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A Survey on Radiofrequency Tissue Ablation

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ABSTRACT: Radiofrequency ablation, sometimes referred to as RFA, is a minimally invasive treatment for cancer. It is an image-guided technique that uses heat to destroy cancer cells. RFA is an effective treatment option for patients who might have difficulty with surgery or those whose tumors are less than one and a half inches in diameter. The success rate for completely eliminating small liver tumors is greater than 85 percent.

KEYWORDS: MWA, SAR, RFA, MCT, HCC

I. INTRODUCTION

Hepatocellular carcinoma (HCC) is one of the most common malignant tumors with an estimated 1,000,000 worldwide deaths per year. Persistent or recurrent liver disease is the major cause of both morbidity and mortality in patients with HCC. The liver is the commonest site of distant metastasis of colorectal cancer and nearly half of the patients with colorectal cancer ultimately develop liver involvement during the course of their diseases. Nearly 150,000 new cases of colorectal cancer will be diagnosed in the US each year with 57,000 deaths. Among men 40 to 79 years old, colorectal cancer is the second leading cause of cancer mortality. Primary and secondary malignant hepatic tumors are among the most common tumors worldwide [1-4].Though the ultimate control of this disease rests with the treatment of at-risk populations with vaccines for both hepatitis B and C, extirpation of tumor is the only potentially curative therapy for established cancers. Chemotherapy and radiation therapy are ineffective to treat liver tumors. Surgical resection is the gold standard for the treatment of patients with respectable isolated hepatic metastases with 40% 5 year and 26% 10 years survival. Patients without treatment will usually die in 1 to 5 years. Ablative treatments have started to become viable alternative methods to treat patients who cannot be treated by surgery. Such ablative treatments include cry ablation, radiofrequency ablation (RFA), microwave ablation (MWA) or also called microwave coagulation therapy (MCT), and ethanol ablation, etc[1].

II. RADIOFREQUENCY TISSUE ABLATION FUNDAMENTALS

The Radiofrequency ablation (RFA) is a treatment that uses imaging guidance to place a needle electrode through the skin into a liver tumor. High-frequency electrical currents are passed through the electrode, creating heat that destroys the cancer cells. RFA is an effective treatment option for patients who might have difficulty with surgery or those whose tumors are less than one and a half inches in diameter. The success rate for completely eliminating small liver tumors is greater than 85 percent.

Your doctor will instruct you on how to prepare. Inform your doctor if there's a possibility you are pregnant and discuss any recent illnesses, medical conditions, allergies and medications you're taking. Your doctor may advise you to stop taking aspirin, non-steroidal anti-inflammatory drugs (NSAIDs) or blood thinners several days prior to your procedure and instruct you not to eat or drink anything for several hours beforehand. Leave jewelry at home and wear loose, comfortable clothing. You may be asked to wear a gown. Plan to have someone drive you home afterward.

Radiofrequency ablation, sometimes referred to as RFA, is a minimally invasive treatment for cancer. It is an image-guided technique that uses heat to destroy cancer cells.

In radiofrequency ablation, imaging techniques such as ultrasound, computed tomography (CT) or magnetic resonance imaging (MRI) are used to help guide a needle electrode into a cancerous tumor. High-frequency electrical currents are then passed through the electrode to ground pads placed on the body, creating focal heat that destroys the cancer cells surrounding the electrode.

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Microwave ablation, also a minimally-invasive cancer treatment, also uses ultrasound, computed tomography (CT) or magnetic resonance imaging (MRI) to guide placement of a specialized needle-like probe into a tumor and uses microwaves to heat and destroy it. Microwave ablation is used for the same indications as for RFA. The procedure is typically performed on an outpatient basis or with overnight observation in the hospital with general anesthesia. Microwave ablation has advantages over radiofrequency ablation (RFA), including the ability to treat tumors that are larger and those that are close to major arteries and veins. It can also be used to treat multiple tumors simultaneously. For the patient, microwave ablation offers minimal risk, typically little or no pain and a short hospital stay. The procedure can be repeated if new cancer appears.

Microwave ablation is effective in overcoming the cooling effects of blood flow in the liver, which allows for larger ablation zones than RFA and other heat-based ablation methods

III. PROCEDURE FOR TREATMENT

Radiofrequency ablation is used to treat many types of liver cancer. The two most common types are:

- Hepatocellular carcinoma, which is a primary liver cancer (meaning it begins in the liver).
- Colon cancer that metastasizes or spreads from the colon to the liver.

