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REVIEW ARTICLE

Introduction and overview of radiofrequency treatments in aesthetic dermatology

Axel R. Delgado MD[1] | Anne Chapas MD[2]

[1]Department of Dermatology, Broward Health Medical Center, Fort Lauderdale, Florida, USA

[2]UnionDerm, New York, New York, USA

Correspondence
Axel R. Delgado, 1600 S Andrews Ave, Fort Lauderdale, FL, 33316, USA.
Email: ardelgado@browardhealth.org

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Abstract

In this introductory article to this special supplement in radiofrequency (RF), we aim to summarize the scientific foundation of RF therapy and its role in aesthetic dermatology. Monopolar, bipolar, and multipolar RF systems are described in detail, along with the different delivery methods such as stamping, dynamic or continuous movement, fractional, fractionated (FR) needling, and non-contact devices as well as the minimally invasive platforms that use subdermal probes. The characteristics of different tissues and the technical parameters that influence the effect of RF therapy, such as the penetration of energy, are summarized. This article expands on the various treatment applications for these devices and the mechanism of action behind skin and adipose tissue remodeling, and also discussed are safety concerns, treatment endpoints, and specific considerations when using RF therapy to provide effective treatment outcomes with reduced patient downtime.

KEYWORDS
aesthetic dermatology, collagen, radiofrequency, remodeling, skin laxity

1 | INTRODUCTION

In the modern era, technology has become a driving force in our society. Technological advancements in medicine have changed the way healthcare is practiced. As patients often live busy lives, there has been a push in aesthetic medicine to develop non-invasive and minimally invasive treatment modalities that offer the advantage of reduced downtime. Energy-based technologies have paved the way to meet our patient's demands, with laser platforms and other modalities such as radiofrequency (RF), ultrasound, and cryolipolysis, among others.[1]

2 | WHAT IS RADIOFREQUENCY?

Radiofrequency is a type of non-ionizing radiation within the frequency range of 30 kHz and 300 GHz, located in the low-energy end of the electromagnetic spectrum. RF therapy is a form of alternating electric current (AC current) used in aesthetic and medical energy-based devices that creates electric fields between two electrodes operating within a limited range of the RF spectrum. The charge produced at the skin's surface changes polarity from positive to negative, which results in collisions between charged molecules and ions that cause these polar molecules to vibrate at a rate of 6 million times per second.[2,3] Impedance or resistance to these vibrations is the source that generates heat in the target tissues, which receive energy transferred from the electric field.[3]

With radiofrequency equipment, energy may be delivered using conductive or capacitive coupling. Conductive coupling is known for concentrating the energy at the distal portion of the active non-coated electrode that delivers energy to the target tissue. Epidermal thermal injury can result from this type of coupling mechanism. In contrast, capacitive coupling allows the dispersal of energy across the treatment surface using an electrode with polyamide coating

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that acts as a dielectric medium, isolating its metal body from the surface of the skin.[3] This allows the formation of a capacitor that provides a uniform heat zone.[4]

3 | TYPES OF RADIOFREQUENCY SYSTEMS

Radiofrequency devices can be classified as monopolar, bipolar, or multipolar. Monopolar RF devices deliver current using a single active electrode that transmits the electromagnetic current toward a passive electrode consisting of a grounding plate, usually located at a distant body region from the active electrode (see Figure 1).[3,5] Monopolar RF systems have been shown to provide uniform volumetric heating, making these devices an effective choice when treating skin laxity.[5] However, they are often associated with increased patient discomfort compared with bipolar systems.[6]

Bipolar RF devices differ from monopolar devices because the electrical current is transferred between two positioned electrodes (see Figure 2).[4] With this configuration, no grounding plate is necessary since the current does not flow through the rest of the body. Bipolar RF devices offer a more controlled and localized energy distribution pattern because the tissue to be treated would ideally be between the two electrodes. The penetration depth of bipolar devices is influenced by the size of the electrodes and the space between them. It has been postulated that the depth of penetration is approximately half the distance between the two electrodes.[6] Therefore, bipolar RF devices offer an additional layer of control over energy penetration, and when compared with monopolar devices, they may also provide the patient with less discomfort during treatment.[6]

Today, bipolar RF devices exist in combination with multiple additional technologies. For example, bipolar RF devices may use a technology known as electro-optical synergy (ELOS). Systems that use ELOS commonly include optical energy sources such as infrared, intense pulsed light (IPL), or diode laser, among others.[4] The goal of these combination devices is to preheat the target tissues by photothermolysis, which alters the tissue impedance and susceptibility to RF. This concept then allows for lower RF energy needed to achieve

