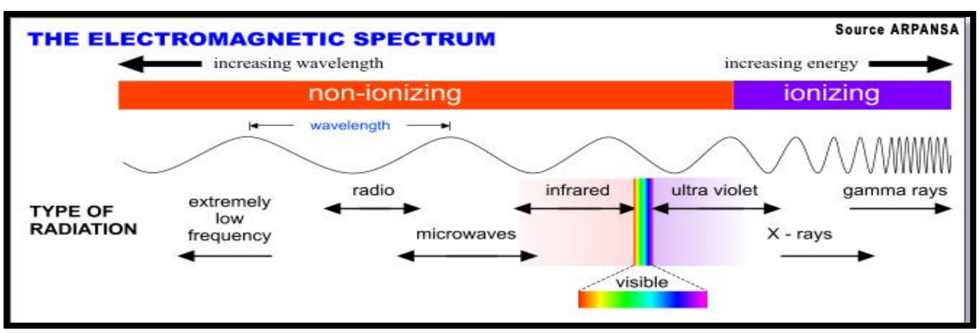
The evolution of this technology and increasing clinical experience have opened up new frontiers in treating, with encouraging results, tumors of other organs including the lung, breast, brain, bone, adrenal gland , prostate , kidney, pancreas, spine, retro-peritoneum, and so on (there are too many publications to cover entirely).

These new developments most likely prelude a fundamental shift in the way physicians traditionally approach cancers ***(Ni et al., ٢٠٠٥).***

MECHANISM OF RADIOFREQUENCY

Radiofrequency thermal ablation refers to the induction of thermal injury due to frictional heat generated by the ionic agitation of particles within tissue following the application of alternating current ***(Goldberg et al., ١٩٩٨).***

Radiofrequency waves themselves do not result in any direct tissue injury. The frictional heat that occurs desiccates the surrounding tissue leading to the evaporation of intercellular water and coagulation necrosis. Since the agitation of ions within the tissue occurs only around the needle or electrode through which the alternating current is applied, the zone of thermal injury can be precisely controlled. Unlike other forms of local hyperthermia, the electrode itself does not become hot. The area of thermal injury can be shaped based upon the size, position, and shape of the electrode used ***(Goldberg et al., ١٩٩٨).***



The heating produced is defined as resistive heating directly proportional to the square of current density *(heating power is equal to current density square divided by the tissue conduction)*, which is in turn inversely proportional to the square of the distance from the electrode. Therefore, resistive heating involves a thin layer of tissue, while larger tissue destruction is due to heat diffusion. The dimensions of RF thermal lesion are related to the current intensity, to the size of needle electrode, to heat conduction, and to heat lost via the circulation (convection) ***(Ni et al., ٢٠٠٥).***

Most current RFA devices are monopolar, i.e., there is a single ''active'' electrode, with current dissipated at a returning grounding pad. During the RFA procedure, an electrode is inserted into the target tissue. RF current flows from the generator through the non-insulated tip of the electrode into the tissue and follows the natural paths in the interstitium toward the dispersive electrode or grounding pad to form entire electric circuit. The only poor conductors in this circuit are biological tissues with higher impedance.

As the ions of the tissue attempt to follow the change in direction of the AC, ionic agitation occurs, resulting in frictional heat of the tissue, i.e., resistive or ohmic heating. Because the large surface area of the grounding pad prevents heat production, the real frictional heat is generated and concentrated only in the immediate vicinity of needle electrode. Hence, it is the tissue around the electrode instead of the electrode itself that is the primary heat source in RFA. When the temperature increases to higher than ٧٠°C, instant tissue coagulation occurs.

A similar type of tissue destruction can be created with bipolar RFA devices that have two ‘‘active’’ electrodes usually placed in close proximity, resulting mainly in destruction of the intervening tissues without the need of a grounding pad ***(Burdio et al., ٢٠٠٣).***

Biologically, the effects of heat-related therapies such as RFA on tissues including tumors involve multiple complex mechanisms and depend on the temperature and duration of heat exposure and on local factors such as organ perfusion, tissue density, and electrolyte concentration. Different characteristics of cellular damage are observed at different temperatures. Although variable among tissues, thermal injury begins at ٤٢°C.