RF Energy in Medicine

Innovative Solutions Using Solid-State RF Power

Abstract

Transistors that generate high-power RF energy are typically associated with powering telecommunications systems that transmit a signal over the air. However, this energy is also used for other many purposes, such as igniting a laser, accelerating particles, or generating heat. In the latter case, the energy field becomes strong enough to raise the temperature of a material to a specific value. This RF energy (also called RF power) is the driving force within a wide range of medical systems that treat disorders ranging from skin aging to neoplasia, heart pathologies, and essential hypertension. The sources of RF power began as rudimentary sources of electricity and quickly transitioned to vacuum tubes after they were invented, and today to solid-state devices. As a result, medical systems today use RF power transistors of various kinds to generate RF power.

As studies increasingly show the benefits of operating at higher frequencies such as 915 and 2450 MHz, LDMOS transistors, proven in hundreds of millions of cellular base station amplifiers throughout the world, are the obvious RF power source. This white paper covers a wide range of topics, from the history of RF in medicine, to typical applications and how they work, and some new experimental applications that show promise.

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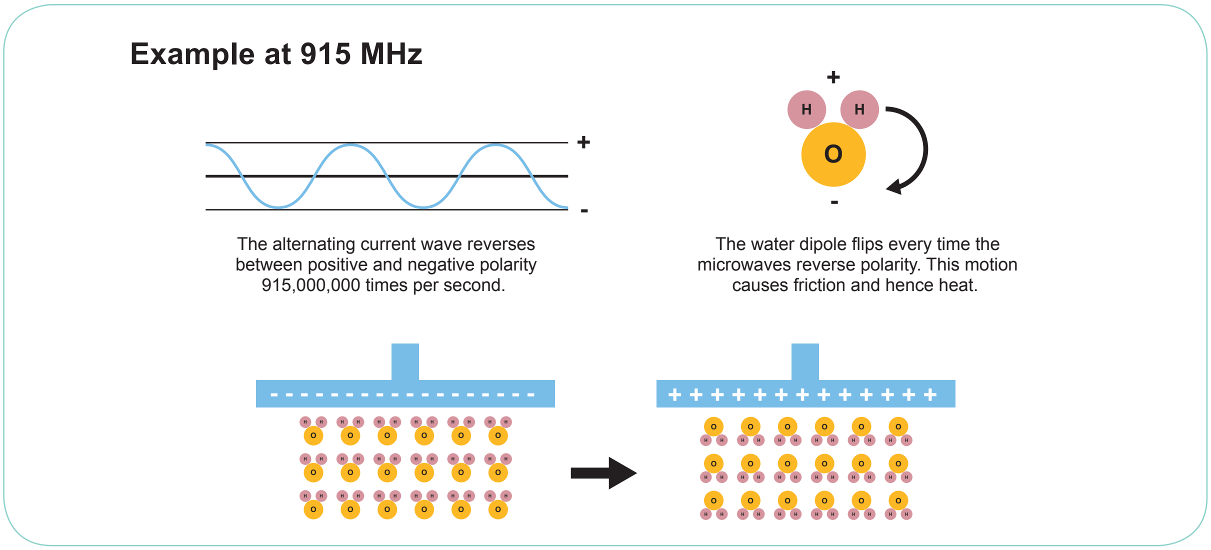
The benefits of RF energy in medicine

The majority of medical treatments that use RF energy rely on its ability to create heat either over small or large areas of the body. In some medical applications such as diathermy, RF energy is used in this way by creating an electric field between two parallel plates, with the area of the body to be heated in the middle. As electromagnetic energy penetrates more deeply into any material at lower frequencies than at higher ones, this in part determines the frequency that is used for various medical procedures.



Example at 915 MHz

The alternating current wave reverses between positive and negative polarity 915,000,000 times per second.

The water dipole flips every time the microwaves reverse polarity. This motion causes friction and hence heat.

How electromagnetic energy heats materials.

