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Physics of radiofrequency in proctology

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Abstract. – Radiosurgery is a new technique that utilizes an instrument, the radiofrequency bistoury, which is able to simultaneously cut and coagulate tissues with the emission of radiofrequencies. The first experiments about the utilization of radiofrequency currents on man were conducted between the end of the 19th century and the beginning of the 20th century. The first medical field of application was in oncology leading to the development of hyperthermia as an anticancer treatment. During the 80's the radiofrequencies have been introduced in cardiology to thermally ablate stable arrhythmic foci. Actually ear, nose, and throat surgery, dermatology, plastic surgery, vascular surgery, orthopaedics, neurosurgery and minimally invasive surgery use this new tool in their practice. The authors show the classification of radiofrequencies in the electromagnetic field, describe their historic development, their physics and their initial clinical applications by making a systematic review of the literature.

Key Words:

Radiofrequencies, Radiosurgery, Radiofrequency bistoury, Proctology.

Introduction

Electromagnetic waves have a length between 3 KHz and 300 GHz and consist of the low frequencies, the intermediate frequencies and the high frequencies[1]. The high frequencies include the radiofrequencies (3-300 MHz) and the microwaves (300 MHz-300 GHz) and are used for industrial and therapeutic devices (radar, MRI), domestic (cellular phones, microwaves ovens) and in every telecommunication apparatus (TV or radio station, radar, radio links). Most of the diathermic bistouries work in the range from 300 KHz to 3 MHz (intermediate frequencies) (Table I) because values lower than 10 KHz increase the risk of neuromuscular stimulation by the patient during surgery[2-4] and values higher than 3 MHz increase the risk of high frequency dispersion currents[5]. Radiosurgery is a new technique that utilizes an instrument, the radiofrequency bistoury, which is able to simultaneously cut and coagulate tissues with the emission of radiofrequencies with a wave length of 4 MHz.

History

The first experiments about the utilization of radiofrequency currents on man were conducted between the end of the 19th century and the beginning of the 20th century. Initially Arsene D'Arsonval (French physicist and physiologist 1851-1940) hypothesized that electric currents superior to 10 KHz wouldn't give neuromuscular contractions during surgery even if they still were able to generate heat. Unfortunately at the age the upper limit of the radio frequencies experimentally obtainable was 10 KHz and his hypothesis was confirmed only after Heinrich Hertz[6] (German physicist 1857-1894) created a machine able to go beyond that barrier. With this device, D'Arsonval[2,3] created high frequency currents and experimented them with success, firstly on himself and later on patients, to verify the truthfulness of his hypothesis. In 1899, Paul Marie Oudin (1851-1923) joined two D'Arsonval solenoids (one smaller than the other) and named this machine "resonator" or self-transformer (Figures 1 and 2)[7]. This machine was able to generate even more powerful currents and was capable to destroy the tissues[2,3]. In the beginning of the 20th century Riviere[8] hypothesized that the smaller the electrode the higher the electrical densities transmitted to the tissues. He began to use this device on small neoplasms of the skin.

Table I. Main utilizations of radio waves (frequency range between 3 KHz and 300 GHz). VLF: Very Low Frequency. MF: Medium Frequency. HF: High Frequency. VHF: Very High Frequency. UHF: Ultra High Frequency. SHF: Super High Frequency. EHF: Extra High Frequency.

Range	Frequency field	Utilization
3-30 KHz	VLF	Naval transmissions
		Video terminals (VDT)
		Domestic electric heat generators
30-300 KHz	LF	Naval transmissions (Loran)
300 KHz-3 MHz	MF	AM radio transmissions
		Radio amateur transmissions
		Industrial electric ovens
		Electro surgical units
3-30 MHz	HF	International transmissions
		Radio amateur transmissions
		City radio station
		Industrial welder
		Short waves diathermy
		Radiofrequency bistoury
30-300 MHz	VHF	FM Radio transmissions
		VHF Televisions
		Mobile and portable transmitters
		Cordless phones
300-3000 MHz	UHF	UHF televisions – Cellular phones
		Microwaves owens and microwaves diathermy
		Airports control towers
3-30 GHz	SHF	Microwave radio links
		Satellites
		Police communications
30-300 GHz	EHF	

