Skin Tightening Technologies

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Abstract

Radiofrequency (RF) and intense focused ultrasound (IFUS) are increasingly used to address skin laxity of the face and neck. Both nonablative RF and ultrasound create a heat-induced tissue response that leads to collagen remodeling and other ultrastructural changes. Although these treatments are not meant to replace surgical procedures, patient satisfaction in the majority of studies has been consistently high. This article discusses the various RF and IFUS technologies currently in use and reviews pertinent clinical studies evaluating their efficacy and safety.

Keywords
- radiofrequency
- ultrasound
- skin tightening
- laxity

Redundant facial and neck skin is a major feature of aging that until recently could only be addressed with surgery. Although surgical intervention is the gold standard for correction of skin laxity of the face, many patients instead opt for less invasive procedures that are associated with less downtime but more modest improvements. For physicians who offer these nonsurgical facial tightening procedures, it is essential to select appropriate candidates, set realistic expectations, and combine tightening procedures with other modalities, such as fillers and botulinum toxin, to optimize outcomes. This review summarizes the nonablative radiofrequency (RF) and focused ultrasound treatments currently available for addressing laxity of the face and neck.

Thermal Collagen Remodeling

Collagen undergoes several changes in aging skin that can create laxity. Although the amount of soluble collagen declines with age, insoluble collagen increases. This is caused by the increase in stable multichain cross-linking, which leads to a loss of skin elasticity. The additional stable cross-linking also leads to an increase in collagen tensile strength with age.[1] The amount of new collagen production decreases with age due to fibroblast changes.[2] Increased proteinase activity also degrades collagen, further diminishing collagen content in the dermis. Exposure to ultraviolet radiation leads to activation of these proteases to further degrade existing collagen.[3] These changes ultimately lead to decreased collagen turnover and thinning of the dermis. The selective reduction of type I collagen also leads to a decreased ratio of type I to type III collagen in the dermis.[4]

Several devices have been developed to address these aging skin changes through the heat modification of collagen. The heating of collagen breaks the intramolecular heat-labile bonds forming the chain cross-links, while the heat-stable intermolecular cross-links are maintained.[5] This serves to unravel the triple helix and shorten the molecule. Electron microscopy has shown an increase in size of the collagen fibrils. Heating to sufficient temperatures stimulates neocollagenesis, but if the temperature is too high, irreversible denaturation changes the ordered crystalline structure of collagen into a random gelatinous form.

After the acute thermal shortening of the collagen molecule, a reparative process follows for approximately 1 month. At 3 months posttreatment, epidermal hyperplasia and thickening with the development of rete ridges are seen. The amount of newly synthesized collagen is significantly increased and may continue for up to 6 months after treatment.[6] Most in vitro and in vivo studies suggest that temperatures in the dermis should approach from 45 to 65°C to achieve the desired = results of collagen molecule shortening. However, for every 5°C decrease in temperature, a 10-fold increase in time is needed to achieve a similar amount of collagen contraction.[7] Thus, no true threshold temperature

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exists, and the amount of contraction is determined by a combination of time and temperature. This controlled heating is the basis for nonablative skin tightening technologies that are currently available.

An Overview of Radiofrequency Technology

Historically, ablative and nonablative laser devices have been used to improve facial skin laxity, and recently novel technologies have emerged that use energy sources other than light and laser. RF is a novel nonablative technology that uses an electric current rather than light to deliver energy to the tissue. RF energy is a form of electromagnetic energy ranging from 300 MHz to 3 kHz that has been used in many areas of medicine including cardiology, urology, and sleep medicine. It was initially developed in the 1920s for electrocautery,[8] but is now widely used in aesthetic applications. In 2002, the U.S. Food and Drug Administration (FDA) approved the first RF device for facial wrinkle reduction.[9] Since the development of this monopolar RF device (ThermaCool; Thermage, Inc., Hayward, CA), many other RF devices have been developed and combined with laser and light sources.