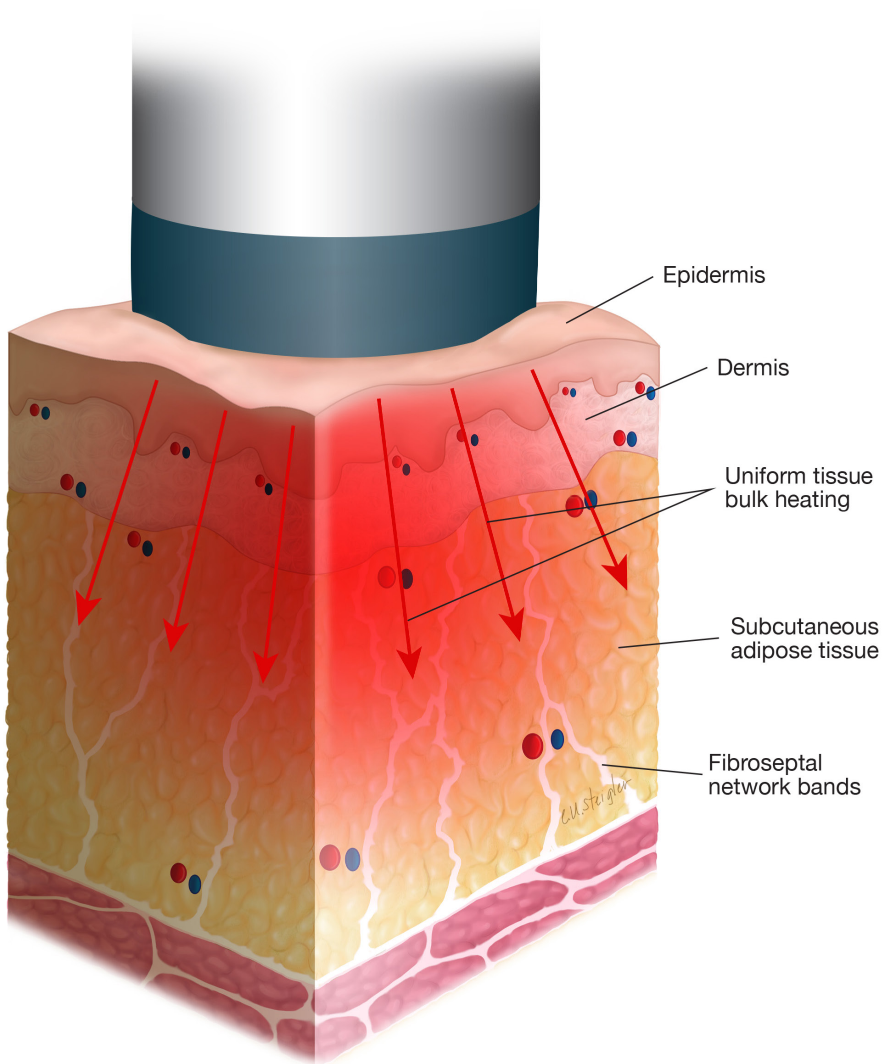

FIGURE 1 Monopolar radiofrequency devices provide uniform volumetric bulk heating of tissue, including the epidermis, dermis, and superficial subcutaneous fat. Epidermal cooling is necessary with these devices

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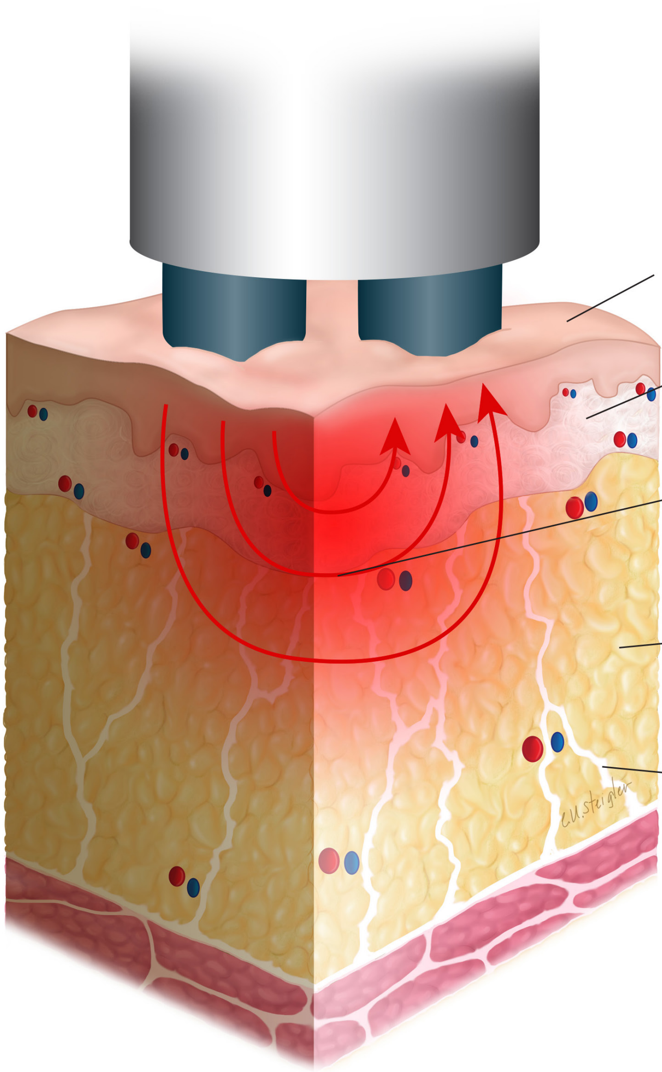

FIGURE 2 Bipolar radiofrequency devices provide shallow localized bulk heating of tissues. Epidermal cooling is necessary with these devices

appropriate heating of the target tissue, thus reducing treatment discomfort and complications.[7,8] Other modalities combined with bipolar RF are suction-controlled current output and vacuum therapy. These devices essentially use suction to fold the skin and allow for a more homogenous contact with the device. Therefore, it provides appropriate heat distribution with greater control of current delivery, which along with optical devices, further allows for lower RF energies needed, decreasing treatment discomfort and associated adverse events.

Multipolar RF devices typically use three or more electrodes (see Figure 3), where one acts as the positive pole while the rest act as negative poles. With this configuration, the current flowing through the positive pole is a summation of the current flowing through the other negative poles. Note that each electrode acts as the positive pole for a short period before becoming a negative pole; this current modulation aids in preventing overheating of the positive pole and subsequent thermal injury to the tissue being treated.[9] Multipolar devices may also employ features such as pulsed electromagnetic fields to improve outcomes.