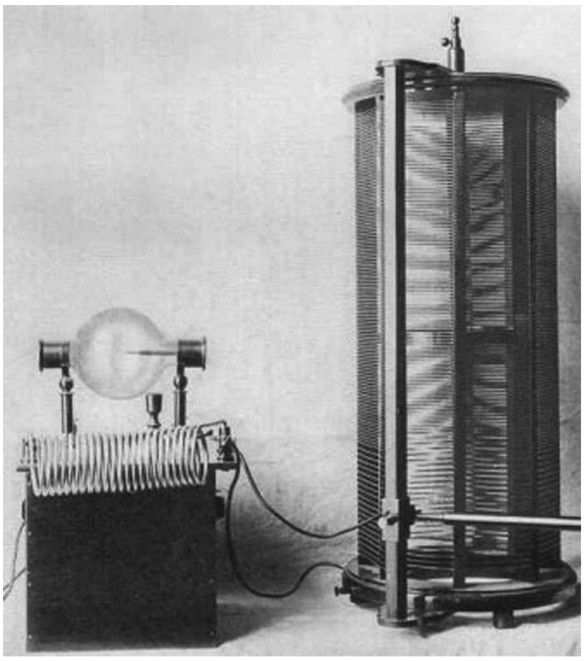

Figure 1. Oudin's "resonator".

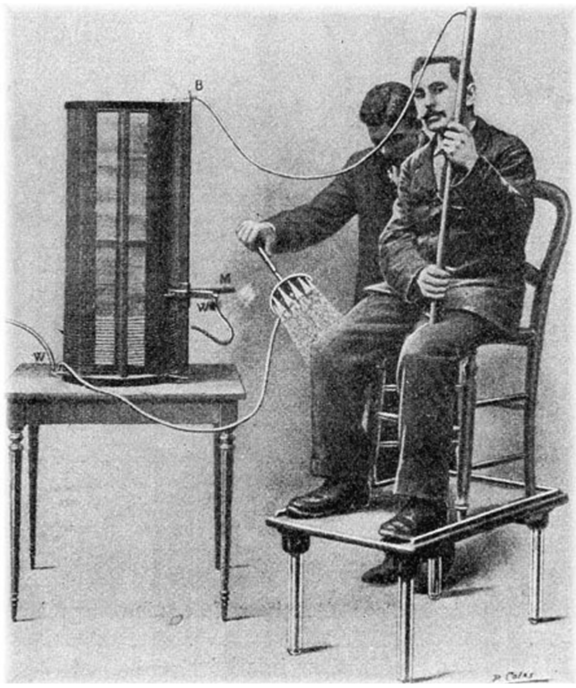

Figure 2. First experiments conducted with Oudin's resonator.

In 1907, De Forest[9] (American inventor 1873-1961) created the triod, an electronic tube that amplifies signals, generating currents reaching 70 Watt of power and 2 MHz of frequency and experimented them on patients. In 1926, a Harvard physicist, William Bowie[10], probably made the most important contribution to the development of electrosurgery. With financial assistance from the Liebel-Flarsheim Co. of Cincinnati, he built an operating room electrosurgical device that offered both coagulating and cutting currents. Dr. Harvey Cushing, a distinguished neurosurgeon, became quite interested in these techniques and, with Bowie at the control, began using electrosurgery for stopping the bleeding and for cutting through the tissues during surgical procedures at Peter Bent Brigham Hospital in 1926. Dr. Cushing's favourable impressions of electrosurgery ensured acceptance of electrosurgery by the surgical world. Ironically Bowie, who sold his patent to Liebel-Flarsheim for $1.00, was not granted at Harvard University due to his poor publication record and reputedly died a poor man.

More recently, in the 70's, the first experiments on animals began[11]. 13.5 MHz radio waves generators were used on pigs to analyse the pattern of tissue heating both on the surface than deeply. 425 MHz radiofrequency generators have been used on rats to analyse the tissue responsiveness[12]. The frequency used was incremented using particular shapes of wave to 2.45 GHz and was observed that the internal homeostasis was unaffected. In fact, the blood stream vanished the excess of temperature that used to locate in particular areas (brain, tail, rectum)[13-15]. Experiments on Rhesus monkeys have outlined the importance of the metabolic and vasogenic response in dissipating the localized excess of temperature. These experiments showed that the exposition to radio frequencies was compatible with life[16,17].

Radiofrequencies were subsequently used in clinical practice. The first medical field of application was in oncology leading to the development of hyperthermia as an anticancer treatment. For this purpose experiments were conducted on prostate, biliary tract[18], lung[19] and kidney cancer[20]. All the studies showed a destruction of cancer cells by radiofrequencies' heating without excessive destruction of normal surrounding tissue. Radiofrequencies are actually used in the palliation of primary and secondary unresectable liver cancer and are experimented in kidney cancer, breast cancer, lung cancer and in osteoid osteomas[21].