It is also why medical applications requiring deep tissue penetration use very low frequencies. These applications include diathermy as well as various cosmetic procedures. However, research and clinical trials in recent years have shown that in some cases microwave frequencies, principally the unlicensed bands at 915 MHz and 2450 MHz, can be very effective and can reduce or eliminate some of the inherent problems and limitations when low frequencies are employed.

In the beginning

To understand how the use of RF power in medicine has evolved over time, it's important to provide some historical perspective. The use of RF energy for medical applications dates back more than 120 years and was first suggested in 1891 by Nicola Tesla, who discovered that it was possible to produce heat in a human body. Unfortunately, it also caused electric shock. Tesla's work was immediately followed by research conducted by French physician and biophysicist Jacques Arsene d'Arsonval who discovered that RF energy applied at frequencies above 10 kHz caused warming rather than electric shock. He worked to find ways to apply high-frequency current using contact electrodes, capacitive plates, and inductive coils.

The use of RF heating for deep tissue was first suggested by Austrian chemist R. von Zaynek, who noted that production of heat in tissue was a function of both frequency and current density. In 1908 German physicist Karl Franz Nagelschmidt coined a name for this treatment—diathermy—during what were the first extensive experiments on humans. Nagelschmidt is considered to be the pioneer in the field, writing the first textbook on the subject in 1913.

There were no solid-state devices or even vacuum tubes during these early days, so the first components employed to generate the RF power (and thus electromagnetic fields) required for diathermy were spark-discharge Tesla coil machines that operated between 100 kHz and 2 MHz. This was called "longwave" diathermy. When John Ambrose Fleming invented the vacuum tube in 1904, they replaced the Tesla coils and allowed diathermy machines to operate between 10 and 300 MHz, which was (and still is) called "shortwave" diathermy. In the ensuing years, microwave frequencies, specifically the unlicensed bands at 434, 915, and 2450 MHz, started being used in diathermy, adding microwave diathermy to the available treatments.

Modern generators of RF power

Today, both vacuum tubes and (increasingly) transistors are the sources of RF power generation for medical applications. As just noted, vacuum tubes were the only choice before transistors developed the characteristics to make them viable. However, RF power transistors have now been used for many years as their reliability, ruggedness, and RF output power have dramatically improved.

The biggest benefit of transistors over vacuum tubes for medical applications is their flexibility. Their output power can be tightly controlled over their full dynamic range, which enables heat transferred to human tissues to be reduced when required. They also generate RF energy over a very narrow frequency range, and support sweeping frequencies within an ISM band (from 902 to 928 MHz, for example). This helps to maximize the energy transferred to the body. Finally, for advanced systems that use multiple probes that combine wave fronts, phase can be controlled to move the areas that must be targeted.

Solid-state devices such as this high-power LDMOS RF power transistor are revolutionizing many medical systems.

The first solid-state devices used in medical applications were bipolar junction transistors (BJTs) and vertical MOSFETs (VMOS), almost always at low frequencies. These devices are still in use. However, the emergence of LDMOS silicon technology (laterally diffused metal oxide semiconductor) in the nineties paved the way to addressing higher frequencies such as 915 or 2450 MHz.

LDMOS transistors' advantages over vacuum tubes	LDMOS transistors' advantages over BJT and VMOS
Flexibility: greater control of power, frequency, and phase because of low-voltage power supply	Unlike VMOS, performance does not fall off rapidly above 100 MHz
Consistency: small part-to-part variations	Extremely rugged
Reliability: great longevity with no performance degradation over time	No beryllium oxide (BeO) in packages; BeO is a carcinogen

Table 1: LDMOS transistors versus older technologies.

The benefits of LDMOS

The two biggest benefits of LDMOS transistors over previous solid-state semiconductor technologies are their ability to operate above 100 MHz and their ruggedness. LDMOS RF power transistors will survive even if almost all the transmitted energy is routed to them because of extremely high impedance mismatch such as a short or open circuit. This durability is important in medical applications in which human tissue can present a variable load to the probe.