In general, radiofrequency ablation is most effective treating tumors that are less than one and a half inches in diameter. It may be used in addition to chemotherapy or radiation therapy or as an alternative to surgical treatment.

Radiofrequency ablation is a viable and effective treatment option if patient:

- Are not a good candidate for surgery because tumor is difficult to reach?
- Have other medical conditions that make surgery especially risky.
- Would not have enough liver tissue left for the organ to function adequately following the surgical removal of a tumor.
- Have liver tumors that have not responded to chemotherapy or that have recurred after being removed surgically.
- You have several small liver tumors that are too spread out to be removed surgically.

IV. EQUIPMENTS USED

The equipment used in this procedure depends on the type of imaging used—magnetic resonance (MR), computed tomography (CT), or ultrasound. Other equipment such as needle electrodes, an electrical generator and grounding pads may also be used.

- **Radiofrequency equipment:** There are two types of needle electrodes: simple straight needles and a straight, hollow needle that contains several retractable electrodes that extend when needed. The radiofrequency generator produces electrical currents in the range of radiofrequency waves. It is connected by insulated wires to the needle electrodes and to grounding pads that are placed on the patient's back or thigh.
- **Computed Tomography (CT):** The CT scanner is typically a large, box-like machine with a hole, or short tunnel, in the center. You will lie on a narrow examination table that slides into and out of this tunnel. Rotating around you, the x-ray tube and electronic x-ray detectors are located opposite each other in a ring, called a gantry. The computer workstation that processes the imaging information is located in a separate control room, where the technologist operates the scanner and monitors your examination in direct visual contact and usually with the ability to hear and talk to you with the use of a speaker and microphone.
- **Ultrasound equipment:** Ultrasound scanners consist of a console containing a computer and electronics, a video display screen and a transducer that is used to do the scanning. The transducer is a small hand-held device that resembles a microphone, attached to the scanner by a cord. Some exams may use different transducers (with different capabilities) during a single exam. The transducer sends out inaudible, high—frequency sound waves into the body and then listens for the returning echoes from the tissues in the body. The principles are similar to sonar used by boats and submarines. The ultrasound image is immediately visible on a video display screen that looks like a computer or television monitor. The image is created based on the amplitude (loudness), frequency (pitch) and time it takes for the ultrasound signal to return from the area

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within the patient that is being examined to the transducer (the device used to examine the patient), as well as the type of body structure and composition of body tissue through which the sound travels. A small amount of gel is put on the skin to allow the sound waves to best travel from the transducer to the examined area within the body and then back again. Ultrasound is an excellent modality for some areas of the body while other areas, especially the lungs, are poorly suited for ultrasound.

- **Magnetic Resonance Imaging:** The traditional MRI unit is a large cylinder-shaped tube surrounded by a circular magnet. You will lie on a moveable examination table that slides into the center of the magnet. Some MRI units, called short-bore systems, are designed so that the magnet does not completely surround you. Some newer MRI machines have a larger diameter bore which can be more comfortable for larger size patients or patients with claustrophobia. Other MRI machines are open on the sides (open MRI). Open units are especially helpful for examining larger patients or those with claustrophobia. Newer open MRI units provide very high quality images for many types of exams; however, older open MRI units may not provide this same image quality. Certain types of exams cannot be performed using open MRI. For more information, consult your radiologist. The computer workstation that processes the imaging information is located in a separate room from the scanner.

Other equipment that may be used during the procedure includes an intravenous line (IV), ultrasound machine and devices that monitor your heart beat and blood pressure.

V. HOW TREATMENT PERFORMED

Image-guided, minimally invasive procedures such as radiofrequency ablation are most often performed by a specially trained interventional radiologist in an interventional radiology suite or occasionally in the operating room.

Radiofrequency ablation is often done on an outpatient basis and its positioned on the examining table.

- Patient is connected with monitors that track the heart rate, blood pressure and pulse during the procedure.
- A technologist will insert an intravenous (IV) line into a vein in patient hand or arm so that sedation medication can be given intravenously.
- The area where the electrodes are to be inserted will be sterilized and covered with a surgical drape.
- The physician will numb the area with a local anesthetic if the procedure is to be done while patient is awake. If general anesthesia is used, patient will have a breathing tube placed through mouth and into trachea after patient is asleep. The breathing tube will be connected to a breathing machine while patient is asleep.
- A very small nick may be made in patient skin to make it easier to pass the RFA electrode into the liver.

