CLASSYS

QUADESSY

The Principle of Needle RF in Human Skin Tissue



Choi Seung(Cheongdam NOEL Clinic)



Skin exhibits low electrical conductivity and dielectric properties. As a dielectric material, skin allows little electrical current (the flow of electrons) to pass through it, while still permitting the formation of an electric field. Consequently, radiofrequency (RF) energy is concentrated in regions with high electric flux density and decreases with increasing distance from the electrode.

Misconceptions and Actual Mechanisms of Conventional RF Current Theory

Figure 1 illustrates the conventional theory of RF current. According to this theory, electrical current flows along the surface of a conductor, while neither electrical current nor an electric field is generated in insulated regions. Current flows only from the exposed tip of the needle, generating heat through the electrical resistance of the skin tissue. These concepts appear to have originated from the direct application of conventional lumped-element models or electromagnetic theories developed for metallic conductors to biological skin tissue.

Within skin tissue, which exhibits dielectric properties properties, a needle functions more as an electrode than as a metallic conductor. The electric field generated by the potential difference between two needles induces ionic polarization within the skin tissue and generates heat through dielectric loss. Insulated needle RF devices commonly use a parylene C coating. However, a coating thickness of 10 μm is insufficient to provide perfect electrical insulation and instead exhibits dielectric properties. Therefore, an electric field can still be established around a parylene C-coated needle. As a result, RF energy is not concentrated exclusively at the needle tip but is distributed more extensively near the skin surface, with energy decreasing toward the needle tip. This phenomenon may explain why previous clinical studies of needle RF devices have shown no substantial differences in clinical outcomes between insulated and non-insulated needles. It may also explain why the theoretical advantage of inserting needles into the skin—minimizing epidermal effects while selectively concentrating RF energy within the dermis or at a desired tissue depth—has not been consistently demonstrated in clinical outcomes.

Similar phenomena can also be observed with monopolar RF and non-invasive bipolar RF devices.

Direct Measurement of Temperature Distribution in MNRF

Inserting and securing a 500 μm thick thermocouple probe at the dermo epidermal junction, located at a depth of approximately 50 μm, had long been considered technically impossible. However, after several years of effort, this challenging procedure was successfully achieved. In microneedle RF (MNRF) applications, additional challenges arise from the need to maintain a consistent distance between the probe and the needles while avoiding the extremely narrow spaces between adjacent needles. Furthermore, ultrasound imaging cannot verify the probe position once the needles have been inserted, necessitating an exceptionally precise experimental design. Recently, these thecnical challenges were successfully overcome, enabling the measurement of temperature changes at different skin depths at 2 ms intervals during MNRF treatment. If RF energy were concentrated at the needle tips, the highest temperature would be expected at the probe positioned at the dermal subcutaneous fat junction, at a depth of 1.65 mm, with a needle insertion depth of 1.5 mm. However, the actual measurements revealed the opposite result, which was consistently reproduced in repeated experiments.

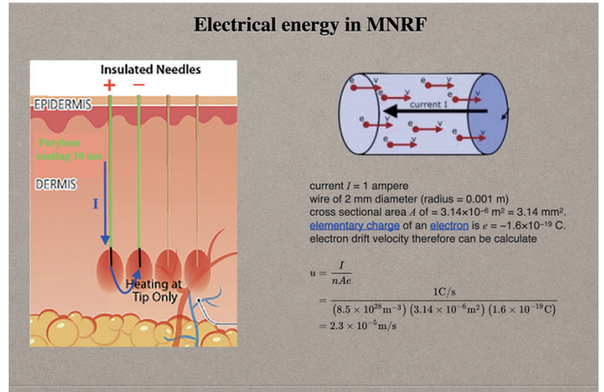


Figure 1. Illustration of the conventional RF current theory in insulated MNRF, showing energy concentration at the needle tip due to electrical resistance generated by current flowing along the needle within skin tissue. Courtesy of Dr. Choi Seung

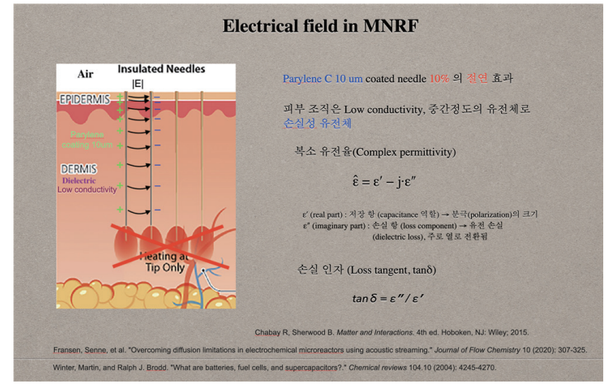
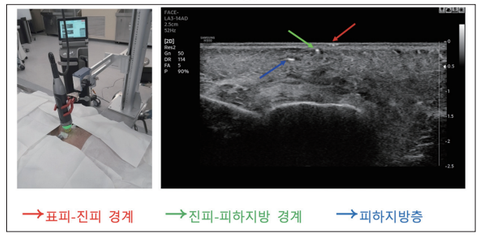


