

Cutaneous Remodeling From a Radiofrequency Perspective

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Radio frequency (RF) is electromagnetic radiation in the 3-kHz to 300-GHz frequency range. The primary effects of RF energy on living tissue are considered to be thermal. The goal of new devices based on this frequency range is to heat specific layers of the skin. Directed use of RF can induce dermal heating and cause collagen degeneration. Wound-healing mechanisms promote remodeling of collagen and wound contraction, ultimately clinically enhancing the appearance of mild to moderate skin laxity. Preliminary studies have reported efficacy in tightening skin laxity of the periorbital area and jowls. Because RF energy is not dependent on specific chromophore interaction, epidermal melanin is not at risk of destruction, and treatment of all skin types is possible. As such, RF systems have been used successfully for nonablative skin rejuvenation, atrophic scar revision, and removing unwanted hair, vascular lesions, and inflammatory acne. The use of RF systems is becoming more popular, although misunderstanding about its mechanisms and limitations remains. This review serves as an introduction and guide to many aspects of using RF in nonablative skin rejuvenation.

Because of the high demand for antiaging treatments over the past decade, a proliferation of laser- and light-based systems has been developed. Nonablative systems have replaced traditional ablative systems, such as CO₂ and erbium:YAG lasers (long considered the standards for skin resurfacing), because nonablative systems induce dermal neocollagenesis without epidermal disruption, thereby limiting adverse effects and virtually eliminating postoperative recovery.¹⁻⁹ However, only modest success has been reported with most nonablative systems. Radiofrequency (RF) systems have been introduced to address this shortcoming and provide the added benefit of tissue tightening.¹⁰⁻¹⁸

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RF IN MEDICINE

RF energy has become increasingly popular for tissue-heating applications in such fields as general surgery, cardiology, neurology, orthopedics, and dermatology. It has been used for more than a century for many medical applications, including tissue electrodesiccation and electrocoagulation,¹⁹ joint capsular tightening,^{20,21} corneal curvature alteration, incompetent saphenous venous closure,²² aberrant cardiac electroconductive ablation,^{23,24} and prostate and liver neoplasm eradication.²⁵ RF energy delivers heat to dermal structures, resulting in nonsurgical lifting and tightening of tissue without disruption of epidermal integrity.²⁶

RF: THE BASICS

RF current is formed when charged particles flow through a closed circuit. As the energy meets resistance in the tissue, heat is produced. The amount of heat varies with the amount of current, the resistance levels in the targeted tissue, and the characteristics of the electrodes. Human tissues, including the skin, are rich in electrolytes and an array of compounds allowing current conductance with

varying degrees of impedance and resulting heat formation. The amount of RF energy applied can be configured to target specific tissues. In addition, the water content of skin varies among different areas of the body and with time of day, environmental humidity, internal hydration, and use of topical moisturizing agents. Thus, the flow of RF energy through the skin depends on multiple factors that may not be uniform between treatment areas. This reaction is dictated by the following formula: $J = I^2 \times R \times T$, where J indicates energy, I indicates current, R indicates tissue impedance, and T indicates time of application. High-impedance tissue, such as subcutaneous fat, generates greater heat and accounts for the deeper thermal effects of RF systems.²⁷

MICROSCOPIC RF COLLAGEN DENATURATION TECHNIQUE

An underlying network of collagen and elastin fibers provides scaffolding for the skin and determines its degree of firmness and elasticity. Over time, this intricate fiber network loosens and unravels, altering the appearance and function of the skin. Adult skin is estimated to lose approximately 1% of its dermal collagen content annually because of increased collagen degradation and decreased collagen synthesis.²⁸

RF collagen denaturation targets microscopic tissue sites within the luminal wall at which the temperature rises to produce focal areas of microscopic collagen denaturation while avoiding tissue necrosis.

Collagen exists in a triple-helical form wherein the peptide chains are stabilized by hydrogen bonds that have been established. Thermal denaturation and shrinkage of collagen occur when collagen is heated above 60°C. When collagen fibers are heated, some of the cross-links are broken, causing the triple-helical structure to unwind. Beyond a certain level, depending on a combination of both the maximal temperature and the exposure time, collagen fibers undergo denaturation. When the cross-links are maintained, at least partially, collagen shrinkage and thickening are achieved.²⁹ The potential for maximal collagen denaturation is dependant on (1) the type of tissue targeted (based on collagen density and concentration; targeting periorbital tissue is different from targeting thickened abdominal tissue), (2) the directed temperature, and (3) the targeted time duration.