4 | RADIOFREQUENCY TREATMENT CHARACTERISTICS

Several parameters may influence treatment regimens with RF devices. Penetration depth is a parameter commonly used in laser dermatology to refer to the distance below the heated skin. In radiofrequency, the effect depth is defined by the attenuation of applied energy with the depth.[10] RF energy is decreased with increasing distance from the active electrode due to current divergence. In contrast, optical energy is attenuated with distance due to scattering and absorption.[10] Other factors influencing penetration depth are skin topology and electrode system optimization.[10] Frequency and wavelength are the two additional components of electromagnetic energy that can alter penetration depth. At lower frequencies or larger wavelengths, penetration depth increases, whereas, at higher frequencies or smaller wavelengths, penetration depth would be decreased. The power is transferred swiftly near the surface at higher frequencies, and the wave is then attenuated deeper within the tissue. In contrast, at lower frequencies,

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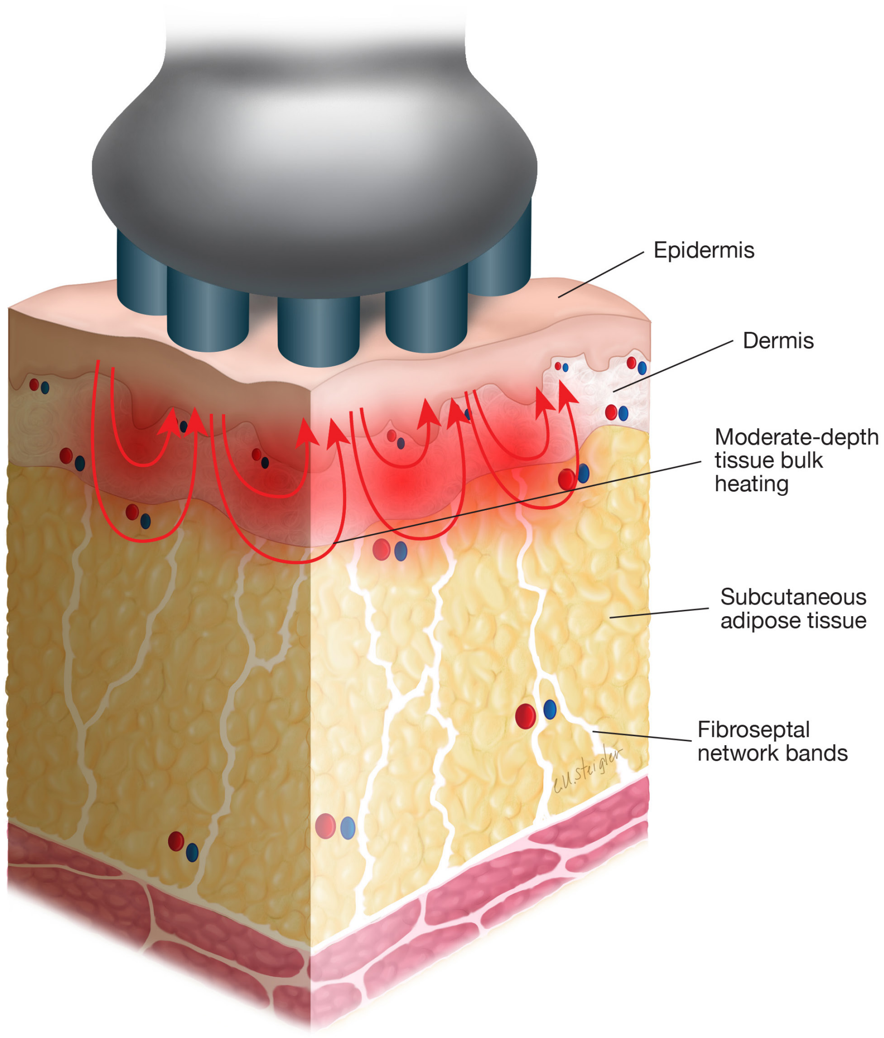

FIGURE 3 Multipolar radiofrequency devices use three or more electrodes to deliver heat deeper than bipolar modalities by creating multiple electrical fields, minimizing the need for epidermal cooling

the larger wavelength can penetrate deeper into the tissue and provide "bulk" tissue heating, where the heating cannot be localized to a focal area.[11]

Tissue characteristics and anatomical structures can also influence the penetration depth of RF. For example, bone tissue has low conductivity, limiting penetration depth when treating over bone. Studies have measured in vitro conductivities at 1MHz on different biological tissues, resulting in blood having the highest conductivity, followed by wet skin, dry skin, and fat, with bone tissue having the lowest conductivity.[10] Although tissues may have significantly different conductivities in vitro, these are less remarkable in vivo. This observation is explained by the presence of a vascular network, connective tissue matrix, and intercellular liquids in some tissues, such as in the adipose layer, that may provide enhanced conductivity. Fundamentally, tissues with higher water and blood content have higher conductivity. Accordingly, this becomes clinically relevant when using tumescent anesthesia, which may significantly increase tissue conductivity by increasing water and salt content.[10]

As with penetration depth, conductivity can vary in specific tissues with frequency and may also be influenced by temperature. The conductivity of the skin increases as a strong function of frequency from 100 kHz to 1 MHz; at higher frequencies, there is a weak increase. Fat conductivity is relatively flat across the frequency ranges utilized in medicine. Temperature is a factor that influences impedance and, therefore, conductivity. Tissue warming to the point of coagulation decreases the viscosity of the tissue along with its impedance, rendering the tissue being treated more conductible.[10]