Illustration of electric field formation in needle RF within skin tissue exhibiting dielectric properties. The electric flux density is greatest at the skin surface and gradually decreases toward the needle tip. Courtesy of Dr. Choi Seung

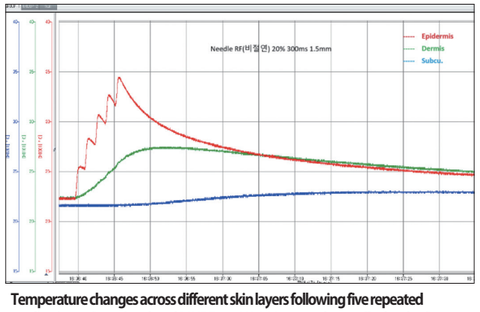
In clinical practice, relatively low-energy settings of approximately 12.5 approximately 2.5 W and 100 ms are commonly used. In comparison, the experimental settings of 5 W and 300 ms represent approximately six times the energy delivered under typical clinical conditions. Furthermore, considering that the experiment employed five consecutive energy applications (stacking) to enable more distinct measurements of temperature changes, the actual temperature changes within skin tissue appear to be considerably smaller than anticipated. An examination of MNRF treatment parameters commonly used in clinical practice reveals a strong tendency to minimize needle insertion depth, reduce RF power and application time, or divide energy delivery into multiple pulses to alleviate procedural pain. However, given that shallower needle insertion depths and reductions in RF power and application time result in minimal temperature changes within the skin tissue, these approaches may contribute to diminished clinical outcomes with needle RF treatment. Therefore, future MNRF development should focus on ensuring sufficient RF energy delivery to the skin tissue. Device design should aim to establish an electric field that minimizes RF energy concentration in the epidermis while promoting relatively greater energy deposition in and around the dermis.

Introduction and Key Advantages of QUADESSY

QUADESSY, the first MNRF device introduced by Classys, features non-invasive bipolar electrodes positioned on all four sides of the central needle RF array. These non-invasive electrodes operate before RF energy is delivered through the needles, inducing preheating within the skin tissue and enabling a sufficient increase in tissue temperature. In addition, they induce ionic polarization around the needles within the skin tissue, acting similarly to a capacitor. This facilitates more efficient heat generation through dielectric loss during subsequent needle RF energy delivery.

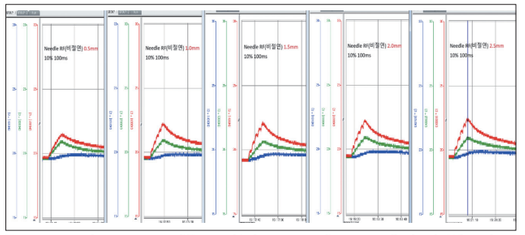


Experiment measuring real time temperature changes across different skin layers in fresh human cadaver skin tissue at 2 ms intervals. A thermocouple probe was inserted and secured at the demo-epidermal junction, located at a depth of approximately 50 μm. Additional probes were placed at the dermal-hypodermal junction (DHJ) and within the subcutaneous fat layer, and their positions were confirmed using ultrasound imaging. The experiment was conducted at the Catholic Applied Anatomy Center. Courtesy of Dr. Choi Seung.

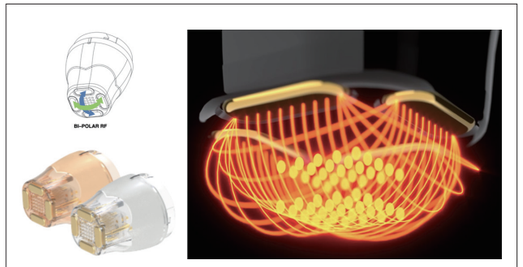


Temperature changes across different skin layers following five repeated applications of non-insulated MNRF at 5 W, 300 ms, and a needle depth of 1.5 mm. A pronounced temperature change was observed at the dermo-epidermal junction. Courtesy of Dr. Choi Seung.

The Deeplus tip, which features non-invasive electrodes positioned on all four sides of the needle RF array, induces more efficient temperature changes across different skin layers compared with conventional needle RF devices. In clinical practice, increasing RF power from 2.5 W to 5 W or doubling the RF application time from 100 ms to 200 ms can result in a substantial increase in procedural pain. However, in Deeplus mode, which incorporates non-invasive electrodes, the dermal temperature can be increased to a level comparable to that achieved by doubling the RF power or application time, without a corresponding increase in pain. Furthermore, in clinical practice, applying two to three consecutive RF pulses to the same treatment area (stacking) enables effective RF energy delivery without substantially increasing procedural pain.