POSTDENATURATION TIGHTENING EFFECTS

Based on the principle of thermal tightening, treatments are designed to shrink dermal collagen using RF current-generated heat. In addition, treatments promote formation of new collagen via the natural wound-healing

response of the skin and a direct effect on the dermal cellular matrix. The extent of collagen shrinkage, fibroblast activation, fibroplasia, and overall collagenesis in the different skin layers is based on a complex multivariate mechanism, which depends on temperature distribution and timing. This mechanism of tightening enables shrinkage at a certain depth, followed by collagenesis at a different, preferably more superficial, layer. Mechanical stress (eg, vacuum) has been reported to stimulate fibroblasts, leading to collagenesis. Notably, both heat exposure and application of vacuum to the skin are also known to increase blood perfusion in the affected area, supporting fibroblast activity and the overall rejuvenation process.³⁰

ELECTRODE CONFIGURATION

Two major electrode configurations are available in RF systems: monopolar and bipolar. Each differs in its derived energy field, but the resultant energy-tissue interaction is similar. In both configurations, under controlled conditions, the tissues, not the electrodes, become hot. In a monopolar configuration, one electrode is active and the other (much larger) is placed far from the first, serving as a grounding pad. The main advantages of monopolar delivery are the concentration of a high-power density on the surface of the electrodes and the relatively deep penetration of the emitted power, making this configuration more suitable for electrosurgery. However, relatively high pain levels and safety concerns may be associated with this configuration for dermatologic applications. In a bipolar configuration, the current flows between 2 identical electrodes that are set a small fixed distance apart. No grounding pad is necessary. That the distribution of current in the tissue is more controlled in this setting is a major advantage over a monopolar configuration. However, in a bipolar system wherein the electrodes are placed flush on the skin, the configuration is disadvantageous: the depth of penetration is limited to approximately half the distance between the electrodes. This means that less energy of sufficient density reaches the deeper structures, rendering a more superficial effect regardless of the emitted energy level.³¹

Both monopolar and bipolar RF systems have been used for cutaneous applications. Monopolar systems deliver current through a single contact point, with an accompanying grounding pad serving as a low-resistance path for current flow to complete the electrical circuit. Monopolar electrodes concentrate most of their energy near the point of contact; energy diminishes rapidly as the current flows toward the grounding electrode. Bipolar systems pass electrical current only between 2 positioned electrodes applied to the skin. No grounding pad is necessary, because no current flows throughout the rest of

the body. Monopolar systems, such as the ablative Visage and the nonablative ThermoCool NXT TC, and bipolar systems, such as the Aurora and Polaris, have shown clinical utility within aesthetic medicine for reducing rhytides, tightening excessive facial laxity, treating leg telangiectasias and acne, and removing unwanted hair. In particular, these systems have proven to be effective in reducing brow ptosis and prominent melolabial folds, as well as tightening cheek laxity.²⁻⁵

MONOPOLAR RF SYSTEMS

Nonablative systems deliver RF energy to the skin with concomitant contact cooling and are approved by the US Food and Drug Administration for the noninvasive reduction of facial rhytides. These systems use a high-frequency generator producing a 330-W, 6-MHz monopolar current signal. A disposable membrane tip encompassing a 1- or 1.5-cm² treatment area is used with a disposable adhesive return pad serving as the grounding point. The depth of heating depends on the size and geometry of the treatment tip being used. A conductive coupling fluid is used during treatment to enhance thermal and electrical contact between the treatment tip and the skin.³² This patented capacitive membrane tip allows delivery of deep volumes of sustained, uniform, and intense heat to a 3- to 6-mm tissue depth. The treatment tip creates an electrical field within the tissue by alternating its charge from positive to negative 6 million times per second, with electrons and ions simultaneously attracted to and repelled from the surface. According to Ohm's law, it is the resistance of the tissue to the movement of these ions that generates heat.³³

Transmission electron microscopy studies have shown immediate heating results in collagen denaturation, with resultant fibril contraction and tissue thickening.³² An inflammatory wound-healing response ensues, with long-term neocollagenesis effecting rhytide reduction and further tissue contraction. In addition, selective heating and tightening of fibrous septae within the subcutaneous layer likely account for immediate posttreatment contour changes in the skin.³³ Skin surface cooling is maintained before, during, and after RF delivery via a cryogen gas-spray device. A balance of deep tissue heating and surface cooling is therefore produced with creation of a reverse thermal gradient; the most intense heat is delivered deep within the dermis and subcutaneous layer, whereas the surface layers remain relatively unaffected by thermal delivery.

Several recent reports have demonstrated the safety and efficacy of RF delivery for reducing rhytides and tightening lax facial and neck skin. Fitzpatrick et al,¹¹ in the largest study to date, demonstrated improvement in

83.2% (99 of 119) of periorbital rhytides and brow elevation of the patients enrolled. Fifty percent (41 of 82) of patients for whom treatment satisfaction data were available at 6 months were satisfied with the outcome; on photographic evaluation, 61.5% (40 of 65) of eyebrows were lifted by approximately 0.5 mm.