Similar to laser and light energy, RF energy interacts with tissue to induce thermal changes. However, it does not follow the principles of selective photothermolysis, and thus does not target a specific chromophore in the skin. Instead, RF devices generate heat as a result of tissue resistance to the movement of electrons within the RF field (Ohm's law). This resistance, also called impedance, creates heat relative to the amount of current (A) and time (seconds).[10,11] Heat is then produced when the tissue's inherent impedance converts the electrical current to thermal energy, indicated by the following formula: Energy (J) $= I^2 \times R \times T$ (where I is the current, R is the tissue impedance, and T is the time of application).[12]

Like other skin tightening treatments, RF treatment is based on lessening skin laxity through contraction and thickening of collagen fibers. The application of RF energy produces resistance within the various layers of the skin. The resistance within the tissue creates an electrical current that is converted to thermal energy. This resistance, also known as impedance, varies according to the tissue's size, depth, and various layers (dermis, muscle, fat, and fibrous tissue). Unlike laser and light-based treatments, this electrical current does not selectively target epidermal melanin. Thus, patients of all skin types can be more safely treated with RF. However, although RF is more theoretically safe for all skin types, there is a risk of dyspigmentation if thermal injury occurs due to overheating of the skin.

With RF treatments, depth of penetration is not the only consideration. The fact that soft tissue is made up of multiple layers, including dermis, fat, muscle, and fibrous tissue, all with varying resistance to the movement of RF energy, should also be considered.[11] Impedance is the principle that allows the heat to reach a larger volume of tissue, and structures with higher impedance are more susceptible to heating and thus to tissue injury.[13]

There are two major electrode configurations available in current RF devices: monopolar and bipolar. Although the interaction between the emitted energy and the target tissue is similar, the energy field created by each configuration differs.

Monopolar Radiofrequency

Monopolar RF devices deliver current using one active electrode that contacts the skin and another that acts as a grounding pad.[11] The active electrode delivers the current to the skin, tightening it via volumetric heating.[14] A cooling spray is applied to protect the epidermis, which also creates a reverse thermal gradient.

The dermis is heated uniformly and volumetrically, sparing the cooled epidermis. The partial collagen denaturation, through breaking hydrogen bonds in the collagen triple helix, leads to collagen contraction and thickening.[15,16] Some collagen contraction may occur immediately due to fibril denaturation.[17] This collagen denaturation occurs at a threshold temperature of approximately 65°C.[18–20] Additional tightening then follows due to an inflammatory wound healing response that triggers neocollagenesis and further skin contraction.[11,15,17] Collagen-based fibrous septae that separate fat lobules in the subcutaneous tissue are also preferentially heated, which leads to further collagen denaturation and contraction of the subcutaneous tissue. This accounts for the immediate tightening and lifting effects noted after treatment.[11,17] It is also thought to be responsible for inward (Z-dimensional) tightening.[21]

The first monopolar RF device used for skin tightening was the ThermaCool device (Thermage, Inc.), which was introduced in 2001 and received FDA approval for the noninvasive treatment of periorbital rhytides and wrinkles in 2002 and for full face treatment in 2004.[22] The ThermaCool device uses capacitive coupling to deliver RF energy to the skin through a thin membrane in the treatment tip. The ThermaCool device has four main components: a monopolar RF generator producing 6 MHz of alternating current, a handpiece, a disposable treatment tip, and a cryogen cooling module. Using a unique capacitive coupling membrane, RF is dispersed uniformly across the thin dielectric material on the treatment tip. The RF generator changes the polarity of the electric field in the tissue 6×10^6 times per second, causing charged molecules to move with the electric field at the same frequency. Heat is then generated from the dermal tissue's natural resistance to electron movement.

The efficacy of monopolar RF has been widely investigated in various applications. Fitzpatrick et al conducted a blinded, multicenter trial in which 86 patients received a single treatment in the lateral canthal and forehead areas.[23] Treatment efficacy was evaluated using the Fitzpatrick Wrinkle Classification System (FWCS), in addition to objective eyebrow position measurements. A total of 83% of patients showed the improvement of at least one point on the FWCS, and 50% of patients were satisfied with the improvement in periorbital wrinkling. Brow lift of at least 0.5 mm was noted in approximately 62% of patients. The authors concluded that there was an objective and subjective reduction of periorbital wrinkles and changes in brow position.[23] Side effects were uncommon, although there was an overall incidence of 0.36% of second-degree burns.

Bassichis et al also evaluated the ThermaCool device for rejuvenation of the upper third of the face by assessing changes in brow position.[24] Twenty-four patients received a single-pass treatment in the temporal and lateral forehead areas. They found that treatment resulted in a statistically significant brow elevation of at least 0.5 mm in 87.5% of patients. Despite this, 64% of patients did not perceive a cosmetic benefit. No complications were reported.

