

Simultaneous Emission of Synchronized Radiofrequency and HIFES for Non-invasive Facial Rejuvenation: The Mechanism of Action

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Abstract

EMFACE is a unique device specifically developed for non-invasive face lifting and wrinkle reduction by targeting all facial layers; skin, connective tissue framework, and facial muscles. It utilizes both Synchronized RF and HIFES technologies simultaneously. Heating the facial tissue to effective temperatures and HIFES stimulation of only specific facial muscles results in a combined effect that causes textural changes to the skin, smoothing, wrinkle reduction, facial repositioning, and an overall lifting effect. The simultaneous and targeted manner of both technologies yields unique benefits by inducing a synergistic effect in the facial soft tissues that cannot be achieved by using these technologies consecutively or as a standalone procedure.

Keywords: HIFES, Radiofrequency, Simultaneous, Application, Supramaximal, Contraction, Muscle, Fat, Reduction, Hypertrophy, Face, Lift

Introduction

Facial aging is a continuous and unstoppable process resulting from age-related changes in all structures present in the face: skin, fat, muscle, fascia, and bone.^{1,2} Age-related changes of all facial soft tissues start at different decades and progress at different speeds, which vary between individuals of different gender and ethnicity. All changes together result in reduced support for the bone-overlying soft tissues, which then follow the effect of gravity. Repositioning and restructuring the affected tissues and layers is the aim of aesthetic procedures via surgical and non-surgical procedures.^{1,2}

Amongst non-invasive aesthetic procedures, radiofrequency (RF) is considered the gold standard for facial skin treatment.³ The effect of RF on the skin tissue is based on dermal heating, which leads to structural changes within the skin and the overall improvement in skin quality.⁴ However, these skin heating procedures focus solely on improving skin

quality and textural improvement, but not the overall facial appearance.

The overall facial appearance is not only influenced by skin quality but also by the facial volume and density of the underlying structures, including the fascial system, facial ligaments, and facial muscles. Therefore, the extent of facial laxity is a composite effect of all implicated structures of which the facial muscles and their interconnection with the skin play a fundamental role.⁵

The most frequently performed non-surgical treatment to date is the administration of soft tissue fillers, which help to restore facial volume.⁶ However, soft tissue fillers only attempt to cover the aging symptoms and do not affect facial muscles, which play a crucial role in natural skin mobility.⁷ Currently, the only way to alter facial muscles is through a surgical lift procedure, where the skin and fat tissues are separated from the muscle, and the muscles are then repositioned.⁸

Recently, HIFES technology has been introduced to the market to target the facial muscles and their connective tissue frameworks for lifting and tightening of the facial contours. This novel technology induces electrical fields to contract facial muscles selectively. These delicate facial muscles are crucial for supporting the facial soft tissues and play a structural role in a more youthful appearance.

EMFACE is the first device on the market utilizing the simultaneous application of both the synchronized RF and HIFES technologies for non-invasive facial lifting and wrinkle reduction. While the HIFES technology targets the muscle and overlying fascial tissue, the synchronized RF heating induces structural changes to the dermal and subdermal architecture. This approach ultimately results in an improved appearance through changes in all facial tissue layers.

The Role of Facial Muscles and Fascial Framework in Aesthetic Appearance

It is widely accepted that facial skin changes over time, with facial wrinkles being only the tip of the iceberg. Loss of structural support due to volume depletion and changes to the facial muscles and their connective tissue framework results in an increased soft tissue laxity which is additionally influenced by the effects of gravity. Facial muscles have been found to age through the process of sarcopenia, which manifests as a loss of muscle mass and volume, similar to skeletal muscles.^{9,10} Since the facial muscles are interconnected via the fascial system and the overlying skin, weakening of these muscles may result in a visible descent of the tissue sagging as we age. The weaker the facial muscles are and the lower is the resting muscle tone, the higher muscle effort is needed to avoid sagging and to hold the overlying tissues in place. When being too weak, they become unable to hold the tissue, resulting in e.g. eyebrow drop or cheek sagging. When the resting muscle tone is increased, the muscles have the strength large enough to hold the overlying tissue in place without drooping and without the need to stay contracted.

