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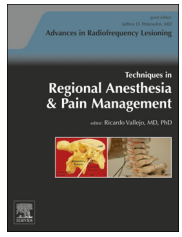

# Technical aspects of conventional and water-cooled monopolar lumbar radiofrequency rhizotomy

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ABSTRACT

Radiofrequency ablation (RFA) is a safe and effective pain therapy with efficacy principally reliant upon induced thermal damage of neural sensory afferents. Most peripheral RFA involves induced axonal damage but cell bodies may be involved indirectly. Radiofrequency electrodes (RFE) are not simple high-temperature probes and better insight regarding RFE function from an electrical engineering viewpoint may improve clinical outcomes by reducing the risk of poor or inadequate heating of the target nerves. RFE heating is highly influenced by the configuration and properties of the perielectrode tissues with the shape and size of RFE-produced protein coagulum seen in vitro with homogeneous media such as egg white, liver, or chicken skeletal muscle undoubtedly significantly different than the biological lesions occurring during in vivo clinical use. Understanding RFA requires consideration of the nature of the specific perielectrode tissues. A theoretical basis for optimized RFE function for lumbar medial branch (MB) neurotomy is presented with introduction of the concepts of clinically useful heating and useless heating. Conventional RFE is limited in the amount of current/heating produced for a given active electrode surface area before producing a radiofrequency generator fault and an inverse relationship exists between clinically useful heating and useless heating. Technical details of RFE function are discussed that may differ from presently accepted technique. Tined RFE, similar in function to conventional RFE, may offer a small advantage if properly used, and possibly a disadvantage if used incorrectly. Directly conducted heat is often neglected in considering RFA, but should be considered, especially with water-cooled RFE (WCRFE). Theory and empirical results suggest that WCRFE might become a preferred tool for much, but not all, RFA, but adoption has been limited by electrode cost and reimbursement policies. Conventional and tined RFE may produce poor outcomes if placed improperly, but complications due to overheating are quite rare. Conversely, WCRFE introduces far more heat into perielectrode tissues and reduces the likelihood of a poor clinical outcome, but avoidance of complications due to overheating of adjacent tissues requires a thoughtful understanding of the spatial and thermal characteristics of the WCRFE.



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## Introduction

Radiofrequency ablation (RFA) is a well-established procedure for damaging target tissues to treat disorders such as cardiac arrhythmias,[1,2] neoplasms,[3-8] and chronic low back pain felt to originate from the Zygapophyseal joints.[9-23,14,19,24] The primary efficacy of RFA in the treatment of pain presumably reflects heat-induced damage to peripheral sensory nerves. However, other processes may be involved, including electroporation,[25-30] damage to the Schwann cells, the *vasa nervorum*, or any other physiological process/structure essential to sensory nerve function.[31,32] Any concept that RFA functionally transects the medial branch, equivalent to transection with a scalpel or curette is unsupported in the literature. Much more likely, the heated nerve segment functions abnormally on a permanent basis, alters the transmission of the afferent pain signal from the periphery to the dorsal horn of the spinal cord, and altering the perception of pain, even distal to the local lesion site. Therefore, a partial, but probably permanent, nerve lesion is our goal in lumbar medial branch neurotomy (LRFA) as opposed to total obliteration of the nerve. In this article, LRFA also includes lesioning of the L5 dorsal primary ramus. In the case of LRFA, the "Target Tissue" is the neurovascular bundle in the medial branch groove over the middle third of the base of the superior articular process (SAP) in a lateral radiograph. Adverse effects may occur when adjacent tissues are heated.

RFA can be described in detail by physics, thermodynamics, and electrical engineering principles, but this requires extensive knowledge of these areas and requires a mastery of advanced mathematics. This article attempts to simplify and consolidate the phenomena discussed. Readers desiring a more detailed theoretical explanation are directed elsewhere.[33-42,41,43]

Only monopolar radiofrequency electrodes (RFE) are discussed in this article with implications for bipolar RFE configuration deliberately omitted. Monopolar RFA uses a grounding pad, or reference electrode (RE) placed sufficiently far from the RFE that it functions electrically only as a source/or sink for current with no appreciable heating occurring at the RE. This is consistent with commercial RF products used as directed.

Posterior declined oblique RFE positioning technique as described by Bogduk and Lau[31] and explicated in the Spine Intervention Society (SIS) guidelines[32] (Figure 1) is assumed in this article unless otherwise stated. Although the interventionalist has the option of positioning the electrode perpendicular to the nerve, perpendicular electrode geometry is meaninfully effective only with the water-cooled RFE (WCRFE), and possibly with some tined RFE. Additional clinical testing is needed with tined RFA (Figure 2).

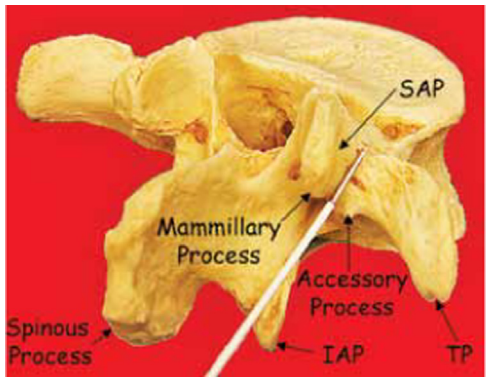


**Fig. 1 – Standard placement of conventional RFE with 10-mm active electrode length. Note that at least some of the rear portion of the 10-mm active electrode is likely within the longissimus thoracis pars lumborum (LTPL) muscle, whereas an RFE with a 5-mm active electrode length would generally be completely within the MB groove and not exposed to skeletal muscle.**

## Coagulum formation in vivo vs in vitro

To some readers, "Radiofrequency Ablation" conjures an image of a RFE immersed in an experimental medium such as egg white with a coagulum of heat-denatured protein surrounding the active tip of the electrode. Egg white is a favored laboratory medium because of low cost and ease of handling. At 62°-65°C, a mixture of egg white proteins readily precipitates to form a highly visible coagulum. Media used for testing RFE, including egg white, liver, and skeletal muscle, generally contain a large amount of water-soluble proteins in their most thermodynamically stable state. Formation of a protein coagulum around an RFE is a thermodynamically based event where heat-induced changes in protein conformation make these newly coagulated protein conformations the most thermodynamically stable state and it is these new water-insoluble "most stable" protein forms that make up the coagulum.

Other than establishing the denaturation temperature range of the egg proteins, conditions for coagulum formation are only very loosely related to the conditions required to produce a functional sensory nerve lesion in vivo.[44-51] In vitro use of chicken breast or liver is similarly limited. Nonetheless, the shape and size of the tissue coagulum is frequently plotted against heating time and temperature, and inferences are drawn to predict RFE behavior in vivo.[24,25] A lesion zone (LZ) for RFA is defined as the tissue area or volume around the RFE where the temperature has been raised sufficiently high and for a sufficient duration to produce adequate damage to the target nerve to achieve the clinical goal of reducing perceived pain, presumably through nonlethal permanent thermal injury.

The concept of a critical lesion temperature (CLT) is introduced here and it is the temperature, or more correctly, the range of temperatures required to induce an observable or clinically relevant physiological change in the lesioned tissue.[52] The CLT required to induce an observable change in vitro may not coincide with functional changes occurring in vivo. In vitro, egg white responds reliably to heating as does excised, nonviable, devascularized skeletal muscle or liver, but in the end, these models bear no perfectly understood relationship to interruption of the active biological processes involved in neural function. In vivo, an entity such as the Schwann cell may be much more, or less, susceptible