5 | RADIOFREQUENCY DELIVERY

Radiofrequency may be delivered in various ways, including stamping, dynamic or continuous movement, fractional, fractionated (FR) needling, non-contact or "hands-free," and by using subdermal probes. Stamping is a term used to describe the static delivery of RF. It is often seen with monopolar devices and delivers a single short pulse of energy when the handpiece is in contact with the tissue to be treated. Stamping requires the operator to move the handpiece to an adjacent area to be treated after firing each pulse. This technique can be slow, but it does not have a steep learning curve, and there are built-in mechanisms that measure the temperature of the skin and maintain it below 45°C using spray cooling.[12]

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With dynamic systems, the handpiece is continuously moved over the areas of laxity to be treated. These devices also have continuous surface temperature monitoring, and treatment sessions are quicker than with the stamping method; however, it demands more technique and skill from the operator.

Fractional devices can deliver RF in a bipolar fashion through needles (FR needling) or electrodes (see Figure 4). The goal is to deliver a thermal injury to the subdermal layer while leaving “islands” of untreated tissue intact between the treated areas. Similar to fractionated laser resurfacing, this helps accelerate the process of recovery. FR needling works by having the needle tips carry a positive charge while the faceplate of the disposable handpiece carries a negative charge. This configuration is popular since it combines the ability to deliver thermal injury deep in the subdermis with the mechanical puncture effect of the needles, which has been shown to improve skin texture and laxity on its own.[4,13] However, not all FR needling devices are equal, and different types of needles can be used. Non-insulated microneedles deliver energy throughout the length of the needle, whereas insulated microneedles deliver energy only at the tip of the needle in the dermis or subdermis, which adds an extra layer of thermal protection to the epidermis.[14]

Another type of RF delivery is seen in multipolar non-contact RF devices (see Figure 5). These are usually not operator dependent and are engineered to selectively deliver energy to the target tissue layer (e.g., adipose tissue) with specific impedance. This mechanism may prove beneficial as it limits energy delivery to the epidermis, dermis, and muscle while providing favorable outcomes in a non-invasive manner.[12]

The desire for optimal and more noticeable outcomes has given rise to minimally invasive devices that use subdermal probes to deliver RF energy (see Figure 6). These bipolar systems consist of internal positive and external negative electrodes. The RF current flows up from the internal to the external electrode, which glides along the epidermal surface in tandem with the internal electrode. This internal probe coagulates subcutaneous adipose tissue adjacent to the electrode in the superficial subdermal space. As energy moves up to the external electrode, it dissipates and provides a gentle thermal effect on the papillary dermis. As a result, these devices can achieve non-coagulative thermal changes in the dermis, and coagulative thermal necrosis at the lower 30% of the reticular dermis, along with disruption of adipocytes, blood vessel coagulation, and contraction of the deep fibroseptal network

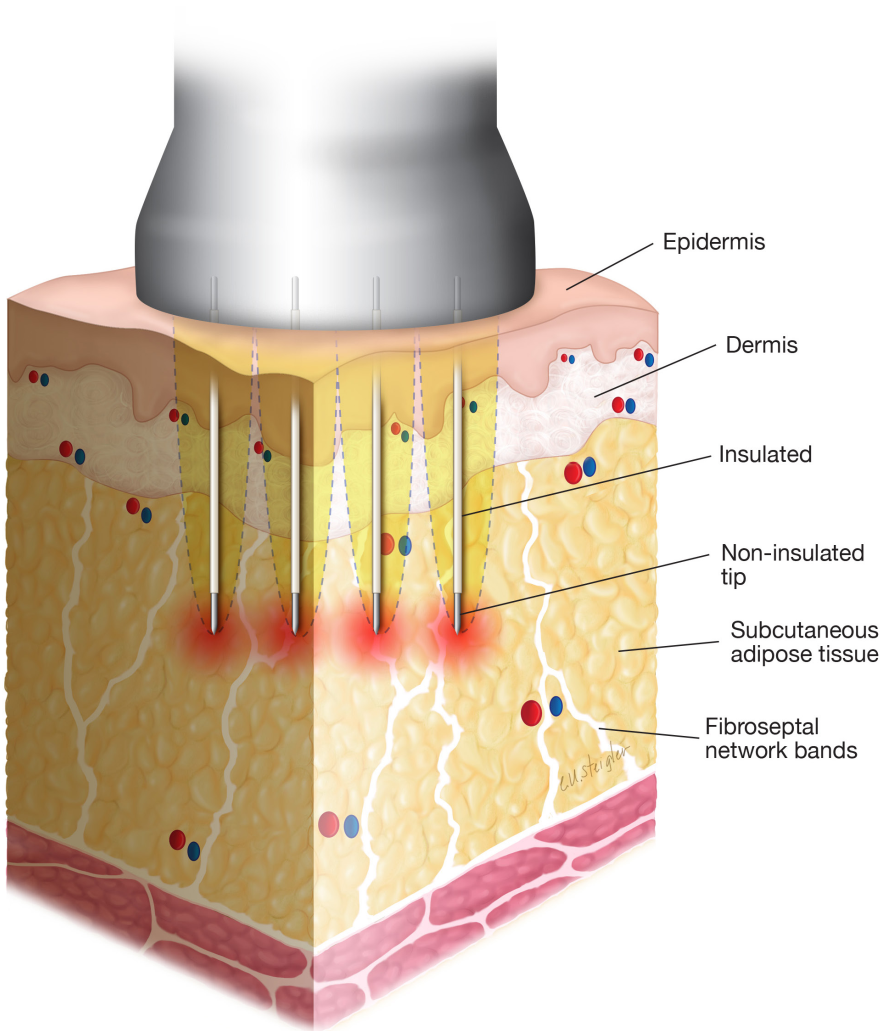

FIGURE 4 Fractionated needling may be used for radiofrequency delivery, providing an additional mechanical component for tissue remodeling. Microneedles may be non-insulated or insulated for epidermal thermal protection; epidermal cooling is necessary with the former. Depth of treatment may vary with microneedle length