Specifically, the muscles in the cheeks are interconnected by the midfacial superficial musculoaponeurotic system (SMAS).¹¹ Weakening of the cheek muscles, especially the zygomaticus muscles, allows for the hypothesis that as we age, the resulting facial muscle weakness can promote midfacial soft tissue descent, resulting in the increased

severity of the nasolabial fold, formation of jowls, and loss of jawline contour.¹² Targeting these muscles and its surrounding connective tissue architecture might allow for midfacial soft tissue repositioning.

Also, the same muscle weakening could be expected for the frontalis muscles due to aging or long-term use of neurotoxins. The frontalis muscles are largely responsible for eyebrow movements¹³. Their connection with the skin is ensured via the supra-frontalis fascia (located superficial to the frontalis muscle) and the sub-frontalis fascia (located deep below the frontalis muscle). Aging of the forehead structures may result in eyebrow ptosis¹⁴ and heaviness, which along with skin aging, may lead to laxity and wrinkle formation in the region.

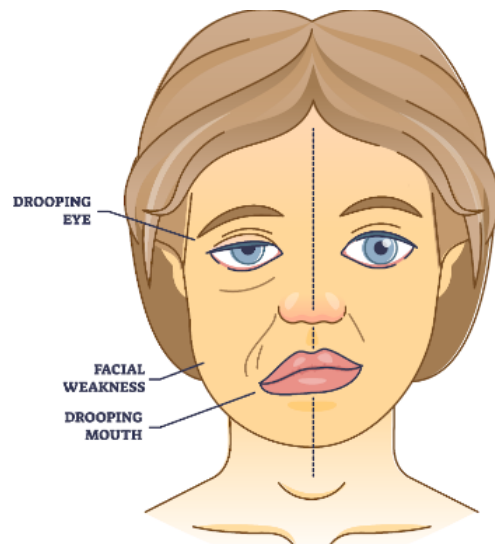


Figure 1: Visualization of the effect caused by weakened facial muscles on the left in comparison to healthy muscles on the right.

In contrast to skeletal muscles, the facial muscles are embedded in a connective tissue framework that interconnects all tissues from bone to skin. Interestingly, in addition, they are connected directly to the brain via the cranial nerves and are responsive to emotional input and the limbic system. Emotional states affect facial contours via resting tone of the muscles and the SMAS. Therefore, the facial muscles need to be seen within their connective tissue environment and addressed accordingly. Assuming that facial muscles affect skin movement alone without the support of a connective tissue environment creates an incomplete picture of facial muscle anatomy.

The combination of age-related facial changes results in an alteration of the facial shape which cannot be

improved by targeting the skin alone. Therefore, more **profound treatment algorithms need to be applied to address age-related facial changes.**^{15,16} This may include addressing **deeper fascial and muscle layers together**, as they have the ability to promote facial repositioning; treating the skin alone will not have such comparable effects.

How EMFACE Targets Facial Muscle and Fascial Tissues?

The Mechanism of HIFES Stimulation

Increased laxity of the overlying skin and the connective tissue framework increases the disconnect between muscular contraction and skin movement; this is more prevalent as we age. Therefore, inducing positive changes to the connective tissue and facial muscle unit will restore the connection between the layers, rejuvenating all layers, including the skin.

The EMFACE utilizes HIFES technology, specifically designed to selectively induce supramaximal contractions of small delicate muscles in the face. The technology generates strong electrical fields that affect the underlying neuronal and muscle tissue. These electrical fields depolarize the membrane of the motor neurons that innervate the muscle. When the motor neurons are depolarized, a signal is created that travels along the neuron, all the way to the neuromuscular junction - the place where the motor neuron is connected to the muscle. These signals overcome the barrier of the neuromuscular junction and progress to the muscle, which is thus forced to contract. This process bypasses the voluntary intention of the brain, inducing a forced contraction through electrical stimulation.

During each treatment, energy is applied to the facial soft tissues, and muscular contractions are induced. The HIFES technology induces up to 250 energy impulses per second (= 250 Hz), which does not allow any time for the facial muscles to relax in between the individual signals. As the muscle is unable to relax, with additional stimuli it is forced to contract even further which continuously builds up the contraction power with every additional signal. The appropriate selection of these two factors (electrical field strength and frequency) results in the so-called “supramaximal contraction”.

