Therapeutic Applications of Millimeter Waves

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Abstract

Electric signals are a major tool of physiotherapy. To avoid contact electrodes, electromagnetic waves could be utilized to transfer energy to the target tissue in the patients' body. Benefits of millimeter waves are introduced here. An account of possible remedy for various kinds of diseases in human is presented. In view of clinical application, the related therapeutic equipment is specified through detailed literature survey. The exposure power that must be delivered to the patient is mentioned for a series of cases. Other parameters are duration of exposure and its sequence. Millimeter waves with frequencies 35.4, 40, 42.2, 48.8, 53.37, 61.2 GHz have been helpful in treatment of chronic pain, migraine and epilepsy. Exposure of human to electromagnetic waves with specific frequency in GHz-range under certain protocols would tranquil chronic pain. Prospectus applications for other diseases are conceivable.

Keywords: Chronic pain; Physiotherapy instruments; Millimeter waves; epilepsy; Migraine

Introduction

Implantable electrical stimulation devices have been successfully used for treating a variety of neurological disorders, such as Parkinson's disease, dystonia, epilepsy, chronic pain, and migraine [1,2]. However, the implantation trauma and chronic risks associated with the presence of the implant in the nervous tissue have limited the widespread use of these devices. This has delayed the onset of stimulation treatment until pharmacological options are exhausted. Hence realizing a minimally-invasive interface with the brain for treating neurological disorders represents a considerable challenge for modern medicine. In recent years, treatment of many kinds of diseases with application of electromagnetic waves has attracted attention in clinical applications.

Electromagnetic waves having frequency between 30 GHz to 300 GHz are called millimeter waves, abbreviated as mmW [3]. The wavelength of is 1 – 10 mm respectively. it is estimated that at present millimeter-wave therapy is used for the management of more than 120 diseases in cardiology, neurology, oncology, gynecology, urology, gastroenterology, surgery, pharmacology and pediatrics [4]. Presently, disorders epilepsy, migraine, and central pain are treated by modulation of neuronal excitability in the deep brain, cortex and spinal cord.

In addition to the disorders of the central nervous system, mmW might be applied for neuromodulation of peripheral nerves for controlling neuropathic pain. In humans, exposure to electromagnetic millimeter waves (mmW) has a hypoalgesic effect. Moreover, the mmW exposure can potentially be used as a neuromodulation treatment [1].

Therapeutic effects of 35.4, 48.8, 61.2 GHz electromagnetic radiations in millimeter wave range have been claimed [5]. Diseases such as chronic pain, migraine and epilepsy have shown improvements by means of patient exposure to mmW [2,6,7].

The basis of medical applications of electromagnetic wave is its non-thermal effects, i.e. the temperature of the target tissue is not elevated significantly (below 0.2 C) or so. Thus the IPD (incident power density) is in order of 1 mW/cm^2 or lower, although higher IPD could manifest non-thermal effects as well. In some experiments, it has been postulated that much lower power density of mmW, in order of $microwatt/cm^2$ produce observable effects [8].

Non-thermal effects of electromagnetic waves are based on their interactions with biological tissues in atomic and molecular scales. In such interactions vibration of cell membrane, expression of genes [5] etc. are triggered in specific frequencies of the incident wave.

It was also found that the biological effects of millimeter-wave as coherent radiation can be detected power flux density that are much lower than 10 mW/cm^2 [9]. Penetration depth of mmW in skin is less than 1 mm [10]. This is due to high absorption coefficient of mmW in materials such as water, lipid, proteins etc. [11]. Electromagnetic waves in GHz range interact with protruded points on the skin, the so called biologically active points [3,12]. This interaction causes stimulation signals production in the nerve-endings in skin which is transmitted to the cortex of the brain [13].

Materials and Methods

1. Instruments

At the turn of the century almost all medical millimeter wave generators were produced in Former Soviet Union (FSU) [14]. In a research [15], 42.2 GHz mmWs were generated with a Russian-made microwave source called YAV-1 to investigate high frequency electromagnetic wave effect on delaying the growth in cancer tumor. This generator has been utilized as state-of-the-art for mmW source in many upcoming researches.