While vacuum tubes require potentially dangerous high voltages that require large, heavy power supplies, transistors operate at 32 to 50 VDC. And when compared with vacuum tubes that have an operating lifetime of about 8,000 hours, LDMOS RF power transistors operate for much longer; in the case of LDMOS transistors, millions of hours. Unlike tubes, they also produce the same RF output power near the end of their lives as they did when they were installed. Magnetrons and all vacuum tubes also operate at potentially dangerous high voltages that require large, heavy power supplies. In addition, the power of a magnetron cannot be varied, so it is either on or off, which becomes obvious when operating a microwave oven in defrost mode, when sounds change as RF power is switched off and on.

Robustness and reliability are the most significant factors that impeded the use of solid-state devices until relatively recently, but today LDMOS RF power transistors for high-power, demanding applications such as magnetic resonance imaging are extraordinarily rugged. Even though their exterior appearance might make them appear fragile, just the opposite is true. For example, LDMOS RF power transistors can deliver their full-rated RF power levels (which can be greater than 1.5 kW) without degradation or failure even when they are subjected to extreme impedance mismatches approaching a direct short, higher-than-specified operating voltages and twice their rated RF input power.

Collectively, the performance of LDMOS RF power transistors has stripped away impediments to the use of solid-state devices for RF power generation. A single LDMOS transistor can today deliver 1500 W up to 500 MHz, 350 W at 915 MHz and 300 W at 2450 MHz. The typical operating frequencies of NXP® RF power transistors for specific medical applications are shown in the table below.

Frequencies used in medicine

The radio frequencies used in medical applications are determined based on three factors: government frequency allocations, efficacy of treatment, and the need to operate at a specific frequency in order for the technique to provide its stated benefit. Frequencies allocated for medical use by the FDA in the U.S. and similar agencies throughout the world are generally within the Industrial Scientific and Medical (ISM) bands and do not require the operator to have a license. Many other types of systems operate in these bands as well, including Wi-Fi®, Bluetooth®, microwave ovens, RF-based industrial equipment, and some other communication systems.

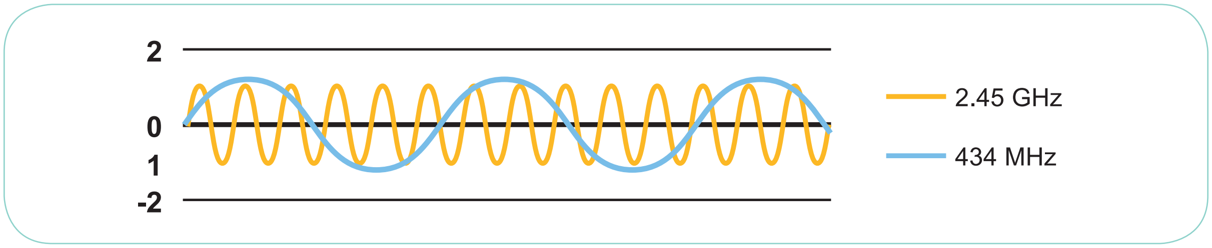
ISM Band	Medical Application
13 MHz	RF ablation Skin rejuvenation Diathermy
27 MHz	Skin rejuvenation Diathermy
40 MHz	Skin rejuvenation Diathermy
915 MHz	Microwave ablation Diathermy
2450 MHz	Microwave ablation Renal denervation

Table 2: NXP RF power transistors for medical applications.

Frequencies that provide most effective treatment are not hard and fast as heating can be created by RF energy at almost any frequency. In addition, developing a system at a frequency other than one allocated by government regulations is extremely expensive. Consequently, there must be a significant benefit for operating at frequencies other than ones already being used. A good example of this is the MRI system that does not operate at frequencies within the ISM band but rather at 64 MHz and 128 MHz depending on the strength of the electromagnetic fields they create.

The time required to heat a specific material such as tissue to the required temperature depends on the amount of applied power (that must be strictly controlled) as well as the frequency of the electromagnetic wave. Various types of tissue react differently to RF energy at different frequencies, and some will require higher power in order to absorb energy and begin warming. Higher frequencies (and thus shorter wavelengths) penetrate less deeply into tissue than lower frequencies, and the higher the frequency, the greater the power density around the source of RF energy.