Although it is poorly understood how and to what extent the facial muscles adapt to external stimuli, research studies conducted in skeletal muscles have revealed that heat shock proteins (HSP) and satellite cells (SC) may be activated by intense muscle exercise as a response to the applied stimuli.^{17,18} HSP are the signaling molecules playing a crucial role in muscle remodeling through the promotion of muscle protein synthesis.^{19,20} SCs are muscle-derived stem cells responsible for myofiber development and renewal.²¹ In a resting state, the SCs remain quiescent, ready to be activated, and provide differentiation to create new myonuclei to existing muscle fibers or generate new muscle fibers. Together, HSP and SC activation can support muscle micro-protein structure alterations. In a healthy muscle this may lead to densification of the muscle tissue and to overall improvement of the muscle quality. In atrophied muscle, the muscle structure alteration may lead to hypertrophic response reversing the atrophy. However, it is not only the muscle reacting to the signaling molecules. It has also been documented that the fascial layer remodels itself in response to heat and mechanical stimuli.²²

Future studies will need to identify similarities between skeletal and facial muscles or provide conclusive evidence that facial muscles behave similarly or differently when targeted by external stimuli.

The Role of Synchronized RF Heating on Facial Muscles and Fascial Framework

Simultaneously with the HIFES stimulation, the EMFACE delivers Synchronized Radiofrequency that heats the facial tissue. Such stimuli affect the connective tissue framework and the facial muscle unit with consecutive adaptive changes to the overlying facial soft tissues.

According to previous studies on skeletal muscles^{19,20,23-25}, HSPs can also be activated by heat within the range of 40°C. Together with the muscular contractions, the heat thus may further increase the levels of released HSP^{26,27}, this effect has been shown in abdominal muscle^{28,29}, gluteal muscle^{30,31}, or in the muscles of the upper extremity.^{29,30} A recent study by Kinney et al.³² measured the facial muscle temperature during the treatment with the EMFACE device and showed that the temperatures in the targeted muscle tissues reached up to 40°C, indicating that a similar

effect could also be seen in the facial muscles during the EMFACE treatment.

The primary effect of Synchronized RF heating on the subdermal tissues can be seen in the fascial framework. The fascial framework primarily consists of collagen and elastin, which are known to be heat responsive. Therefore, heating to adequate temperatures may induce remodeling of collagen and elastin within the fascial framework, leading to increased elasticity and tightness of the fascial web.²²

Clinical Effect of EMFACE on Facial Muscles and Fascial Tissues

Forehead application

The EMFACE applicators are designed to target specific muscles of the face. The forehead applicator has been designed to specifically target the frontalis muscle and its surrounding connective tissue environment, composed of the supra-frontalis fascia (located superficial to frontalis muscle) and of the sub-frontalis fascia (deep to frontalis muscle), enveloping the only eyebrow elevator like a sleeping bag. The applied stimulus during the treatment with the EMFACE device affects the connective tissue framework and the facial muscle unit simultaneously, which have a soft tissue thickness in the range of 3 – 7 mm³³ for the forehead. The applied energy induces changes to the entire unit, which results in its structural alteration. A tighter fascia (sleeping bag) allows for the relaxation of the enveloped muscle, which in turn most likely reduces its baseline contractile tonus. The latter effect is clinically visible in the form of reduced horizontal forehead lines. Since the frontalis muscle is an eyebrow elevator, strengthening formerly atrophied frontalis muscle may aid with eyebrow ptosis and lead to brow elevation.

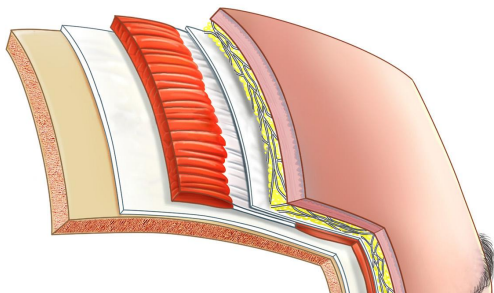


Figure 2: The frontalis muscles is enveloped by the supra-frontalis and sub-frontalis fascias. The condition of both the muscle and the fascias affects the overall appearance of forehead.