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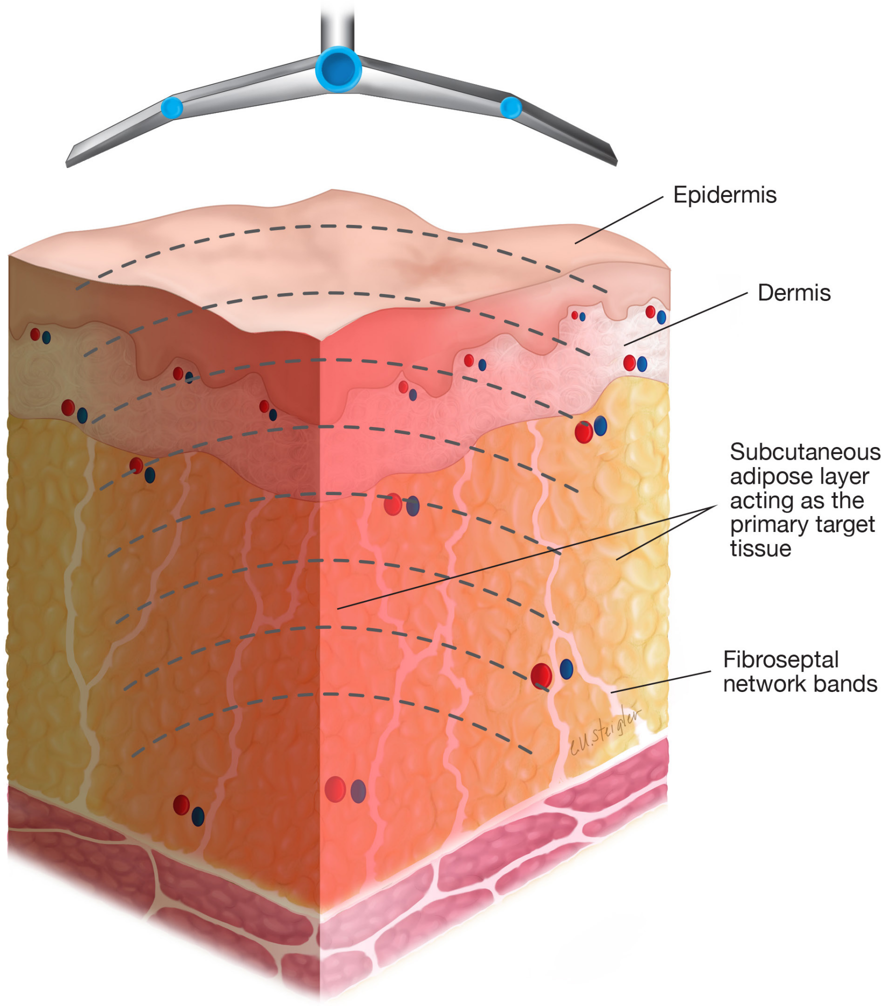

FIGURE 5 Non-contact radiofrequency devices selectively deliver thermal energy, with the adipose tissue layer being a common target

bands.[15] These sophisticated bipolar devices are also equipped with temperature-regulating sensors with safety mechanisms for patient protection.

6 | RADIOFREQUENCY MECHANISM OF ACTION

As briefly stated above, radiofrequency's mechanism of action on tissues is best explained at the atomic and molecular levels. The transfer of energy from the electric field to the charges in the material occurs through three mechanisms: a) orientation of electric dipoles that already exist in the atoms and molecules in the tissue; b) polarization of atoms and molecules to produce dipole moments; and c) displacement of conduction electrons and ions in the tissue.[11]

The main protagonists in the multifactorial skin aging process are loss of volume, skin laxity, and rhytids (see Figure 7). Clever breakthrough technologies have been developed, such as laser systems, that target chromophores through selective photothermolysis. However, certain laser wavelengths may present a challenge when treating darker skin phototypes, with post-inflammatory hyperpigmentation (PIH) as an unfavorable outcome. Although PIH can also be a consequence of RF treatment, the impact on melanin is less because these devices do not depend on selective photothermolysis but rather on non-selective tissue heating.[12,14] Therefore, RF can present as a safe and effective treatment choice for all skin phototypes, especially V-VI.[16]

7 | TISSUE TARGETS AND APPLICATIONS FOR RADIOFREQUENCY TREATMENT

RF treatment effect is a function of temperature and time. The Arrhenius equation (1) can better explain this, where time/pulse duration is a pre-exponential factor and temperature is an exponential factor:

$$D = At\,exp\left(\frac{-\Delta E}{RT}\right) \tag{1}$$

This equation explains how the degree of damage is a linear function of pulse duration and an exponential factor of tissue temperature. Therefore, tissue temperature is more influential on the