As shown in the figure below, there is a vast difference in length measured in meters between low and high frequencies. For example, a full wavelength at 6.78 MHz is about 44 m while at 2450 MHz it is only 12 cm.



Wavelengths at microwave frequencies are much shorter than those at lower ones.
The result is shallower penetration at the higher frequencies.

Major medical applications using RF power

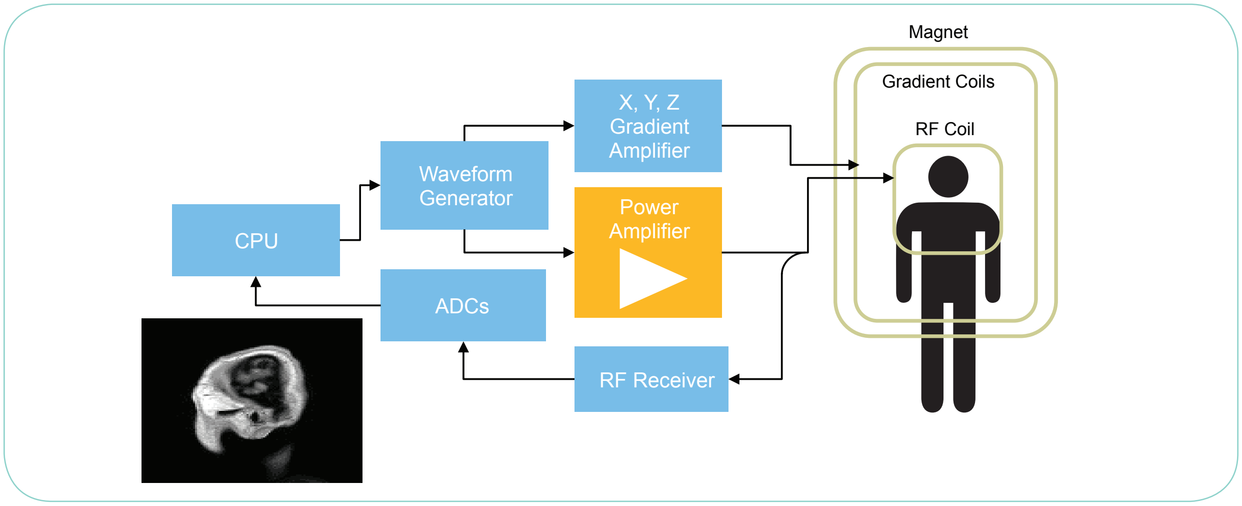
While the applications described below are not the only ones using RF energy, they are the most widely used. For example, various types of lasers must be excited by an electromagnetic field created by an RF power source. They are covered only briefly here because they do not directly use RF energy for treatment purposes.

Nine types of lasers in which RF power is often used to ignite a plasma are employed for a wide array of applications in medicine that include angioplasty, cancer treatment, cosmetic dermatology, laser mammography, and ophthalmology. Some of these systems, especially those used in cosmetic dermatology, combine the benefits of optical and RF energy to produce results neither technology alone can deliver.

CO_2 lasers require excitation produced by a high-level RF power source. Vacuum tubes were the initial power source, then VMOS, but the most recent source is an RF amplifier powered by far more rugged LDMOS transistors that can survive the energy reflected back when the plasma ignites. This is especially true at the laser power levels typically used in some medical applications.

Magnetic resonance imaging (MRI)

MRI is likely to be familiar to more people than any other medical system. What many people do not know is that every MRI system uses RF transistors to generate the electromagnetic field that is the essential ingredient. MRI is one of the few medical applications that does not use RF energy to produce heat. Rather, it uses RF power sources to create an extremely strong, pulsed, electromagnetic field around a patient from which detailed pictures of organs, soft tissues, bone, and virtually all other internal body structures can be produced.



The fundamental force driving all types of MRI systems are RF power sources that generate intense electromagnetic fields.

The foundation of MRI is nuclear magnetic resonance, which dictates that certain atomic nuclei will absorb and emit RF energy when placed in an external magnetic field. Specifically, hydrogen atoms that are widely present in the body and especially in water and fat can generate a detectable RF signal that can be received by antennas near the body. The imaging system can map their location by varying pulse characteristics and different levels of contrast can be generated between tissues.