VI. METHODS OF RF ABLATION TECHNIQUE

Radiofrequency ablation is performed using one of three methods:

- Surgery.
- Percutaneous: In which needle electrodes are inserted through the skin and into the site of the tumor.
- Laparoscopic: In which needle electrodes within a thin, plastic tube is threaded through a small hole in the skin in a procedure called a laparoscopy.
- Using imaging guidance, physician will insert the needle electrode through the skin and advance it to the site of the tumor.Once the needle electrode is in place, radiofrequency energy is applied. For a large tumor, it may be necessary to do multiple ablations by repositioning the needle electrode into different parts of the tumor to ensure no tumor tissue is left behind.
- At the end of the procedure, the needle electrode will be removed and pressure will be applied to stop any bleeding and the opening in the skin is covered with a dressing. No stitches are needed.
- Patient intravenous line will be removed.
- Each radiofrequency ablation takes about 10 to 30 minutes, with additional time required if multiple ablations are performed. The entire procedure is usually completed within one to three hours.

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Advantage:

- Radiofrequency ablation can be an effective treatment for primary liver cancer and for cancers that have spread to the liver in select patients whose liver tumors are unsuitable for surgical resection.
- In most studies, more than half of the liver tumors treated by radiofrequency ablation have not recurred. The success rate for completely eliminating small liver tumors is greater than 85 percent.
- Treatment-related serious complications are infrequent and discomfort is minimal.
- Radiofrequency ablation may be used repeatedly to treat recurrent liver tumors.
- The percutaneous method of radiofrequency ablation, in which electrodes are inserted through the skin, is minimally invasive, produces few complications, and does not require hospital admission.
- RFA is a relatively quick procedure and recovery is rapid so that chemotherapy may be resumed almost immediately in patients who need it.
- Radiofrequency ablation is less expensive than other treatment options.
- No surgical incision is needed—only a small nick in the skin that does not have to be stitched.

Disadvantage:

- Any procedure where the skin is penetrated carries a risk of infection. The chance of infection requiring antibiotic treatment appears to be less than one in 1,000.
- Depending on the site of treatment, radiofrequency ablation may cause brief or, rarely, long-lasting shoulder pain; inflammation of the gallbladder that subsides after a few weeks; damage to the bile ducts resulting in biliary obstruction; or thermal damage to the bowel.
- Roughly one in four patients may develop a "post-ablation syndrome" with flu-like symptoms that appear three to five days after the procedure and usually last about five days. An occasional patient may remain ill for two to three weeks. Acetaminophen or ibuprofen taken by mouth is commonly used to control fever and other symptoms.
- Some cases of bleeding have been reported but it usually stops on its own. If bleeding is severe, an additional procedure or surgery may be needed to control it.
- Organs and tissues near the liver, such as the gallbladder, bile ducts, diaphragm and bowel loops, are at risk of being injured. Although this occurs only 3 to 5 percent of the time, it may require surgical correction. The risk of this complication is related to the location of the liver tumor that is treated.
- Less than one percent of patients may develop a localized infection (abscess) at the site of the tumor ablation three to four weeks after the treatment. A liver abscess will require tube drainage and antibiotics to cure. Patients who have had a surgical procedure in which the liver bile duct has been connected to a loop of bowel are at much greater risk of developing a liver abscess after ablation.
- Women should always inform their physician or x-ray technologist if there is any possibility that they are pregnant.
- This procedure may involve exposure to x-rays. However, radiation risk is not a major concern when compared to the benefits of the procedure.
- Severe pain after RFA is uncommon, but may last a few days and require a narcotic for relief.

VII. PROBLEMS AND CHALLENGES OF CURRENT RFA TECHNOLOGIES

MWA There is a limit to the volume of tumor tissue that can be eliminated by radiofrequency ablation. This is due to limitations with current equipment. Hopefully technical advances will permit larger tumors to be treated in the future. Radiofrequency ablation also cannot destroy microscopic-sized tumors and cannot prevent cancer from growing back.