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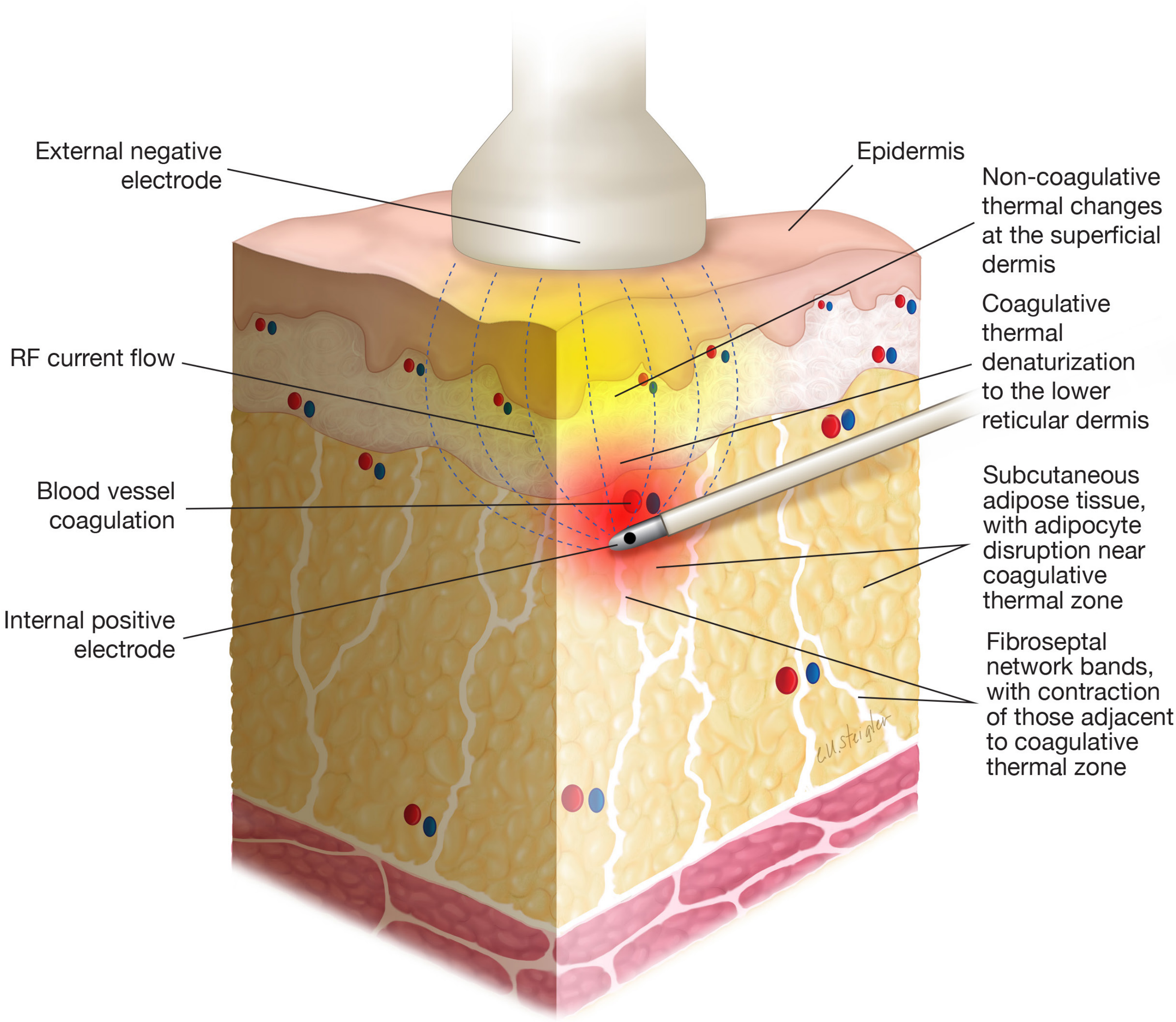

FIGURE 6 Radiofrequency devices using minimally invasive subdermal probes provide thermal changes to superficial and deep tissue structures for optimal and significant outcomes. A coagulative thermal zone immediately surrounds the positive electrode

treatment effect or the degree of damage than the pulse duration. Pulse duration is a critical parameter in RF therapy because timing influences the thermo-chemical process in tissues. Energy dissipation away from the treatment zone is another effect of pulse duration, and it is due to heat conductivity from the target area to the surrounding tissue.[17]

Because RF energy may be delivered through different tissues, such as skin, fat, and muscle, this technology has multiple applications. One of the most common applications of RF is in the treatment of skin laxity by decreasing the distention of the loose connective tissue through collagen denaturation (see Figure 8). Fibroblasts synthesize collagen, a triple helical structure composed of polypeptide chains. Thermal energy causes denaturation of the triple helix, which leads to tissue retraction, disrupting the crystalline structure by breaking the intermolecular hydrogen bonds.[3,9] Temperatures of 85°C for one millisecond or 67°C for three seconds are sufficient to produce structural changes to collagen.[3] However, to prevent adverse effects such as skin burning, several authors recommend the longer exposure times of three to five minutes with lower temperatures of 43°C.[3]

The typical sequence of tissue response to temperature increase, as reported by Kreindel and Mulholland, is as follows. 37–44°C: acceleration of metabolism and other natural processes. 45–50°C: conformational changes in proteins, including collagen; hyperthermic cell death. 50–80°C: coagulation of soft tissue; collagen contraction. 90–100°C: formation of extracellular vacuoles; evaporation of liquids. >100°C: thermal ablation; carbonization.