During the 80's the radiofrequencies have been introduced in cardiology to thermally ablate stable arrhythmic foci for both supraventricular and ventricular arrhythmias, but an accurate analysis of the data published in literature shows that the frequencies used for these purposes are only intermediate and not high frequency waves[22-28].

Physics

Usually the diathermic classic bistoury uses very high external temperatures (300-900° C) to reach the target temperature for cutting and coagulating of tissues because thermal energy is produced on the surface by Joule effect and is transmitted deeply into the tissue by convection, lowering itself during the tract. Thereby the deeper the point to be reached, the higher the external temperatures required. These higher temperatures used with classic diathermy cause often severe and painful burns.

Radiofrequencies work differently than diathermy: they add energy to the electrons inducing a vibration of the cellular ions. This vibration, called "molecular resonance", affects the low energy molecular bindings and generates heat. The generation of molecular resonance is strongly dependent on the frequency of the wave used[29-31]: the maximal resonance in men is activated approximately 35 MHz for a man that is grounded and 70 MHz for one who is insulated. For this reason radiofrequencies waves are much closer to the resonant frequency of the body than 60 Hz power lines or other forms of low frequency energy and are preferred among the others. Additionally, radiofrequencies belong to the non ionizing radiations because do not affect cellular macromolecules (DNA) and therefore they are neither carcinogenic nor teratogenic[32-34].

Radiofrequencies develop the target temperature within the tissues producing a constant heating pattern in all of the cells through the passage. Using lower external

Figure 3. Sealing vessel electrode.

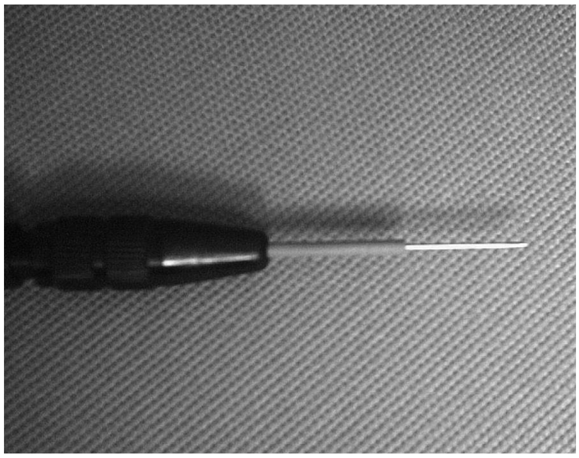

Figure 4. Radiofrequency electrode.

temperatures than classic diathermy (even if reaching the same target temperature inside the tissues), they have a cutting temperature that is always lower than 45° C and called "atraumatic" because doesn't burn the tissues. The coagulating temperature is around 65° C and is produced by protein denaturation (temperatures higher than 45° C permanently damage proteins and fuse cellular membranes). These temperatures give minor burns and pain[29].

Moreover radiofrequencies work with lower temperatures even if compared to the sealing vessel generator technology. This technique works fusing the tissues with a peculiar combination of pressure and energy that creates the seal by melting the collagen and elastin in the vessel walls and reforming it into a permanent, plastic-like seal. The combination of pressure and energy gives the ability to use lower powers than diathermy (that lacks of the pressure component) but still too high if compared to those used by radiofrequencies. Furthermore, the sealing vessel generator uses a particular electrode created for the pressure-energy effect (Figure 3) that limits the use of this technology to the hemorrhoids surgery. The radiofrequency surgery use a fine electrode with a smaller tip (Figure 4) allowing more precise operations in every type of proctology surgery.

The main differences among the cutting-coagulating devices actually used in surgical practice are listed in Table II. It is evident that the higher the frequency used the lower the power required to reach the target temperature inside tissues. This explains the remarkable reduction of the temperature used by radiofrequencies compared to classic diathermy and to the sealing vessel generator.

In conclusion, the peculiar features of the radiofrequencies give many advantages over the other techniques in different types of surgery. In proctology this is more evident because the use of the radiofrequencies is combined with the smaller electrode giving more flexibility to the surgeon.

Table II. Main differences among cutting-coagulating devices actually in use in surgery.

	Diathermy	Sealing vessel generator	Radiofrequency bistoury
Way of application	Contact	Contact and pressure	Contact
Wave frequency (Hz)	300-600 KHz	473 KHz	4 MHz
Power (Watt)			
• cutting	200-300 W	–	120 W
• coagulation	100-150 W	95-150 W	60 W
Tissue temperature	300-600° C	100° C	45-65° C

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