Solid-state RF power sources have been used by all MRI manufacturers for years as they operate without maintenance or replacement. They also allow RF energy levels to be infinitely varied, which is essential in order to keep the patient safe.

The strength of the electromagnetic field used in MRI systems is measured in levels of tesla. The most common MRI systems use magnetic fields of 1.5 tesla. High-performance MRI systems with magnetic fields of 3 tesla can produce higher levels of image resolution. MRI machines with magnetic fields of 1.5 tesla operate between 61 and 64 MHz, and MRI machines with magnetic fields of 3 tesla operate between 123 and 128 MHz. MRI systems in production today use VMOS (vertical MOSFETS) but are gradually migrating to LDMOS, as VMOS devices do not operate well above 100 MHz.

Ablation using RF energy

There are several ways to ablate tissue, including lasers and cryoablation. However, ablation using RF energy at a specific frequency is one of the most widely used. In general, electric current is produced by an RF power source that in turn produces heat that can be directed to induce thermic apoptosis of the tissue. It is used to treat diseases including cancer, cardiac arrhythmia, varicose veins, uterine bleeding, and many others. The surgeon performing the procedure is typically guided by images generated by one or more types of systems such as MRI, computed tomography (CT), or ultrasound that make it possible to precisely address a specific location with the RF-powered electrode. The electric current produced by the RF power source causes tissue heating around the probe at temperatures high enough to cause tissue necrosis.

There are two types of ablation systems that rely on RF energy. The first, called RF ablation, typically operates between 450 and 500 kHz, primarily because this frequency was used by its predecessor, electrosurgery. This frequency range had already received regulatory approval, so approval of RF ablation was much easier. The second, called microwave ablation, typically operates at either 915 MHz or 2450 MHz.

RF ablation

There are two types of RF ablation: monopolar and bipolar. In monopolar RF ablation, a single group of electrodes delivers energy at the tumor site using a ground pad to complete the circuit through the body. The pad, which acts as a return path for the RF current, is generally located on the patient's thighs or back. Bipolar RF ablation allows current to flow between multiple groups of electrodes but does not require the use of grounding pads.

The procedure is performed by inserting the aforementioned probe into the target tissue destined to be destroyed. Tissue is heated by applying current between the probe and the ground pad. To ensure that tissue heating occurs only where desired, some parts of the probe may be insulated.

Cell death depends on temperature and application time, ranging from a few minutes to induce apoptosis in cells at 50 °C but just a few seconds at higher temperatures. The maximum temperature range is between 50° C and 110 °C. One of the issues with RF ablation is that when current densities are very high they can produce charring of tissue, making precise temperature control essential. In order to increase the region in which ablation is effective, the probe can be cooled using water.

Microwave ablation

Although the mechanism used to produce cell death using microwave ablation is similar to its RF counterpart, it has advantages in certain cases. In microwave ablation, molecules continuously realign as the microwave energy field oscillates, which increases kinetic energy and tissue temperature.

Unlike lower-frequency currents, energy at microwave frequencies can permeate all biological tissues, which include those with a high resistance to electric current, such as bone and lungs. Consequently, they can generate a far greater volume of energy surrounding the probe, which makes the procedure faster, produces higher temperatures, and expands the ablation zone. This means that fewer applications are typically needed.

Microwave ablation is now in its third generation. The first generation had no active antenna (probe) cooling so lower power was used over shorter periods. The second generation added cooling but allowed only modest increases in power, and the third generation allows increased cooling and the use of greater RF power levels.

The design of the microwave probe has a critical effect on how large and in what shape the ablation zone can be. As a result, researchers have produced many different types of probes with varying degrees of effectiveness in controlling the transfer of RF energy. In fact, more than one probe can be used in order to create a larger ablation zone and precisely conform to the target area. Each of these probes can be varied in phases that make it possible to create zones of "constructive" and "destructive" wave interaction that can have a dramatic positive effect on the results.