VIII. LITERATURE REVIEW

Xiaoyin Tang et al. [2017] Radiofrequency ablation (RFA) is a relatively new procedure for treating benign thyroid nodules. The purpose of this study was to evaluate the safety and efficacy of RFA for treating benign thyroid nodules so as to serve as a reference for future clinical practice.This study retrospectively analyzed the clinical data of patients

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receiving percutaneous RFA for treating thyroid nodules from November 2014 to July 2015 in our medical center. One hundred and eight patients with a total of 380 nodules received ultrasound-guided RFA for treating thyroid nodules. Comparisons of the volume change of thyroid nodules before and after RFA treatment, post-treatment complication, and change of thyroid function, were carried out afterwards.Before treatments, all patients received fine needle aspiration biopsy (FNA) which supported the diagnosis of benign tumor. There were 13 males and 95 females included in the study. Twenty-six cases (24.07%) had single nodule, and 82 cases (75.93%) had multiple nodules. Before treatments, the thyroid functions (FT3, FT4, and TSH) were normal originally or adjusted to normal range by endocrinology treatment. The preoperative nodules had minimum volume of

0.01mL, maximum volume of 70.89 mL, and mean volume of 1.02 ± 4.24mL. The volume of nodules one month and three months after RFA were 0.29 ± 0.72mL and 0.15 ± 0.87mL, respectively. In addition, volume reduction ratio (VRR) of nodules one month and three months after RFA were 64.12% and 85.54%, respectively. Both volume of nodules and VRR had statistically significant differences for pre-operative and post-operative comparison ($P<0.05$). Thyroid functions were in normal range after treatments, and there was no serious complications.

Ultrasound-guided RFA treating benign thyroid nodules had the advantages of definite efficacy, safety, strong in control ability, no incision, less damage to surrounding normal tissues and no effect on thyroid function. It can be used as one of the main treatment methods for treating benign thyroid nodules.

Kazuyuki Saito et al.[2015]In recent years, various types of medical applications of microwaves have widely been investigated and reported. Among them, microwave thermal therapy is one of the useful applications and is modality for cancer treatment. In this treatment, there are several schemes of microwave heating. The authors have been studying thin coaxial antenna for intracavitary microwave heating aiming at the treatment of bile duct carcinoma. In this treatment, an endoscope is first inserted into the duodenum and a long and flexible coaxial antenna is then inserted into the forceps channel of the endoscope, which is used to insert the tool for surgical treatment. Finally, the antenna is guided to the bile duct through the papilla of Vater, which is located in the duodenum, and is inserted in the bile duct. Up to now, the heating characteristics of the antenna are investigated by numerical simulation, experiment using tissue-equivalent phantom and extracted organs. In this study, the authors have an experience on animal experiment using a swine. In the experiment, temperature rises around the antenna inserted into the bile duct were measured. From the results of this experiment, cooling effect by blood circulation was cleared.

MainiSurita et al. [2009]The purpose of this paper is to illustrate the microwave coagulation therapy (MCT) that can be used mainly for the treatment of hepatocellular carcinoma. In this treatment invasive technique are used in which thin microwave coaxial antenna is inserted into the tumor and the microwave energy heats up the tumor to produce the coagulated region including the cancer cells. We have to heat the cancer cells up to at least 60°C above which the cells are coagulated. It is very difficult to estimate the properties of a certain antenna shape, due to complicated relationship between the geometry of the antenna & the electromagnetic fields. To evaluate the performance of any antenna, computer simulations based on various numerical techniques are used. Finite Element Method is an efficient technique used for performing analysis of complex structures allowing the flexibility in changing the shape of the antenna. This method consists of representing a given domain, however complex it may be by geometrically over which the approximation functions can be systematically derived. The Finite Element Method not only overcomes the shortcomings of the traditional analytical and numerical methods but it also endowed with the features of an effective computational technique. FEM models can provide users with quick, accurate solutions to multiple systems of differential equations. Flexibility is the greatest advantage of finite element method with respect to the other traditional methods. In this method the subdivisions may consist of triangles, general quadrilaterals (of first order or higher orders) or their combinations with or without curved sides. These can be fitted very easily to the profile of any complex shaped domain. The grid can be made fine or coarse in different regions of the solution domain in a very flexible way as and when required. The solutions obtained by finite element method

using COMSOL Multiphysics, as compared with all numerical methods, are approximate,

though any degree of accuracy can be achieved provided sufficient numbers of elements are used. In many practical problems, however, the desired accuracy can be achieved with few elements. As with all numerical methods, separate solution is required for each set of parameter of a problem.