Brow elevation was also studied by Nahm et al in a study involving ten patients.[25] One side of the face was treated with a single pass using the ThermaCool device. By 3 months posttreatment, there was a statistically significant average elevation of 4.3 mm of the mid-brow and 2.4 mm of the lateral brow, with a 1.9 mm increase in the level of the palpebral crease.

Using a different monopolar RF device (Biorad, Guangdong, China), El-Domyati et al treated patients for 3 months at 2-week intervals. All six patients exhibited notable improvement in skin tightening in the periorbital and forehead regions, with continued improvement for 3 months after treatment. Skin tightening improved from 35 to 40% at the end of treatment to 70 to 75% at 3 months following treatment.[26]

A 4 MHz monopolar system (Pelleve, Ellman International, Inc., Oceanside, NY) has recently been evaluated for the treatment of periorbital rhytides. Javate et al evaluated patients 1, 3, and 6 months after treatment, and statistically significant changes were noted clinically and according to electron microscopic evaluation.[27] Taub et al evaluated this device using a continuous motion technique, achieving a surface temperature of 40 to 42°C and maintaining that temperature for an additional four to six passes.[28] Two weeks after the first treatment, patients noted an overall 25 to 30% improvement. Although there was a reduction in results after the second treatment, the treating physician and patient rated an average improvement of 46 and 30%, respectively, 6 months after the final treatment.[28]

Treatment of laxity in the lower face and neck with the ThermaCool device has also been investigated. Jacobson et al treated 24 patients with laxity of the neck, nasolabial folds, marionette lines, and jawline, with 17 of the 24 patients showing notable improvement up to 3 months following treatment.[29] Alster and Tanzi reported similar findings, with improvement in moderate cheek laxity and nasolabial folds.[30]

Side effects are generally mild and self-limited following monopolar RF treatments. Weiss et al published an extensive retrospective chart review that investigated the rate and degree of side effects after treatment using the ThermaCool device.[31] Most side effects experienced were transient erythema and edema. However, there were rare cases of superficial crusting, slight depression of the cheek, subcutaneous erythematous papules, and neck tenderness that were noted. The overall rate of adverse side effects was 2.7%, but none of these side effects were experienced when using a lower energy multiple-pass treatment algorithm.[31]

Hybrid Monopolar and Bipolar Radiofrequency

A hybrid RF system takes advantage of two mechanisms of RF-induced tissue heating by using two handpieces: one monopolar and one bipolar (Accent RF, Alma Lasers, Ltd., Caesarea, Israel). The monopolar handpiece achieves deep volumetric heating of the skin (up to 20 mm) through the rotational movement of water molecules in the alternating current of the electromagnetic field.[32] The bipolar handpiece is used for more superficial localized (nonvolumetric) heating, at a depth of 2 to 6 mm, based on tissue resistance to the RF conductive current.[32,33]

A study investigating hybrid monopolar and bipolar RF treatments for the treatment of facial rhytides and skin laxity found that 56% of participants had some degree of improvement. And when divided into two age groups, the younger age group reported statistically significantly higher satisfaction scores when compared with the older group.[33] In the study, the authors supported their observation by citing a study that suggested that heat-labile collagen bonds are progressively replaced by irreducible multivalent cross-links as the tissue ages, rendering older skin less amenable to RF tissue tightening.[34] Patient satisfaction scores were also higher in the younger age group in this study.

Alexiades-Armenakas et al compared the monopolar and bipolar handpieces in a split face study for the treatment of facial rhytides and laxity. After four treatments, the degree of improvement for each handpiece approached but did not achieve statistical significance.[9] Although there was a slightly greater degree of improvement with the bipolar handpiece, this difference did not achieve statistical significance.

As with other RF devices, side effects are uncommon, but there is still risk of burns, skin breakdown, and scarring with the use of inappropriately high energies.[35] Using pain as a feedback mechanism and operator technique are both important for optimal patient safety. The handpiece should be kept in continual motion when in contact with the skin to prevent overheating.