Molecular spectrum of emission and absorption of nitric oxide was studied using YAV-1 generator at 150, 176-150, 664 GHz at a power density 0.2 mW/cm^2. prescribed apparatus., incident power density was measured as 36.5 ±5 mW/cm^2 [16].

A RF generator (IMG-53.37, Micro Med Tech) see figure 1 & 2, with output power of 39 mW at 53.37 GHz frequency conical horn antenna was used for in-vitro investigation of neuromodulation [17].

Experiments was carried out using (MTA-KB2-Universal) apparatus producing 53.37 GHz electromagnetic waves in an amplitude modulation regime with 8 Hz for 15 minute while 10 mW/cm^2 intensity was applied to manifest analgesic effects [4]. It is mentioned that transmitter Pramn M14T-Z working at 42 GHz was effective for palliative treatment of cancer patient to alleviate neuropathic pain [18]. Therapeutic application of millimeter-wave was explored by exposure of rats to radiation produced by model Chengdu Hengbo Medical Instrument Co., Ltd., China [19].

2. Power requirements

Detailed literature survey, referenced as the following, brings to our attention that for therapeutic purposes the area under irradiation receives approximate electromagnetic power density in the range of 1-20 mW/cm^2. The role of field intensity in the experimental results has been elaborated [20]. For example, the nose area of mice was irradiated with15 mW/cm^2 of 61.2 GHz with15 minutes duration to examine the production of opioids [21]. Later, it was demonstrated that 30 – 40 GHz with 4 mW/cm^2 promotes synthesis of extracellular matrix [22].

For analgesic effects for wrist pain, 61.25 GHz radiation with 17 mW/cm^2 incident power density (IPD) produced analgesic effect in the patient. Millimeter wave 61.25 GHz was irradiated for 30 minutes on the Palm side of the wrist [23].

M. K. Logani [15], demonstrated that millimeter electromagnetic waves irradiation at 42.2 GHz frequency can inhibit tumor metastasis. The mmWs were produced by YAV-1 generator with incident power density 36.5 ± 5 mW/cm^2. Kalantaryan [24] carried out studies on the changes of cancerous DNA samples when exposed to low power, IPD = 10 $microwatts/cm^2$ mmW.

3. Procedure

Here an outlook of the experimental sequence of exposure whether in laboratory or in the clinic is presented. It was known that 61.2 GHz waves for 15 minutes to the nose causes release of opioids in mice [21]. In case of animal experiments aimed to control cancer tumors, exposure time lasted for 5 minutes per animal [16].

A study demonstrated that sensitivity threshold changes using different frog nerves. The exposures to mmW lasted 2–3 h, either with a regular frequency change of 1 GHz every 8–9 minutes or with a random frequency change every 1–4 min (53–78 GHz band, 0.1–0.2 mW/cm^2). The latter regimen induced an abrupt CAP (compound action potential) change in an unforeseeable manner. The other exposure regimen altered the CAP peaks components in 30–40 minutes [25].

In a human experiment, the palmar side of the wrist was exposed to mmW (61.25 GHz, 17 mW/cm^2) for 30 minutes, 1 h, & 1.5 h. Microwave treatment consisting of 10 s of pulsed microwave at 2.1 GHz and 0.5 mW/cm^2 was applied. Sensation of pain in the patient was diminished. In another human experiment, knee joint stiffness was treated selecting the parameters are as the following 10 mW/cm^2 on 6 cm^2 for 30 min/day, 5 days a week for 6 weeks [19].

Results

Diseases eligible for treatment

1. **Chronic pain**

Millimeter wave therapy (MWT), a non-invasive complementary therapeutic technique is claimed to possess analgesic properties. An early review of the pain-relief effect of MWT has been carried out [26]. The excitability of neurons in cutaneous tissue was shown to modify by application of millimeter waves. Analgesic effects were observed after mmW exposure [4].

In this regard, mmW therapy (MWT) was reported to be effective in the treatment of headache, arthritic, neuropathic and acute postoperative pain. The rapid onset of pain relief during MWT lasting hours to days after, remote to the site of exposure (acupuncture points), was the most characteristic feature in MWT application for pain relief. The most commonly used parameters of MWT were the mmW frequencies between 30 and 70 GHz and power density up to 10 mW/cm^2.