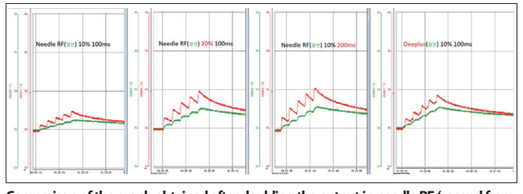
Temperature changes across different skin layers according to needle depth. When the needle depth is reduced to 1 mm or less, the magnitude of temperature change decreases sharply due to limitations in tissue heat capacity. Courtesy of Dr. Choi Seung.



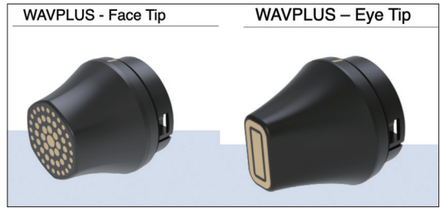
A novel MNRF design featuring non-invasive electrodes positioned on all four sides of the central needle RF array. Courtesy of Classys.

Key consideration for Combining Wavplus with Needle RF

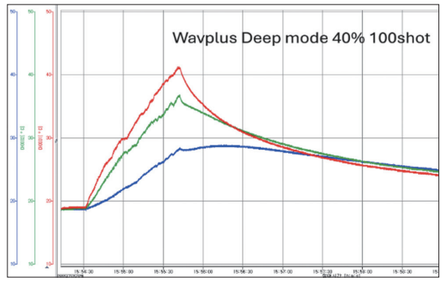
Contrary to the expectation that most RF energy would be confined to the upper dermis, the non-invasive bipolar RF handpiece known as Wavplus can affect the entire dermis and extend to a depth of approximately 5 mm into the subcutaneous tissue. According to conventional RF current theory, non-invasive bipolar RF would be expected to affect only the epidermis and upper dermis. However, experimental findings demonstrated that sufficient temperature elevation could be achieved not only throughout the entire dermis but also at depths of approximately 3 - 5 mm within the subcutaneous tissue.



Comparison of the graph obtained after doubling the output in needle RF (second from the left) and the graph obtained after doubling the RF application time (third from the left) shows that, when non-invasive electrodes are added, the temperature change in the epidermis (red) is relatively reduced, whereas the temperature in the dermis (green) increases slightly more than that observed with either increased output or prolonged RF application time. Courtesy of Dr. Choi Seung.



The Wavplus non-invasive bipolar RF tip uses printed circuit board (PCB) electrodes instead of conventional stainless steel (SUS) electrodes, helping to reduce procedural discomfort while improving safety by lowering the risk of adverse events such as burns. Courtesy of Classys.



Non-invasive bipolar RF can also directly affect the subcutaneous tissue. The blue curve represents the temperature increase measured by a probe positioned within the subcutaneous tissue, demonstrating a gradual and stable rise in temperature. Courtesy of Dr. Choi Seung.

A key difference from monopolar RF lies in the pattern of temperature elevation. Monopolar RF produces a rapid, spike-like rise in temperature, whereas Wavplus and other non-invasive bipolar RF systems induce a more gradual increase in tissue temperature. This difference in thermal patterns may be one of the major factors contributing to their distinct clinical effects. To overcome the limitation of insufficient temperature elevation with MNRF, Wavplus may be used to increase the overall facial skin temperature before needle RF treatment. Subsequent application of needle RF may thereby further enhance the treatment effect without substantially increasing procedural pain. Pain associated with needle RF can be broadly categorized into three components: needle insertion, stimulation of nerve endings by RF current, and heat. Lower-power RF delivery may offer an advantage in reducing pain associated with electrical stimulation. However, further investigation is needed to better understand this aspect. Taken together, the findings discussed above can be summarized as follows: ① Needle RF does not selectively target the dermis, and the resulting increase in tissue temperature is relatively limited. ② Because skin tissue has low electrical conductivity, only minimal electrical current flows through the tissue during needle RF treatment. Instead, RF energy is primarily delivered through the electric field generated within the skin tissue between the needles, with dielectric loss serving as a major mechanism of heat generation. ③ When needle depth, power, and pulse duration are reduced, tissue temperature elevation may become insufficient, potentially limiting the expected clinical effects. ④ When non-invasive electrodes are positioned on all four sides of the needle RF array and activated before needle RF delivery, preheating increases tissue temperature, while the tissue between the needles may function in a capacitor-like manner. Together, these effects may enable RF energy to be concentrated more selectively within the dermis. ⑤ The addition of non-invasive electrodes may produce approximately twice the thermal effect even when the same RF power and application time are used. ⑥ Non-invasive bipolar RF systems such as Wavplus can produce sufficient thermal effects even within the subcutaneous tissue. When used for preheating before needle RF treatment, they may maximize the effects of needle RF while minimizing procedural pain.