In another study, Kist et al¹² treated 3 subjects in the preauricular region with the RF system using single or multiple passes (3 or 5) in the same 1.5-cm² treatment area with a slight delay between passes to allow tissue cooling. Biopsies from each treatment area and a control biopsy were taken immediately, 24 hours, or 6 months posttreatment for electron microscopic examination. Sections were examined by 2 blinded observers. The morphology and degree of collagen change in relation to the area examined were compared with the control tissue and estimated using a quantitative scale. The ultrastructural examination of tissue showed that an increased amount of collagen fibril changes with increasing passes at energies of 97 J (3 passes) and 122 J (5 passes). The changes seen after 5 multiple passes were similar to those seen after much more painful single-pass, high-energy treatments. The study demonstrated that similar collagen fibril alteration can occur with multiple-pass, low-energy treatments and single-pulse, high-energy treatments. However, the lower-fluence, multiple-pass approach is associated with less patient discomfort, fewer side effects, and more consistent clinical results.

A study by Kushikata et al¹⁷ showed gradual improvement in lower-cheek jowling and nasolabial folds after a single treatment with RF energy. Most of the 85 patients treated reported high satisfaction rates for the jowls (79.3%), marionette lines (67.1%), and nasolabial folds (76.3%) at 3 months, but the scores dipped slightly 6 months posttreatment. The authors surmised that for enhanced clinical results, re-treatments would best be performed within 5 to 6 months after the original treatment session. Also, the authors noted that energy-level selection with the system is best determined by constantly evaluating each patient's level of pain tolerance during the procedure. It should be noted that different skin types have different resistance and will therefore directly affect the penetration and thermal deposition within tissues.

A promising use of RF energy in rejuvenating the eyelids has been investigated.³⁴ Although the study used a relatively small sample of patients, the authors reported continuous improvement posttreatment.

Moderate to severe acne vulgaris has been targeted by RF studies.³⁵ In one study, 22 patients received 1 or 2 RF treatment sessions with a dual benefit: reductions in both atrophic scarring and active cystic lesions were noted. The authors hypothesized that RF delivery not only

stimulated dermal remodeling, resulting in scar reduction, but also directly inhibited sebaceous gland activity to improve acne. A study by Prieto et al³⁶ evaluated the efficacy of Aurora AC, a system delivering light and RF by electro-optical synergy (ELOS). The study demonstrated a reduction in acne lesion count, as well as the percentage of follicles with perifolliculitis and the sebaceous glands. The results of both studies suggest that RF energy is a promising nonablative alternative for treating acne. Insufficient information is available to explain the exact mechanism of action; however, RF systems are believed to cause destruction of bacterial porphyrins by pulsed light, as well as thermolysis of sebaceous glands by both light and RF energy.³⁷

GUIDELINES FOR DELIVERING RF TREATMENT

Recommended treatment algorithms with RF systems have changed significantly since the technology was introduced to the medical marketplace in 2004. Initially, patients were treated with a single pass of an RF system at high-energy settings, often resulting in mixed clinical results and significant patient discomfort. Newer treatment guidelines using a multiple-pass technique with reduced-energy settings have been proposed, effecting superior clinical and histologic results, as well as significant reduction in patient discomfort.^{15,32} Although most practitioners initially delivered 100 to 150 pulses to the entire face and neck, current guidelines advocate using more than 400 pulses for the same areas. Patient feedback regarding tolerability is vital during treatment to avoid excessive thermal delivery to the skin. Although topical anesthetic preparations and oral anxiolytics help intraoperatively, caution should be used with general anesthesia because of reduced subjective patient feedback, which may increase the risk of epidermal injury and subsequent thermal burns.³²

Most patients experience mild erythema and edema, but these adverse effects usually subside within a few hours posttreatment. There have been isolated reports of vesiculation and superficial burns after RF treatment, which have been attributed to operator error or using high-energy settings. Although tightening of skin laxity is not as pronounced as that observed with surgical lifting procedures, the advantages of RF treatment include virtually nonexistent postoperative recovery and an extraordinarily low risk of serious adverse effects. Patients should be counseled preoperatively regarding the potentially modest results of the treatment despite the significant skin tightening caused by collagen contraction and tissue edema often observed immediately posttreatment.