Studies have been conducted at both 915 MHz as well as 2450 MHz in order to determine which one is "best." It was initially believed that the lower frequency could produce larger zones of ablation thanks to deeper penetration, but other studies have shown the opposite.

Generally speaking, the benefits of microwave versus RF ablation include:

- Reduced application time (can be as little as a few minutes)
- The ability to achieve higher temperatures
- Reduced sensitivity to various types of tissue
- Reduced need to reposition the probe
- The ability to treat tumor types on which RF ablation cannot be used.

Renal denervation (RDN)

A typical catheter used for RDN ablation.

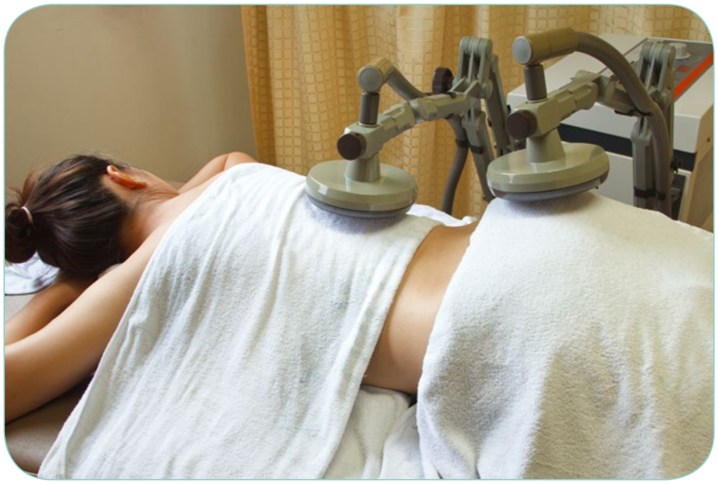
While not specifically called "ablation," renal denervation nevertheless uses this technique, and is an emerging treatment for uncontrolled hypertension in patients for whom medication and changes to lifestyle and nutrition are not effective. It is a minimally-invasive procedure that reduces blood pressure by ablating renal nerves using a small catheter placed in the femoral artery (for access to the nerves serving the renal artery).

The nerves are ablated by passing electromagnetic energy into the artery and transmitting low-dose power through the catheter tip placed in the kidneys. The energy transmits through the vessel wall to damage the renal nerves. After the procedure, the patient can resume activities within hours, and can leave the facility the following day.

Although there are other forms of RDN treatment such as ultrasound and micro-infusion, ablation using RF for denervation at either low or microwave frequencies is currently undergoing clinical trials championed by multiple companies. Results of early clinical trials demonstrated a high rate of success but more recent, better-controlled studies have failed to confirm them. Consequently, the jury is still out as to whether or not this treatment will be effective.

Diathermy

Diathermy is a very effective treatment for a wide variety of conditions and has continually added to its treatment portfolio over the years. Depending on the wavelength used by the equipment, it either applies heat directly to the skin (shortwave diathermy) or heats it using a probe situated a short distance from the body that directs energy to the skin (microwave diathermy).



Microwave diathermy does not use applicators placed on the skin but rather aims the energy at the skin via probes.

Shortwave diathermy operates at 13, 27, or 40 MHz, and microwave diathermy operates at either 915 or 2450 MHz. Although vacuum tubes (magnetrons) have long been used as the RF power source for both shortwave and microwave diathermy, LDMOS RF power transistors are replacing them thanks to their longevity, infinite power control, simpler control mechanisms and other benefits.

As heat increases so does blood flow, which can improve flexibility in joints and connective tissue (except cartilage that lacks vascular supply), and as inflammation is reduced so is the pain related to it. As a result, arthritic patients can increase their range of motion. Other applications include treatment of sprains, strains, lesions, degenerative joint disease, rheumatoid arthritis, stiffness in the joints, hematoma, bursitis and synovitis.

Diathermy can also be used for surgical procedures in which a probe is applied to a blood vessel, causing the blood to coagulate and cauterizing the area.