Affecting the connective tissue framework and the facial muscle unit of the forehead indirectly influences the glabellar muscles. All upper facial muscles (consisting of frontalis, procerus, corrugator supercilii, and orbicularis oculi) connect with the skin at the level of the upper margin of the eyebrow both in the midline and laterally. Affecting the frontalis m. will indirectly influence the eyebrow depressors and cause, most likely, a **change in their position** (relative to the underlying bone) by being pulled upward. Muscular contractions of the glabellar muscles are not observed during the treatment. The effect is thus indirect, only due to the supporting fascial framework, which stabilizes and guides muscular actions.

Cheek application

The cheek applicators are designed to stimulate the zygomaticus major and minor muscles and the risorius muscle.

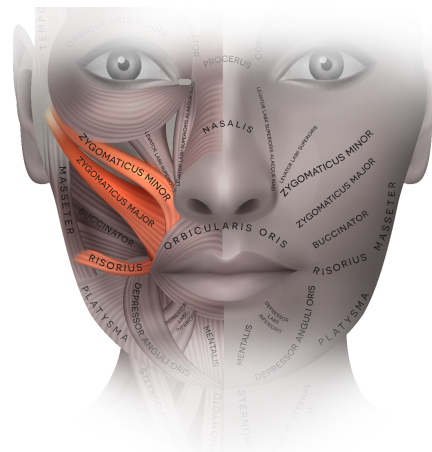


Figure 3: The cheek muscles stimulated by EMFACE cheek applicators: Zygomaticus major & minor muscles and risorius muscle.

The zygomaticus minor muscle is attached to the skin at the nasolabial fold. The zygomaticus major muscle is connected to the underlying maxilla by a connective tissue sheet termed the transverse facial septum.³⁴ This septum forms the inferior boundary of the midfacial fat compartment and forms a biomechanical unit with the overlying muscle. Stimulating this unit allows for conformational change of the septum, elevating the entire cheek, increasing the midfacial volume², and improving the nasolabial fold.³⁵

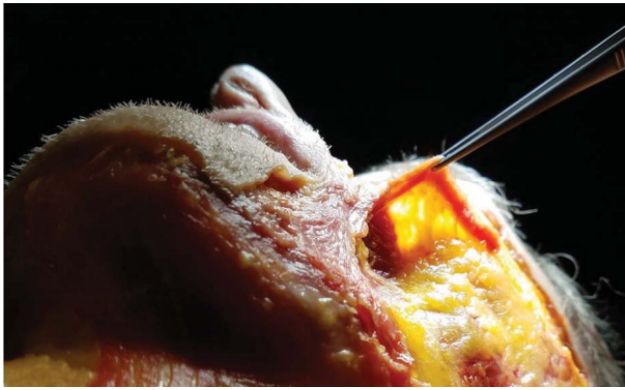


Figure 4: Cadaveric dissection of the left side of the face showing the transverse facial septum connecting the zygomaticus major muscle to the maxilla. Image taken from Cotofana et al.³⁴

Repositioning the midfacial soft tissues, especially the superficial fat compartments, influences the balance between total facial elevators and depressors. The platysma is the strongest facial depressor, due to its extent and fascial connection to the SMAS, the superficial temporal fascia, and the orbicularis oculi muscle. Decreasing the caudally oriented vector of the midface will shift the balance toward the zygomatic facial elevators, allowing for repositioning not only midfacial but lower facial soft tissues. The resulting clinical effect is a reduction in jowls and an increase in jawline contouring. In addition, the masseter muscle, deeper muscles of facial expression like the buccinator or levator anguli oris do not display muscular contractions during the treatment.

It is important to note, facial muscles are not expected to increase in their thickness as compared to the structural changes observed in skeletal muscle following strength training. However, these delicate muscles do keep their genetically predisposed thickness: frontalis muscle approx. 3 mm³⁶, zygomaticus major approx. 3.6 mm³⁷, and approx. 0.5 mm for the zygomaticus minor³⁸ and risorius muscles.³⁹ Future studies will need to identify similarities or differences between these muscle groups.