Thermal energy delivered through precise time and temperature calculations induces fibroblasts to activate neocollagenesis. This process, which leads to an increase in collagen types I and III in the

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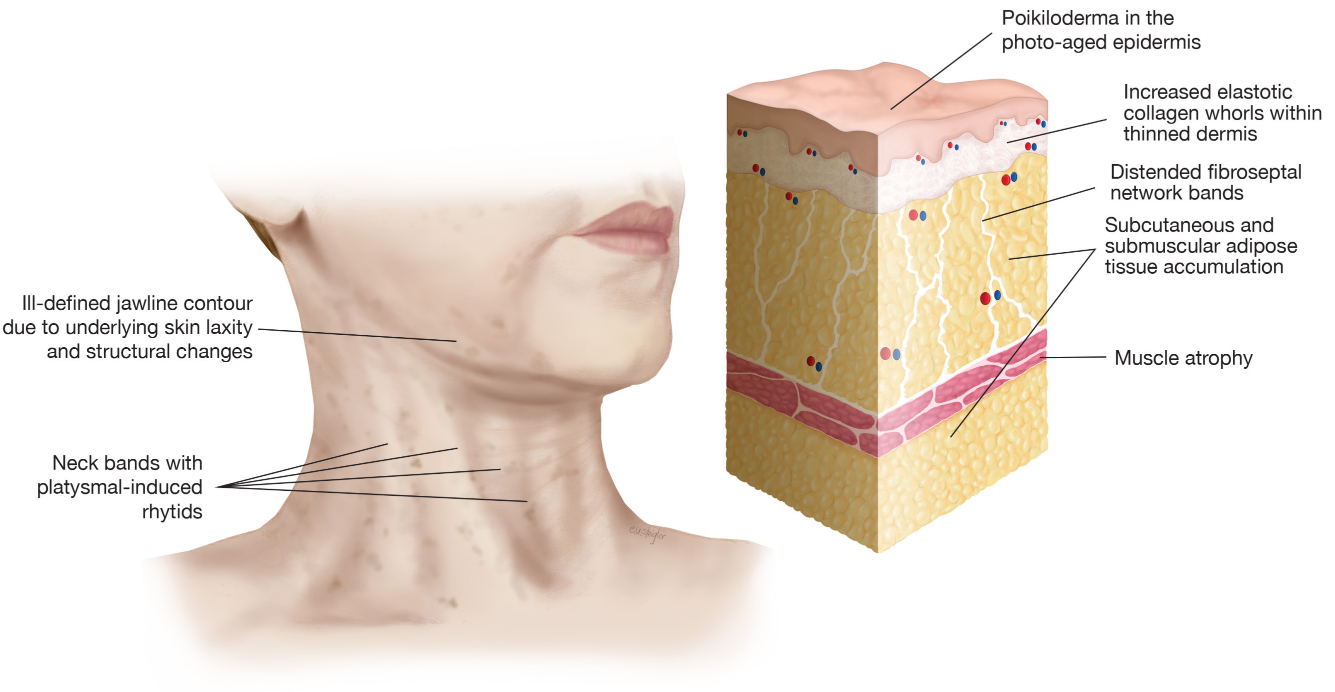

FIGURE 7 Characteristic changes of the skin aging process. With aging and years of environmental insults, the skin and underlying tissues undergo detrimental changes such as poikiloderma, rhytids, and loss of connective tissue elasticity. These are often most apparent in the head and neck areas

dermis, occurs in a three-dimensional form and continues for up to three months after treatment.[3] This type of progression is due to the RF current's modulating effect on specific sirtuin genes (SIRT), such as upregulating SIRT6 while downregulating SIRT1, 3, 5, and 7. The result of this gene modulation process is neocollagenesis and increased fibroblast longevity.[9] Several physiologic responses to thermal energy also affect collagen remodeling. The heat generated by the RF current stimulates heat shock protein (HSP) synthesis in the fibroblast, with subsequent expression of TGF-β1, which stimulates HSP-47 and HSP-72 to promote increased collagen production by fibroblasts. These two specific HSPs protect type I collagen during its synthesis.[3]

Focal reduction of adipose tissue is another popular use for RF therapy. Thermal stimulation of adipose tissue is thought to lead to apoptosis of adipocytes, stimulation of adipocyte metabolism, and increased activity of lipase-mediated enzymatic degradation of triglycerides into free fatty acids and glycerol.[11,12] Therefore, treatment of fat deposits with RF therapy can be used to effectively reduce the circumference of body areas such as the thighs, upper arms, abdomen, and flanks.[18]

Treatment of cellulite, the dimpled appearance of the skin caused by fatty deposits trapped and tethered between dermal fibrous septae, can also be achieved with RF therapy. RF bipolar devices that combine infrared light with suction and massage have been shown to improve the appearance of cellulite. Researchers hypothesize that this is achieved due to increased circulation, stimulation of adipocyte metabolism, and mechanical stretching of the fibrous cords.[19]

8 | SAFETY CONSIDERATIONS

Although RF platforms offer reduced downtime with their non-invasive and minimally invasive approaches, there are risks associated with these devices that should be considered. Furthermore, RF therapy is often contraindicated in patients with pacemakers and implantable cardioverter-defibrillators (ICDs) due to the potential risk of device interference. Therefore, appropriate patient education and screening are essential.

