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A review on hyperthermia via nanoparticle-mediated therapy

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Revue sur le traitement par hyperthermie médiée par nanoparticules

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Summary

Hyperthermia treatment, generated by magnetic nanoparticles (MNPs) is promising since it is tumour-focused, minimally invasive and uniform. The most unique feature of magnetic nanoparticles is its reaction and modulation by a magnetic force basically responsible for enabling its potential as heating mediators for cancer therapy. In magnetic nanoparticle hyperthermia, a tumour is preferentially loaded with systemically administered nanoparticles with high-absorption cross-section for transduction of an extrinsic energy source to heat. To maximize the energy deposited in the tumour while limiting the exposure to healthy tissues, the heating is achieved by exposing the region of tissue containing magnetic nanoparticles to an alternating magnetic field. The magnetic nanoparticles dissipate heat from relaxation losses thereby heating localized tissue above normal physiological ranges. Besides thermal efficiency, the biocompatibility of magnetite nanoparticles assisted its deployment as efficient drug carrier for targeted therapeutic regimes. In the present article, we provide a state-of-the-art review focused on progress in nanoparticle induced hyperthermia treatments that have several potential advantages over both global and local hyperthermia treatments achieved without nanoparticles. Green bio-nanotechnology has attracted substantial attention and has demonstrable abilities to improve cancer therapy. Furthermore, we have listed the challenges associated with this treatment along with future prospective that could attract the interest of biomedical engineers, biomaterials scientists, medical researchers and pharmacological research groups.

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Nanoparticules magnétiques

Introduction

In oncology, the term hyperthermia describes the treatment in which body tissue is exposed to high temperatures (up to 113° C), using external energy source. Hyperthermia has a long history in the annals of cancer management. A correlation between erysipelas (a streptococcal skin infection) and tumor regression had been observed for over a century before William Coley in 1891 [1] first documented evidence of a relationship between infection and cancer regression in sarcoma patients. The devastating research on the hyperthermic treatment of cancer has spanned over the past four decades [1–9]. In some hyperthermia treatments, the patient's blood is warmed up by an external device before it is retransfused to the target volume (e.g. isolated limb perfusion and convective whole-body hyperthermia), and those utilizing contact heating (hyperthermic peritoneal and vesical perfusion) [6]. The different approaches are best categorized by the physical mode of power deposition (radiant vs. capacitive vs. convective), and their target volume (local vs. regional vs. whole-body hyperthermia). Locoregional hyperthermia can be differentiated into external, interstitial and endocavitary hyperthermia. Different heat delivery systems are available: antennae array, capacitive coupled, and inductive devices. Depending on localization and size of the tumour different methods and techniques can be applied: superficial, intratumoral (thermoablation), deep hyperthermia, endocavitary, and part-body hyperthermia. Randomized clinical trials have been performed mostly with electromagnetic applicators for superficial hyperthermia in combination with radiotherapy, deep hyperthermia with and without radiation, and endocavitary hyperthermia in combination with chemotherapy and radiotherapy. In randomized clinical trials, it could be demonstrated, that locoregional deep hyperthermia with antennae array or capacitive coupled hyperthermia devices may increase response rate, disease free survival and overall survival of patients with cancer in combination with radiotherapy or chemotherapy without increasing the toxicity of standard therapies. The heating sources are in general practice placed outside the body and locally illuminate the tumour region with electromagnetic waves (micro-waves or radio-waves), provided that the tumour location in the respective organ is well-located by corresponding imaging techniques (CT, MRI etc). In contrast, whole body hyperthermia is recommended when carcinomas with distant metastases are present. Wust et al. [7] and latter on Hahn [8] and Deatsch and Evans [9] provided details on the hyperthermia techniques. Conductive heating techniques include cavitational water-heating; extracorporal blood heating; RF needles [10]. The electric properties of each tissue are important in heat delivery methods. In contrast to the ex-vivo based measurements, Balidemaj et al. [11] presented the in vivo conductivity of human muscle, bladder content and cervical tumours, acquired with magnetic resonance-based electric properties tomography (MR-EPT). The temperature-based optimisation was performed with patient models based on conductivity values. Their observations revealed that a higher conductivity in the bladder and in the muscle tissue surrounding the tumour leads to higher power dissipation in the bladder and muscle, and therefore to lower tumour temperatures.

The capacitive heating of tumors using a radiofrequency (RF) electric field is another hyperthermia technique that is unsuitable for site-specific hyperthermia because it does not allow specific heating of the tumors alone. In capacitive hyperthermia, the normal tissue is also warmed in the part picked up with an electrode. The specific adsorption rate of electric energy depends on electric resistance and permittivity of each tissue type. Since there are no significant differences in the electrical properties of tumor and normal tissues, it is difficult to specifically heat only the tumor. To protect the healthy tissue, mild heating is one option but this approach is often insufficient for treating tumor. To overcome this problem, magnetite cationic liposomes (MCLs) as fine magnetic particles of submicron size in inductive hyperthermia were used by Kobayashi et al. [12,13]. MCLs were devised in order to improve adsorption by tumor cells and had 10-times higher affinity for tumor cells than fine magnetic particles with no electric charge. Kobayashi et al. demonstrated that magnetic nanoparticles serve as a medium that induces efficient heat generation in RF capacitive heating [14]. In an in-vivo experiment, they observed that heat generation using magnetic nanoparticles was similar to that using inductive heating employing an alternating magnetic field. Therefore with MCL injection, mild hyperthermia generates heat to raise the temperature greater than 108.5° F, required for cancer cell treatment. In contrast, other tissues that have not