The effect of EMFACE on muscle structure has been investigated in a study by Kinney et al.³², who found a 19.2% increase in muscle density and a 21.2% increase in the number of myonuclei after four EMFACE treatments. Structural changes post-EMFACE treatments were also suggested in a study by Halaas et al.⁴⁰, who used ultrasound echogenicity to evaluate

muscle quality, also called muscle tone. In this study, the muscle quality increased by 30%.

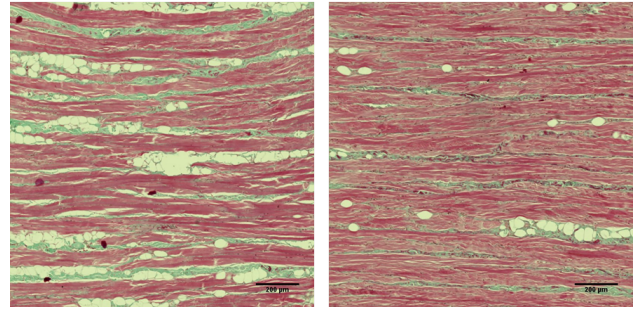


Figure 5: Histologic images of muscle tissues before (left panel) and 2 months after (right panel) the treatment with the EMFACE device³².

Additionally, clinical studies on the EMFACE device further support the proposed mechanism of action. A clinical study by Kinney and Boyd et al.⁴¹ investigating EMFACE found a brow lifting effect of 23.1% coupled with 91.2% patient satisfaction. In addition, a study by Halaas and Gentile et al.⁴² reported a 36.8% wrinkle reduction. These studies additionally revealed that clinical changes peak at approximately 2 to 3 months post-treatment, which is in line with the time frame needed for structural changes to be implemented into the connective tissue framework and the facial muscle unit.

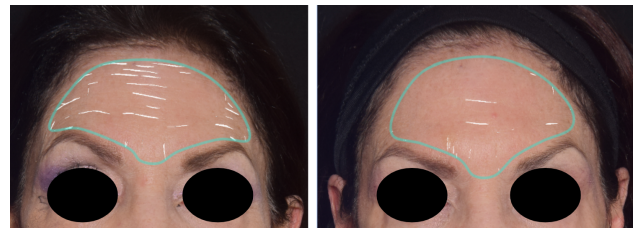


Figure 6: Example of patient results in wrinkle reduction as evaluated by automated software. Baseline on the left and 1 month after on the right. Taken from Halaas et al.⁴²

The effect of EMFACE on facial skin tissue

Regarding skin, fine lines and wrinkles accompanied by loss of skin volume are usually the first indicators of skin aging, a normal physiological process influenced by genetic and hormonal changes. However, external factors also influence aging, e.g., exposure to UV radiation, skin^{43,44}, smoking⁴⁵, diet, air pollution⁴⁶, or chemicals and toxins.^{47,48} During the skin aging process, the dermal blood vessel structure is disrupted, and in turn, the dermis is not supplied with

nutrition and oxygen, thus slowing cellular regeneration.

The major building blocks of the skin are collagen and elastin fibers, responsible for skin elasticity and firmness. These components are also affected by aging. During the aging process, collagen and elastin synthesis decreases, collagen bundles lose their extensible configuration and become fragmented⁴⁸, and the elastin fiber network is degraded, leading to the loss of structural integrity of microfibrils.⁴⁹ As the extracellular matrix is degraded, skin thickness is also reduced.^{50,51}

As a result of aging, collagen and elastin deficiencies are the main cause of wrinkle formation. Amount of skin collagen and elastin is decreasing every year due to aging process. It is estimated that adult skin loses 1%⁵² of overall collagen content annually.

Effect of RF heating

RF heating is known to address aging factors within the skin effectively. EMFACE utilizes a novel Synchronized RF electrode that allows the simultaneous application of an RF field together with HIFES, which is impossible with any other RF technology. During the 20-minute treatment, the skin tissue is heated to 40-42°C. This therapeutic temperature range is reached within the first 2 minutes of the treatment, as documented by the thermal probe measurements and by thermal camera by Kent et al.⁵³

Radiofrequency current flow achieves the heating through the dermal and subcutaneous tissues. As the RF current flows through the tissue, a portion of the RF energy is absorbed by the tissue, transforming the energy into heat and the desired thermal effect. The level of RF energy absorption in the tissue depends on the RF frequency⁵⁴ and tissue impedance⁵⁵, among other factors. Since the skin, muscle, and fat tissues have different impedances⁵⁶, it is possible to selectively target the energy and achieve the thermal effect only in the desired tissue(s).