Millimeter waves with fixed frequencies 42.25 and 53.53 GHz (corresponding wavelengths 7.1 and 5.6 mm) and power density 10 mW/cm^2 were applied to the palms of the hands and the soles of the feet for 2–7 min per field of exposure daily or every other day for 3 weeks after surgery. The total number of MWT sessions ranged from 5 to 10.

Possibility to apply wireless bimodal neuromodulation to treat disorders like chronic pain and epilepsy has been explored [27]. It is a foundation for developing microwave based wireless neuromodulation devices for drug-free treatment of seizures and chronic pain.

The mmW emitting wristband, being a non-invasive device, transmits 61.2 GHz radio waves mainly to the palmar side of the wrist. It can be activated for sessions that last 30 minutes and during which radiations are transmitted through the antennas towards the wrist skin. The waves penetrate the epidermal layer of the skin and stimulate its nerve endings. The wave emission automatically stops at the end of a session [28].

In humans, exposure to electromagnetic millimeter waves has a hypoalgesic effect. Hypoalgesia and parasympathetic effects of millimeter waves in human volunteers have been observed experimentally [23]. In animals, this effect has been shown to depend on innervation density of the area exposed. Such effects were observed when mmW was applied on the palmar side of the wrist in healthy participants. Exposure to mmW for no more than 30 minutes led to remarkable enhancement in pain thresholds compared to the sham condition, but no increase of pain tolerance. All conditions led to decreased heart rate, while no change in blood pressure was observed. No change in skin state or temperature was observed for any of the conditions.

2. Migraine

Realizing a minimally-invasive interface with the brain for treating neurological disorders represents a considerable challenge for modern medicine. Implantable electrical stimulation devices have been successfully used for treating a variety of neurological disorders, such as Parkinson's disease, dystonia, epilepsy, chronic pain, and migraine. However, the implantation trauma and chronic risks associated with the presence of the implant in the nervous tissue have limited the widespread use of these devices [1]. Hence mmW radiation is a brilliant option for treatment of nervous disease.

Excitability of neurons was reduced with using 40 GHz with 0.01 mW for migraine. It has also been stated explicitly that mmW may inhibit neuronal excitability in the trigeminal nerve in the spinal cord, resulting in analgesia. Still, the mechanism of this effect needs further experimental evidence [29].

3. Epilepsy

Epilepsy is pathological condition caused by neuronal hyperactivity in the patient's brain [30,31,32]. It is possible to elongate the time between seizures using neuronal inhibition techniques. In the context of the present work, the idea is to expose the brain or related acupuncture points of the body by mmW with proper frequency and power density. VGSCs are responsible for the initiation of APs in excitable cells, such as neurons and represent a common target for the therapy of epilepsy and many neurodegenerative diseases.

Stimulation of “nervus vagus” to treat epilepsy is an approach to treat epilepsy [33] complete relief of postoperative cranial pain after 3–5 mmW therapy sessions followed by improvement of cognitive brain function, although these parameters were described only qualitatively. During the treatment, the incidence of seizure events was reduced without additional pharmacological treatment. The clinical improvement was accompanied by a normalization of the bioelectric brain activity [26].

Neuronal signal inhibition has been achieved with the use of 2.1 GHz electromagnetic induction to prevent epileptic seizures in patients [34]. After microwave treatment, the average spike amplitude in neuronal signals was significantly reduced. Thus microwave treatment has the ability to reduce neuronal activity in-vivo. With optimized microwave treatment parameters, it is possible to further reduce the magnitude, and thus the impact of a seizure in patients suffering epileptic disease.

For conditions involving excessive neural activity, such as epilepsy and chronic pain. However, the detailed biophysical mechanisms remain to be studied. This study has applications in wireless bimodal neuromodulation to treat disorders like chronic pain and epilepsy [27].

4. Cancer

Experiments on in-vivo mouse model provided evidence for shrinkage of cancer tumor. The experiment parameters were selected as 61.22 GHz; average incident power density 13.3 mW/cm^2; single exposure duration; 15 min and exposure area was nose [35].