Vacuum-Assisted Bipolar Radiofrequency

Vacuum-assisted bipolar RF (Aluma, Lumenis, Inc., Santa Clara, CA) combines bipolar RF with a vacuum technology known as FACES (Functional Aspiration Controlled Electrothermal Stimulation). This device uses a handpiece that incorporates a vacuum to suction a segment of skin between two electrodes. This limits the volume of treated tissue to the skin between the electrodes, allowing the use of lower overall energy. As only targeted layers of skin and subcutaneous fat are suctioned between the electrodes, nontarget structures such as muscle and bone are avoided.[35] Although not clinically proven, some have postulated that exposure to the vacuum may cause mechanical stress on fibroblasts and increased collagen formation to increase clinical efficacy.[16,36]

Gold et al studied vacuum-assisted bipolar RF in 46 patients with facial skin laxity. Using the Fitzpatrick-Goldman Classification of Wrinkling and Degree of Elastosis scale, the mean elastosis score decreased from 4.5 (pretreatment) to 2.5 (6 months posttreatment). Despite the overall satisfaction of treatment outcome among the participants, satisfaction levels declined during the follow-up period.[16] The authors noted that this declining satisfaction did not correspond with the progressive improvement noted by the investigators, a phenomenon often observed with long-term follow-up of aesthetic treatments. This decline in satisfaction is also thought to be a common finding in RF skin treatments because of delayed neocollagenesis and the long-term wound healing response, with slowly progressive, incremental changes.

Side effects that can occur after vacuum-assisted bipolar RF procedures include erythema, burns, blistering, edema, purpura, crusting, and transient hyperpigmentation.[16]

Combined Bipolar Radiofrequency and Optical Energy

Although monopolar RF devices have only one active electrode contacting the skin, the bipolar configuration consists of two active electrodes placed a short distance apart that overlie the treatment area. The current flows between the two electrodes, and the depth of penetration is approximately half the distance between the two electrodes.[15] Depth of penetration is the major limitation of the bipolar configuration. Though offering a more shallow depth of penetration, this configuration does provide more controlled distribution of energy and less pain.[37]

Bipolar RF devices are frequently combined with light-based technologies, termed electro-optical synergy (ELOS).[12,38] The ELOS system (Syneron Medical Ltd., Yokneam, Israel) uses the synergistic effects of light- and RF-based devices. The light energy preheats the target tissue through photothermolysis, lowering the tissue's impedance. This in turn makes the tissue more susceptible to the RF component. The advantage is that lower energies of both the light and RF can be used to deliver a safer treatment with fewer side effects.[15,38] The RF also allows for deeper penetration into the dermis than nonablative lasers, which are subject to scatter within the tissue.

Common ELOS systems incorporate intense pulsed light (IPL), a diode laser, or infrared light. Earlier systems such as the Aurora SR and Polaris WR (Syneron Medical Ltd.) used the bipolar configuration with an IPL and a 900-nm diode laser, respectively. The optical and RF energies are delivered simultaneously through the treatment tip. Recently, a newer generation ELOS Plus platform was made available that also incorporates both an IPL and a diode laser with RF energy.

A clinical study by El-Domyati et al evaluated the histologic changes and clinical outcomes using the Aurora SR system.[39] Six subjects were treated in the periorbital region over six sessions. Both clinical photographs and punch biopsy samples were analyzed both immediately and 3 months after treatment. At 3 months, improvements in skin tightening, skin texture, wrinkles, and overall satisfaction were 75 to 80%, 70 to 75%, 95 to 100%, and 95 to 100%, respectively. On histologic analysis, increased epidermal thickening, a 53% reduction in elastin content and a 28% increase in newly synthesized collagen fibers were noted.

A second study using the Aurora SR system was conducted by Sadick et al, who reported similar findings in 108 patients.[40] Each patient received five full-face treatments and were assessed according to photographic evaluation and patient satisfaction. Although overall skin improvement was 75.3%, which included wrinkle improvement, pore size, and pigmentation, among other factors, skin laxity improved 62.9%. Patient satisfaction was 92% at 15 weeks following treatment.

The Polaris WR system was also evaluated for the treatment of facial rhytides and skin laxity.[41] The succession of RF and diode laser energy led to heating at a maximal dermal depth of 2 mm. Twenty-four patients underwent three treatment sessions. Improvements were noted in both skin laxities in facial rhytides, most notably in the periorbital region. Continued improvement in skin laxity was observed at 6 months posttreatment.