Shortwave diathermy

Shortwave diathermy employs two plates placed on either side of the body part to be treated or by using induction coils that can be molded to fit the body or wrapped around a limb. As the high-frequency waves travel through the body tissues between the plates or coils, they are converted into heat. The degree of heat and depth of penetration depend in part on the absorptive and resistance properties of the tissues that the waves encounter.

It is most effective for treating pain caused by sinusitis, kidney stones, and pelvic infections as well as for other conditions that cause pain and muscle spasms. Shortwave diathermy can produce heat deep inside a targeted tissue as far as 2 inches from the skin's surface. In this method, the patient's tissues are a dielectric between the plates so the body is part of the electrical circuit. The oscillation and rotation of the molecules of the tissues produces heat.

The heat induced and pain management are related to the inflammatory process in which the white cells recruited to the lesion zone release their cytokines. Some of them are anti-inflammatory in nature, helping in reducing the effect the pro-inflammatory cytokines have over nociceptor cells.

Three techniques are used for shortwave diathermy depending on the required treatment: contraplanar, coplanar, or longitudinal. The contraplanar approach places plates on either side of a limb, while the coplanar technique places electrodes in parallel along one side of the body. In the longitudinal approach, electrodes are placed at each end of a limb.

Microwave diathermy

Microwave diathermy uses microwave energy to generate heat in the body and is very effective for evenly warming tissues without heating the skin. Unlike shortwave diathermy, microwave diathermy does not apply heat directly to the body but rather beams RF energy to it from a probe that generates heat within the targeted tissues. However, as it cannot penetrate into deep muscles, its primary current applications are for areas closer to the skin, such as shoulders.

The probe focuses the RF energy field directly on the targeted tissue in a more concentrated area than shortwave diathermy. Unlike shortwave diathermy, the patient does not become part of the electrical circuit. Absorption of the energy causes heating in the tissues, more deeply than infrared solutions but not as deeply as shortwave diathermy.

As microwave energy is effectively absorbed by water, tissues with high fluid content are heated most while fat and other tissues are heated less. It is also effective for heating tissues such as muscle that have significant blood supply. Microwave diathermy has demonstrated its ability to treat inflammatory lesions, where it can increase blood supply and thus relieve pain and muscle spasms, and rheumatic conditions that affect soft tissue and joints.

Two types of probes are used for microwave diathermy, which vary widely depending on the manufacturer. The circular type produces heat that is more intense at its periphery than at its center and is effective for both small and large areas, and rectangular probes are used for elongated areas with radiation density concentrated at the middle. In either case, the size of the treatment zone varies with the distance of the probe to the skin and the amount of power directed to it. Treatment takes between 10 and 20 minutes.

Skin rejuvenation

There are many techniques that fall within the broad term of cosmetic (also called aesthetic) therapy that employ RF power either alone or in combination with a source of light. The use of optical energy to treat dermatologic problems has been widely used for two decades, sometimes combining lasers and intense pulse light (IPL) for epilation, removal of vascular and pigmented lesions, reduction of fine wrinkles, acne treatment, and others. However, the limitations of optical techniques caused researchers to look for new forms of energy that could expand their ability to treat more types of skin conditions more effectively. RF energy has become the most popular of these as it relies on tissue’s electrical properties rather than on concentration of molecules in the skin for thermal destruction.

As RF technology transfers heat to the dermis at relatively low temperatures, it is well suited for acting on collagen molecules without effects to the epidermis, enables more effective wound-healing, and provides effective skin rejuvenation in a short time.

There are several types of RF-based treatments, the first of which is called monopolar RF, in which a single electrode tip is applied to the target area and another plate serves as a ground pad. Bipolar RF refers to a technique in which tissue is targeted using two points on the tips of a single probe, and tripolar RF employs multiple electrodes to heat both shallow and deep layers of the skin at the same time.

Another technique called fractional RF, which is relatively new, uses a very thin needle-type electrode and can service multiple zones of tissue without affecting the epidermis and adnexa, which results in faster healing.

Still another approach called unipolar RF works without delivering current to the skin but rather uses energy to induce rotational oscillations in water molecules. It targets the reticular dermis and subcutaneous junction in contrast to the bipolar technique that affects the papillary and mid-level dermis.