Complications should also be separated from expected sequelae presenting as side effects from RF therapy. Most of the side effects associated with RF devices have a thermal component. Therefore, these systems often include various safety features that monitor RF energy, tissue impedance, electrode coupling, and skin surface temperature to minimize risks. Unfortunately, tissue overheating may occur and is often connected to an overdose of RF energy and hot spots created due to the non-uniform application of RF energy. Skin overheating can appear sequentially as erythema, edema, blistering, full-thickness skin burn, and charring with eschar.[10] Erythema and edema are short-term reactions that usually dissipate after 30 min but may persist up to 24 h following treatment; for many treatment modalities, these may be endpoints that the operator wishes to see.[10] Poor technique, improper parameters, and variable patient sensitivity may lead to poor outcomes and possible side effects.

There are general recommendations to minimize the risk of adverse events during RF treatment. The recommendations are as follows: (1) Use test spots in less visible areas to determine how the skin will react, (2) Start with lower settings, gradually increasing the

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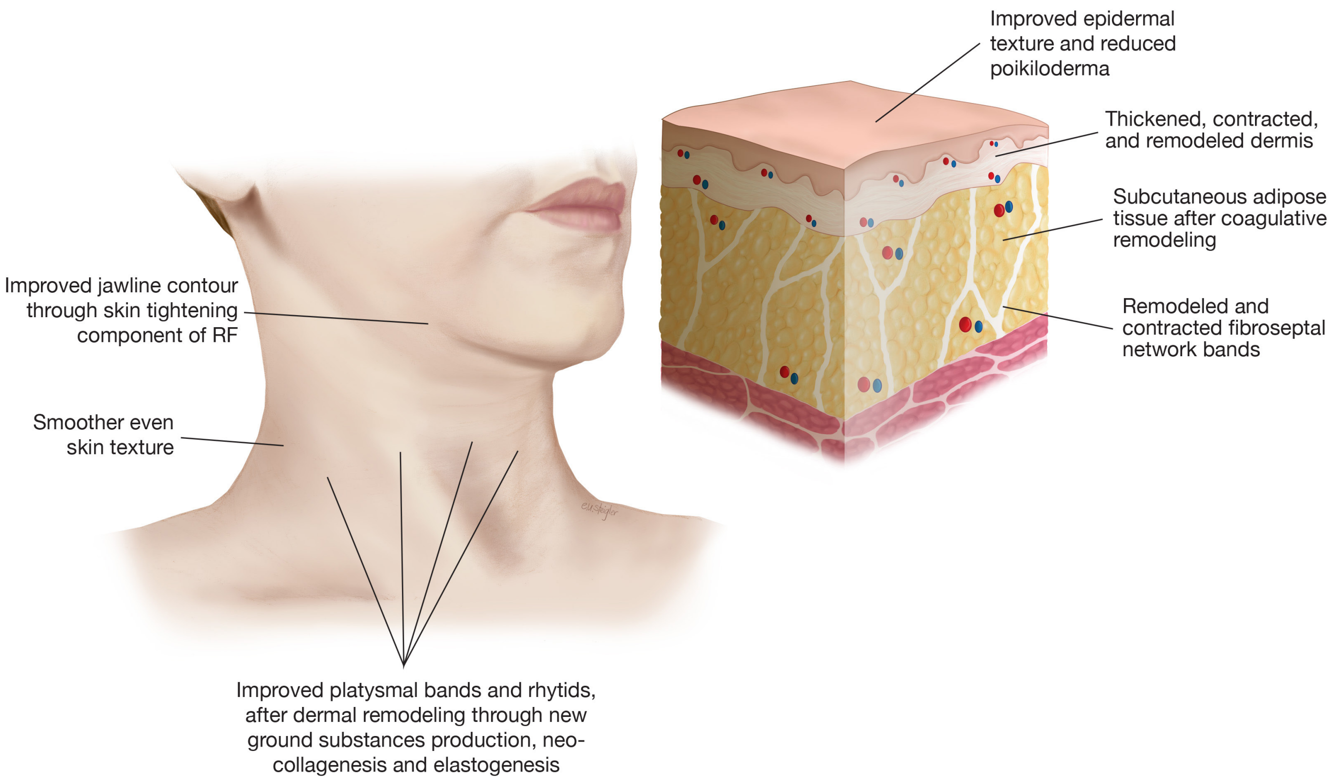

FIGURE 8 Following radiofrequency treatment, changes in the skin lead to clinically evident remodeling of epidermal, dermal, and subcutaneous tissue layers

energy to optimal/advanced parameters, (3) Use lower settings on small zones, bone prominences, and high curvature areas, (4) Always observe the immediate skin reaction, (5) Stop the treatment when there is any concerning indication and reassess treatment continuation, and (6) Do not rush the treatment.[10]

9 | CONCLUSIONS

Every patient is different, and effectively delivering safe treatments with energy-based devices such as RF systems requires the operator to have a full breadth of knowledge and mastery of the devices available. The operator can then develop a patient-specific treatment plan and adjust parameters appropriately to achieve effective outcomes while reducing potential adverse events when using these non-invasive or minimally invasive RF devices. In addition, RF therapy is continuously evolving with the development of new devices and technologies that will provide the patient with more treatment options that are safe, effective, and ideal when considering aesthetic dermatology procedures with downtimes that fit into their schedules.

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CONFLICT OF INTEREST

Dr. Delgado has no relevant conflicts of interest to declare. Dr. Chapas is a research investigator for InMode MD Ltd.

ETHICAL APPROVAL

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DATA AVAILABILITY STATEMENT

Data sharing is not applicable to this article as no new data were created or analyzed in this study.

ORCID

Axel R. Delgado https://orcid.org/0000-0002-9224-594X
Anne Chapas https://orcid.org/0000-0003-2840-9994

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