In a detailed experiment accomplished by Logani et al. [15] it was demonstrated that millimeter electromagnetic waves irradiation (42.2 GHz) can inhibit tumor metastasis in mice. Over a period of 30 minutes, the incident power density was measured as 36.5 ± 5 mW/cm^2.

Discussion

1. Neuromodulation:

Modulation of neuronal activity is the rudimentary concept that is used for drug-free treatment of seizures and chronic pain based on wireless devices. Neuromodulation is a potentially more robust and precise method for treating neurological disorders by directly altering the firing patterns of target neurons and effecting long-term neuroplastic changes. One aspect of neuromodulation is variations that have been observed in the neuronal pulse rise time and fall time when the nerve is exposed to mmW. The radiation has been shown to non-thermally modulate neural activity [1,27,36,37].

It was demonstrated that 660 mW/cm^2 microwave at 2.05 GHz pulsed at 10 Hz for 10 s can inhibit neurons when used with a split-ring resonator (SRR). However, when the same microwave was applied without the SRR, no significant effect was observed [27]

2. Mechanism

Mechanism of mmW therapy was studied [13]. The major form of cell response to external radiofrequencies (RF) is vibration of the cell membrane [38]. Another concept declared by Frolich [39,40] suggests that biological cells may exhibit high-frequency electrical oscillations (GHz to THz) with the source of oscillations emanating from the cell membrane due to its high transmembrane potential. possible mechanism for the generation of millimeter waves by living organisms was the generation of these extremely high-frequency electromagnetic waves is subject to metabolic energy. Moreover, these waves are coherent and are characterized by their well-determined frequency, phase and polarization.

In case of patient exposure for treatment of neural disease, mmW penetrates to the depth of less than a millimeter in subcutaneous region. This causes nerve-endings to vibrate and send electric signal to CNS (central nervous system). In this regard, ionic channel conductance is an important factor to get into considerations [14].

Another mechanism assumed behind the mmW neuromodulation is the central release of neurotransmitters following the peripheral stimulation on nerve endings. This activates the descending pain inhibitory pathway, deactivates the salience network, and changes functional connectivity, thereby leading to pain relief. A study on healthy patients showed that exposure to mmW raises the pain perception threshold [28].

Voltage gated potassium channels (VGPCs) are extremely important in shaping action potentials, where they are responsible for membrane's repolarization and in the general, modulation of neuronal excitability. Due to the major role of calcium as a second messenger, VGCC (Voltage Gated Calcium Channel) dysfunction is responsible for a wide variety of CNS (Central Nervous System) pathologies, including epilepsy and neuropathic. The particular electrical sensitivity of VGCs themselves makes them a perfect target for EMF effects [41].

Table 1 – Radiofrequencies with beneficial effects for treatment purposes.

Frequency (GHz)	Wavelength (mm)	Application	Reference
30 - 40	10 – 7.5	Synthesis of chondrocytes	Xihai Li 2013
42.25 – 53.5	7.1 – 5.6	Chronic pain	Usichenko 2006
40	7.5	Migraine	Sivachenko 2016
2.1	143	Epilepsy	Marar 2024
2.05	146	Chronic seizure	Marar 2025

Conclusion

Building a miniaturized mmW emission system to be worn on the wrist would provide access to ambulatory mmW therapy for pain management.

Excessive activity in nervous system might be extinguished via neural inhibition methods. This is achievable in cases of migraine and epilepsy through non-thermal mechanisms. While neural stimulation has been achieved through various techniques, neural inhibition is less common yet may be more effective at treating conditions involving excessive or synchronized neural firing. This helpful in treatment of epilepsy or migraine. The cellular mechanisms of microwave neuromodulation remains to be elucidated.

Remarkable side effects in chemotherapy and radiation therapy of cancer treatment appears. Using radiofrequency for treatment purposes does not produce side effects.

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Fig. 1 – Millimeter wave generator IMG-53.37, Micro Med Tech

Figure 2 – Power supply for IMG-53.37, Micro Med Tech