When the therapeutic temperature is reached in the skin tissue for the desired time period, the hydrogen bonds tying the collagen fibers together begin to unwind, and collagen denaturation occurs. However, these temperatures do not lead to permanent damage.⁵⁷ As the tissue dissipates the mentioned thermal effect, the bonds begin to renature, and the skin's architecture

is changed to a more youthful level.⁵⁷ After repeating this process during multiple treatments, the structure of older collagen and elastin fibers is changed. It begins to take on the structure similar to newly formed collagen and elastin fibers.

This thermal effect is also accompanied by a heat-induced wound healing response and increased fibroblast activity. Fibroblasts are the dermal cells responsible for producing new collagen and elastin fibers. As we age, their activity decreases to a level equivalent to an overall "net loss" of fibers. This means that the amount of newly formed fibers does not exceed the number of fibers being degraded, which accelerates the appearance of skin aging. Nevertheless, studies have shown that heat stress increases fibroblast activity, leading to an increased synthesis of collagen and elastin - neocollagenesis & neoelastogenesis.⁵⁸

RF heating supports the skin to regain its volume, elasticity, and a more youthful appearance by restoring the collagen and elastin fiber structure and enhancing the synthesis of new collagen fibers.

Clinical studies on EMFACE, which focused on structural changes, demonstrated a prominent skin remodeling effect. The outcomes of a study performed on a porcine model by Kent et al.⁵³ correlated with the human histology study by Goldberg et al.⁵⁹, as both found that collagen increased by 27% and 26%, respectively. In addition, elastin was found to have doubled in the study by Kent et al.⁵³, while in the Goldberg study⁵⁹, the elastin levels increased by 129%.

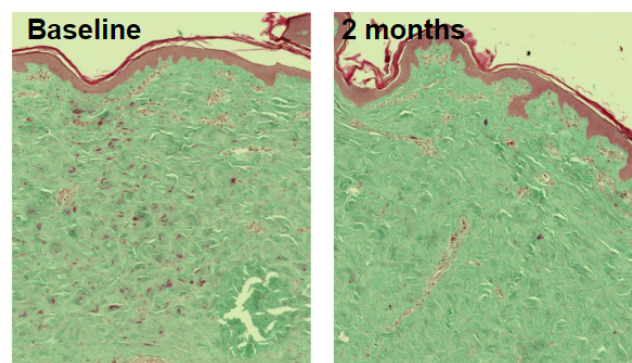


Figure 7: Densification of the collagen fiber network at 2 months post EMFACE treatment (right) in comparison to baseline (left) documented in Kent et al.

The effect on skin has also been documented in additional studies. For example, a study by Halaas and Gentile et al.⁴² reported 36.8% wrinkle reduction and

25.3% skin evenness improvement. Wrinkle improvement was also reported in a study by Cohen et al.⁶⁰ Similar to the muscle studies, the skin results also peaked at 2 to 3 months post-treatment.

The Effect of EMFACE on Fat Tissue

During the treatment with EMFACE, the temperature in the fat tissue does not exceed the 43°C⁶¹ needed for induction of an apoptotic process. Any direct effects in the fat tissue thus have not been observed.

Summary

EMFACE is a unique device specifically developed for non-invasive face lifting and wrinkle reduction by targeting all facial layers; skin, connective tissue framework, and facial muscles. It utilizes both Synchronized RF and HIFES technologies simultaneously. Heating the facial tissue to effective temperatures and HIFES stimulation of only specific facial muscles results in a combined effect that causes textural changes to the skin, smoothing, wrinkle reduction, facial repositioning, and an overall lifting effect. The simultaneous and targeted manner of both technologies yields unique benefits by inducing a synergistic effect in the facial soft tissues that cannot be achieved by using these technologies consecutively or as a standalone procedure.

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