Fractional Radiofrequency

A recent nonablative approach involves fractional RF, which is currently delivered in two ways. Formerly known as Matrix RF, Sublative Resurfacing (Syneron Medical Ltd.) uses a series of electrodes to deliver RF energy; another device (ePrime, Syneron Medical Ltd.) uses an array of microneedles arranged in pairs between which RF energy is delivered.[42] Thermal wounds are created in a fractional manner directly to the reticular dermis. The tissue directly beneath the electrodes or microneedles is selectively targeted for deep dermal heating, while the surrounding areas are left intact.[43] The unaffected areas serve as a reservoir of cells that promote wound healing in the treated areas.

Fractional RF devices contain an applicator with a disposable tip that contains parallel rows of electrodes or microneedles that are arranged in a bipolar array. A closed circuit of bipolar RF current is created between positively and negatively charged electrodes or microneedles.

A prospective multicenter study was performed on 35 subjects who underwent three treatments on their entire face with the Matrix RF device.[43] Eighty-seven percent of patients showed improvement in skin tightening, with a trend toward less wrinkling and elastosis. Eighty percent of patients were satisfied with their treatment. Other than one patient experiencing prolonged edema, side effects were minimal.

Another study was undertaken to assess the efficacy and safety of the Matrix RF treatments in photoaged Asian skin.[44] Moderate (26–50%) and incremental improvements were observed in each category of physician evaluation, including smoothness and tightness. The degree of elastosis also decreased significantly. Importantly, no pigment alterations or fat atrophy were observed.

Intense Focused Ultrasound

Intense focused ultrasound (IFUS) has been investigated as a tool for treating solid benign and malignant tumors for many decades and has recently emerged as a potential noninvasive alternative in tissue tightening.[45] The primary mechanism of heat-induced tissue response is through coagulative necrosis with precisely defined, sharp margins caused by absorption of acoustic energy.[46] The ultrasound waves induce a vibration in the composite molecules of a given tissue, and the thermoviscous losses in the medium create tissue heating. As with RF, the cellular changes depend on the increase in temperature and the exposure duration. This can range from subtle ultrastructural cell damage with modulation of cellular cytokine expression to total cell necrosis.[46] These findings parallel those found after laser or light-induced heat applications.

IFUS uses short, millisecond pulses with a frequency in the megahertz domain, using significantly lower energies (0.5–10 J) than with traditional high-intensity focused ultrasound. Initial experiments on postmortem skin using a prototype device (Ulthera Inc., Mesa, Arizona) showed a focal depth of 4.2 mm below the skin surface.[45] This depth would potentially permit the targeting of surgical planes, such as the superficial muscular aponeurotic system.

Initial clinical evaluation with the Ulthera device showed significant tightening with a 1-mm eyebrow lift in more than 75% of study participants.[47] This helped lead to FDA approval in 2009 for tightening of the skin around the eyebrow. Recent studies have investigated the effects of IFUS on tightening of the lower face and neck. Suh et al treated 22 subjects, and improvements of the nasolabial folds and jaw line were assessed. Objective improvement was seen in both areas, and 77 and 73% of patients reported improvement in the nasolabial folds and jaw lines, respectively.[48] Histologic evaluation of biopsy samples showed greater dermal collagen with thickening of the dermis and straightening of elastic fibers in the reticular dermis after treatment.

Another study evaluated ultrasound tightening of skin laxity of the lower face and neck using a two-pass protocol.[49] Ten subjects were treated using the two-pass approach using two different probes. In this study, 80% of blinded clinicians and 90% of the subjects reported subjective improvement. The safety of focused ultrasound has also been evaluated in Asian patients.[50] Focal bruising was present in up to 25% of treatment sessions. Interestingly, two cases of postinflammatory hyperpigmentation were seen on the forehead at 1 month posttreatment. The only other notable side effect was pain, which was recorded as severe in 54.4% of treatment sessions.

Summary

Current skin tightening technologies present an attractive alternative to patients who are seeking nonsurgical intervention. However, these treatments are not meant to replace surgical procedures. Although these treatments produce modest results, patient satisfaction in the majority of studies has been consistently high. Ensuring patient satisfaction depends on proper patient selection and realistic patient expectations. Overall, patient satisfaction can also be increased by combining skin tightening treatments with other noninvasive treatments. In spite of the significant development that has occurred in nonsurgical tissue tightening, questions remain regarding ideal treatment parameters. More controlled randomized comparative clinical trials are necessary to optimize the clinical usefulness of these technologies.

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