COMBINED RF AND OPTICAL ENERGIES

ELOS, a unique combination of RF and optical energies, has emerged to address the limitations of traditional light-based systems.¹⁶ Using optical-based systems alone for skin rejuvenation and rhytide reduction has presented several challenges because tissue scatter and melanin absorption significantly decrease light penetration within the skin. Higher treatment energies are therefore required to adequately target dermal structures, which in turn increase the risk of integumentary injury and adverse effects. This dual-energy system has been used for treating photorejuvenation, leg telangiectasias, acne, and sebaceous hyperplasia, as well as for removing unwanted hair. A synergistic effect is obtained when the light energy component is used to heat the target tissue, which lowers the impedance of that tissue. The RF component used this lowered impedance to selectively heat the desired target. This synergy allows lower levels of both types of energy to be used, thus minimizing adverse effects such as blistering, burns, and inflammatory nodules.³⁸ Two ELOS systems, the Aurora and Polaris, are available to treat a number of clinical applications. Derivatives of the Aurora are the Comet, the Galaxy, and the Pitanga. Table 1 lists available ELOS systems.

One dual-energy system is the Aurora SR, which uses intense pulsed light as its optical energy source, with emissions from 400 to 980 nm, 580 to 980 nm, and 680 to 980 nm. The optical energy preheats dermal structures, creating a temperature difference between the targeted structures and the surrounding tissues. It is used for skin rejuvenation, including rhytide reduction and improvement in skin texture and tone. Patients typically undergo 3 or 4 treatment sessions at 3- to 4-week intervals for rejuvenation. The system may also be used for treating facial acne and removing unwanted hair.^{39,40}

TABLE 1

ELOS Systems Available in 2008

System	Type
Aurora	Intense pulsed light/RF
Comet	Diode/RF
Galaxy	Intense pulsed light/RF
Pitanga	Intense pulsed light/RF
Polaris	Diode/RF

Abbreviations: ELOS, electro-optical synergy; RF, radiofrequency.

TABLE 2

Specifications of the Aurora and Polaris Systems

Parameter	Aurora	Polaris
Clinical applications	Acne Skin rejuvenation Removal of unwanted hair	Wrinkle reduction Removal of unwanted hair Telangiectasias/vascular lesion treatment
RF energy	5–25 J/cm ³	≤100 J/cm ³
Energy source	Intense pulsed light	900-nm diode
Setting	480–980 nm (acne) 580–980 nm (skin rejuvenation) 680–980 nm (removal of unwanted hair)	NA NA NA
Fluence	10–45 J/cm ²	≤50 J/cm ² (wrinkle reduction) ≤140 J/cm ² (telangiectasias/vascular lesion treatment)
Skin-surface cooling	5°C–20°C	5°C
Spot size	12×25 mm	8×12 mm
Pulse repetition rate	0.7 pps	2 pps

Abbreviations: NA, not available; pps, pulse per second; RF, radiofrequency.

It has been approved by the US Food and Drug Administration for removing unwanted hair and for treating vascular and pigmented lesions. The system is also reported to remove lightly pigmented and white hairs because it does not rely solely on melanin absorption for target destruction.

Another dual-energy system using ELOS technology is the Polaris WR, a 900-nm diode laser with an RF energy device. Optical energies are delivered through a bipolar electrode tip with fluences ranging from 10 to 50 J/cm² and RF energies of 10 to 100 J/cm³. These energies are simultaneously delivered to the tissue, and whereas the RF energy penetrates more deeply and stimulates collagen production, the diode laser addresses superficial rhytides, pigmentation, and vascularity. The 2 energies therefore work synergistically to treat deep wrinkles, as well as the more superficial signs of photoaging.¹⁴ See Table 2 for a comparison of the specifications of the Aurora and Polaris systems.

A recent study by Doshi and Alster¹⁸ was the first to evaluate the dual-energy Polaris WR RF/diode laser system for reducing wrinkles and tightening skin laxity. Multiple laser passes were performed at each session and were well tolerated. Evaluations 6 months posttreatment demonstrated modest improvements in wrinkles in most of the patients treated. Periorbital rhytides displayed

greater improvements than perioral rhytides in mean clinical scores by the end of the study. There were no significant adverse effects; 80% of the patients reported only mild treatment-associated discomfort.

SUMMARY

Nonablative skin rejuvenation with RF systems produces skin tightening through controlled dermal collagen contraction and neocollagenesis without integumentary injury. This nonsurgical approach to rhytide reduction thereby avoids many of the inherent risks associated with surgical rhytidectomy. Experience with nonablative lasers and light sources has proven that tissue enhancement is possible with controlled dermal wounding without epidermal disruption. RF systems achieve greater depths of thermal injury with tissue penetration to the level of the dermis and subcutaneous layer without producing thermal burns. Tissue tightening and reduction of prominent nasolabial folds or jowling are produced as a result.

RF systems have become popular because of their minimal morbidity and low risk of postoperative complications. There have been rapid advances in RF technology over the past few years, and the nonsurgical face-lift or neck-lift using this technology offers great promise to our aging population. Further studies are warranted to

elucidate ideal treatment settings particular to each RF system, identify the most appropriate candidates for treatment, and discover novel applications for RF systems within aesthetic medicine.

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