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Basic Sciences and Bioengineering of Microwave Hyperthermia in Limb Salvage

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The use of low and deep-set heat generated by high frequency alternating current as a means to destroy cancer cells was first proposed by Nikola Tesla in 1891 termed as “Medical Diathermy”. This innovative idea has gone through a long evolution in medical oncology now defined as “Hyperthermia” using different method to generate and deliver the heat to treat both resectable and un-resectable tumor. For musculoskeletal tumor, the most desirable method is the microwave dielectric heating method using pointed antenna to penetrate and reach various parts of the afflicted connective tissues. Although the scientific basis for tumor cell ablation and the technical aspects in limb salvage application are insufficiently established, QY Fan, of Xi’an, China has pioneered this method in extensive clinical trial since the early 1990s with impressive results. To assure a safe ablation margin in comparison to regular en bloc resection method, over-heating was implemented in all cases. Theoretically, hyperthermia has several major potential advantages: 1) optimal heat delivery could achieve safe and effective tumor ablation; 2) low temp treated bone, though completely devitalized, maintains greater biomechanical strength and with higher potential to regenerate; 3) the remaining osseous structure after curettage serves as biologic scaffold making reconstruction easier and with less metallic implant; 4) retain muscle-to-bone attachment to allow easier regeneration for better functional results.

However, there are several concerns that must be adequately addressed before widespread clinical trials could be safely recommended. These are: 1) assurance of tumor ablation to prevent local recurrence; 2) improvement in antenna design and surgical application; 3) ability to achieve optimal heat dispersion throughout the tumor bed with sufficient and desirable safety margin; and 4) adequate protection of normal tissue and organ surrounding and adjacent to the treatment field. These concerns could all be satisfactorily resolved through basic sciences research and bioengineering development. Using proper animal models and tissue type, different heat conduction and dispersion properties under realistic physiological conditions can be quantified and validated. Through advanced imaging techniques and simulation technology, pre-treatment planning and intraoperative execution steps can be worked out for optimal tumor cell ablation in different anatomical location and extend. Various cooling methods are available to protect the connective tissues and structure such as the cartilage, ligaments, tendon-to-bone junction etc. For the vessels, nerves, and spinal cord closely imbedded within the cancerous tissue bed may be managed by the irreversible electroporation technique currently explored by QY Fan.

Hyperthermia is a promising method to bring the current standard and success of limb salvage to a new level. To reach there, coordinated R&D effort is mandatory as no single institution can meet all the prerequisites in basic science, engineering technology and clinical trial to make this method well accepted. Musculoskeletal tumor is a relatively small field to attract major funding from available sources. Multi-institutional collaboration with foundation and industrial support may offer the opportunity to bring this practical, most important but low payback venture to reality. Thus far, it has been a dedicated effort of a single person and institution. However, their outcome we all have witnessed deserves proper consideration and support. Although the current science and technology of applying this method are limited, more clinical trials using the present method and instruments on difficult malignant cases involving the pelvis and the aggressive benign GCT in the long bones should be encouraged to solidify the theoretical advantages for the purpose of enhancing the confidence amongst the orthopaedic oncologists. This is one of the most desirable fields to harness the available high-tech in bioengineering, thus making computer-aided and robotic assisted limb salvage surgery a practical reality!