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SuritaMaini [2015]There are many perceived advantages of microwave ablation have driven researchers to develop innovative antennas to effectively treat deep-seated, non-resectable hepatic tumors. In this paper a coaxial antenna with a miniaturized sleeve choke has been discussed for microwave interstitial ablation therapy, in order to reduce backward heating effects irrespective of the insertion depth into the tissue. Two dimensional Finite Element Method (FEM) is used to simulate and measure the results of miniaturized sleeve choke antenna. This paper emphasizes the importance of factors that can affect simulation accuracy, which include mesh resolution, surface heating and reflection coefficient. Quarter wavelength choke effectiveness has been discussed by comparing it with the unchoked antenna with same dimensions.

Saito, K.[2010] Microwave thermal therapy is one of the modalities for cancer treatment. There are several schemes of microwave heating. The authors have been studying thin coaxial antenna for intracavitary microwave heating aiming at the treatment of bile duct carcinoma. Up to now, the heating characteristics of the antenna are investigated by numerical simulation and experiment for finding a possibility of the treatment. In this study, in order to consider practical situations of the treatment, heating characteristics of the antenna inserted into a metallic stent is evaluated by numerical simulations. Moreover, the relation between coagulation size of the tissue and the radiation power from the antenna is investigated experimentally. It must be considered, when the input power of the antenna is high (around several tens of watts). From these investigations, some useful results for practical treatments were found.

Saito, K [2011]In recent years, various types of medical applications of microwaves have widely been investigated and reported. Among them, microwave thermal therapy is one of the useful applications and is modality for cancer treatment. In this treatment, there are several schemes of microwave heating. The authors have been studying thin coaxial antenna for intracavitary microwave heating aiming at the treatment of bile duct carcinoma. In this treatment, an endoscope is first inserted into the duodenum and a long and flexible coaxial antenna is then inserted into the forceps channel of the endoscope, which is used to insert the tool for surgical treatment. Finally, the antenna is guided to the bile duct through the papilla of Vater, which is located in the duodenum, and is inserted in the bile duct. Up to now, the heating characteristics of the antenna are investigated by numerical simulation, experiment using tissue-equivalent phantom and extracted organs. In this study, the authors have an experience on animal experiment using a swine. In the experiment, temperature rises around the antenna inserted into the bile duct were measured. From the results of this experiment, cooling effect by blood circulation was cleared.

Kano Saito et al. [1999] Microwave coagulation therapy (MCT) has been used for the treatment of small hepatocellular carcinoma. In the treatment a thin microwave antenna is inserted into the tumor, and the microwave energy heats up the tumor to produce a coagulated region including the cancer cells. We have to heat the cancer cells up to at least 60 °C above which the cells are coagulated. Previously, the antenna for MCT has been developed only by experiment and numerical analysis has not been conducted. In this paper, we describe the numerical analysis of the antenna for MCT. During the MCT treatment, the medium properties of the tissue change because the characteristics of the tissue change as the temperature rises. Therefore we should consider this point when analyzing the heating performance of the antenna.

M. Chaichanyut et al. [2015] Microwave thermal therapy is one of the modalities for cancer treatment. There are several schemes of microwave heating. The authors have been studying thin Coaxial Quarter Conductor Antennas (CQCA) for intracavitary microwave heating aiming at the treatment of hepatic cancer. Experimental protocol was composed by a radiation microwave power system and a thermometry system. We apply the microwave power during experiments was 10W, 20W, 30W, 40W, 50W, 60W, 70W and 80W which we set the maximum temperature control at 90°C for all case Experiment, Thermal sensors were placed next to the antenna at 1mm, a large number of experiments on porcine liver are carried out, the temperature distribution within the porcine liver are measured , for cases of different injected microwave power. Experiment for finding a possibility of the treatment. In this study, in order to consider practical situations of the treatment, heating characteristics of the antenna inserted into sample tissue. Moreover, the relation between coagulation size of the tissue, the radiation power from the antenna and the volume of lesion which the hepatic cancer was successful hepatic ablation. From these investigations, some useful results for practical treatments were found.

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IX. RESEARCH METHODOLOGY

In hyper thermic oncology, cancer is treated by applying localized heating to thetumor tissue, often in combination with chemotherapy or radiotherapy. Some of the challenges associated with the selective heating of deep-seated tumors without damaging surrounding tissue are:

- Control of heating power and spatial distribution
- Design and placement of temperature sensors among possible heating techniques, RF and microwave heating have attracted much attention from clinical researchers

X. CONCLUSION

Radio Frequency coagulation therapy is one such technique where a thin Radio Frequency antenna is inserted into the tumor. The radiofrequency heat up the tumor, producing a coagulated region where the cancer cells are killed.

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