Another aspect of cosmetic medicine, body contouring, allows reshaping of the body without surgery and has resulted in numerous noninvasive and often proprietary techniques. RF energy is used for the purpose by delivering current deep into areas of fat cells in order to destroy them.

Connective tissue and fat both contribute to the development of cellulite, for which RF energy has proven to be effective in minimizing. The heat produced causes collagen proteins in connective tissue to change and tighten and studies have shown that it may also increase blood flow and fat metabolism at the treatment site. RF energy also affords its noninvasive capabilities for liposuction. A technique called radiofrequency assisted liposuction (RFAL) uses RF energy to produce heating through the use of two electrodes, one of which is external and one of which is internal and connected to a handheld controller.

Still another application is permanent hair removal that has often been conducted using optical energy but is limited to darker hair colors. As noted earlier, treatment of dark skin types is limited using optical energy, so a promising technique employs both optical and RF energy, as the latter is not limited in this respect.

Finally, electro-optical synergy, or e-light technology, combines both RF and optical energy. Its goal is to reduce the intensity and thus potential side effects of using optical energy by using it in conjunction with bipolar RF. Studies have shown that it can be used with all hair types and is effective in removing white hair.

Telangiectasia treatment

Telangiectasia is an abnormal dilatation of capillaries. Common causes of telangiectasia are believed to be genetic, environmental, or a combination of the two factors. Telangiectasia presents as tiny blood vessels that cause a threadlike appearance on the skin and often form in clusters. The condition is often referred to as spider veins, owing to its web-like appearance. Telangiectasia is treated by using either sclerotherapy, laser (optical) treatment, surgery or endoluminal RF heating therapy. Studies show that RF (and possibly microwave) ablation can be used to reduce the plaques typical of this disease using lower temperatures with fewer side effects.

The RF-based approach is essentially a form of RF ablation. Using the spider veins in a leg for example, the site is anesthetized, and an RF catheter is inserted inside the greater saphenous vein near where it connects to the femoral vein. The catheter heats the vein to about 85 °C, causing scarring and sealing of the vein. The procedure is performed without general anesthesia and averages about 20 minutes in length.

The technique called VNUS Closure, introduced by VNUS Medical Technologies in 1998, uses a similar approach that uses an injected saline solution to numb the leg, squeeze blood from the vein, and protect surrounding tissue. Ultrasound imaging is used to locate the treatment site, guide the catheter, and confirm that the vein has been fully closed. After the procedure, blood is naturally re-routed through other healthier veins. It is said to be faster than some other techniques, reduces recovery time, and causes less discomfort during and after the procedure, along with little or no scarring, bruising or swelling.

RF power is commonly used for telangiectasia treatment. Systems using microwave energy are being investigated.

Emerging applications

RF technology is being used to treat other pathologies as well, and many rely on RF ablation. For example, it is being used to treat various heart conduction disorders, of which there are many. The procedure has been demonstrated to be safe with a mortality rate of less than one per 2000 procedures. RF ablation is also being used to treat hepatocellular carcinoma, the most common type of liver cancer. The electrodes are inserted into the liver tumor under ultrasound image guidance using percutaneous, laparoscopic, or open surgery.

As it is a local treatment and has minimal effects on normal healthy tissue, it can be repeated multiple times. The technique has proven to have four-year survival rates similar to those of surgical resection and as it has a minimal effect on healthy tissues, it can be repeated several times. Finally, a condition called Barrett's esophagus, which is a serious complication of gastroesophageal reflux disease, is also being treated using RF ablation. The RF energy is delivered through an endoscope that is inserted into the esophagus that allows abnormal cells to be destroyed while protecting the healthy cells underneath.

Summary

The use of electromagnetic energy in medicine has a long history and has proven its effectiveness either alone or in combination with light. Advances in solid-state device technology that enable new levels of control, and especially in LDMOS RF power transistors to address higher frequencies, are making it possible to replace older technologies that have for decades been the primary RF power source. In the future, it is likely that more and more procedures will exploit the benefits provided by RF energy that are better suited than other technologies in terms of performance, longevity and the risk of complications.

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