REVIEW

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THE ROLE OF INTERVENTIONAL RADIOLOGY IN THE TREATMENT OF BREAST TUMORS

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Summary

Radiological interventional procedures are minimally invasive techniques that use imaging guidance for the diagnosis and treatment of breast pathologies. These procedures involve various ablation methods that are used to destroy tumors by applying high or low temperatures. This group includes radiofrequency ablation (RFA), microwave ablation (MWA), high-intensity focused ultrasound (HIFU), laser-induced thermotherapy (LITT), and cryoablation. The main difference between them is the energy source they use. The goal of these ablative techniques is to destroy or decrease the size of unwanted lesions while using precise imaging guidance for monitoring. Compared to traditional surgery, interventional procedures have several benefits: being less invasive, having fewer complications, reducing hospital stays, and providing better cosmetic results. However, more research is needed to compare these radiological procedures and assess their long-term effectiveness and safety.

KEYWORDS: *ablation, breast, interventional radiology*

INTRODUCTION

Interventional radiology involves minimally invasive procedures with a lower risk of complications than invasive surgical procedures. It also provides better opportunities for disease diagnosis through procedures such as fine needle aspirations and tissue biopsies, allowing for more precise disease identification. These procedures are typically performed through minor percutaneous access points under X-ray control. However, today, ultrasound (US), magnetic resonance imaging (MRI), or computed tomography (CT) can also be used for visualization. Recently, interventional radiology has demonstrated certain benefits in the treatment of breast diseases compared to traditional surgical techniques(1,2).

Breast tumors are one of the most frequently diagnosed diseases in women. The increasing number of cases, younger age of newly diagnosed patients, intense emotional distress, and significant drop in quality of life are just some of the reasons why this issue remains concerning. Benign breast diseases often cause physical discomfort, affect the appearance of the breast, and cause anxiety but do not represent a direct threat to life. On the other hand, breast cancer continues to be a serious concern to women's health. It is the most common malignant tumor in women and a significant public health problem. Treatment of breast disease requires a multidisciplinary approach that includes radiologists, pathologists, surgeons, oncologists, and other health professionals(3,4).

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INTERVENTIONAL PROCEDURES FOR THE TREATMENT OF BREAST DISEASES

Surgical treatment of breast tumors has undergone an evolution over the past few decades. The removal of the malignant tumor has progressed from radical mastectomy, through modified radical mastectomy, to lumpectomy. The next inevitable step in advancing breast cancer treatment would be to replace lumpectomy with non-surgical methods, at least for a specific group of patients. Inserting a needle or catheter directly into the tumor and using heat, cold, or chemicals to destroy it is known as ablation. Therapeutic interventional procedures involve various ablation methods that destroy tissue. These techniques have been proven effective for lung, liver, and bone tumors. Their application in breast disease treatment is being studied, and the results are promising(5).

Minimally invasive treatments are associated with fewer complications, shorter hospital stays, and potentially lower costs. With a greater focus on cosmetic outcomes for patients, less invasive procedures emphasizing tissue preservation have become more common. However, these techniques have some limitations, such as the retention of the tumor since there is no surgical removal of the targeted tissue, which may cause concern for some patients. Another limitation is the lack of a tissue sample for final pathology analysis. Ablative techniques are often a more suitable option for patients with multiple comorbidities or poor health, where surgery is contraindicated(6).

Tumor ablation methods are evolving to provide less invasive treatment options. Tissue destruction is achieved through heat (hyperthermia) or cold (cryotherapy). At temperatures above 60°C, hyperthermia causes protein coagulation, leading to cell death. This method of tissue destruction is utilized in HIFU, RFA, MWA, and LITT. In contrast, cryoablation destroys tissue by cooling. The main complication is frostbite, i.e., skin or chest wall burns. Table 1. compares the characteristics of the leading interventional techniques for breast tumor treatment. The methods differ in energy source, temperature, side effects, the radiological technique used for guidance, price, time requirements, and degree of invasiveness(7). Every ablative technique has a different source of energy based on the physics of the generation of the waves. The highest temperature is used in RFA and MWA, while cryoablation is the only method with negative temperatures. Thus, the common side effect is frostbite, not burn or edema, as in heating ablative techniques. Various guidance methods can be used, but the US is the most common one, and every listed interventional procedure can be guided by the US. HIFU is used externally and, unlike others, is a non-invasive method. However, HIFU is the most expensive and demands the most time.

RADIOFREQUENCY ABLATION (RFA)

The application of RFA in breast diseases is a developing focus of research(8). This technique is used for the treatment of various tumors in the

Table 1.

Comparison of ablative techniques and their features.

Technique	Energy Source	Temperature °C	Common Side Effects	Guidance Method	Invasiveness	Time requirement	Price
High-Intensity Focused Ultrasound (HIFU)	Ultrasound waves	60-90	Burns, edema	US or MRI	Non-invasive	Long	Expensive
Radiofrequency Ablation (RFA)	Radiofrequency waves	95	Burns, edema	US, CT, or MRI	Minimally invasive	Medium	Affordable
Microwave Ablation (MWA)	Microwaves	90	Burns, edema	US or CT	Minimally invasive	Medium	Affordable
Laser-Induced Thermotherapy (LITT)	Laser light	60	Burns, edema	US, CT, or MRI	Minimally invasive	Medium	Affordable
Cryoablation	Cooling (cryogenic temperatures)	-40	Frostbite	US or CT	Minimally invasive	Medium	Affordable

HIFU– High-Intensity Focused Ultrasound, RFA– Radiofrequency Ablation, MWA– Microwave Ablation, LITT-Laser-Induced Thermotherapy

body, including those in the liver, lungs, kidneys, breasts, and bones. In this technique, low-frequency radio waves with long wavelengths generate heat, leading to coagulative necrosis. The procedure involves placing an electrode into the target tissue, through which high-frequency alternating current is passed. This current causes ionic agitation, creating molecular friction and heating the tissue. Unlike other techniques, in RFA, the heat is not delivered directly by the probe itself, which limits the volume of tissue that can be ablated. As a result, larger lesions often require multiple probes. RFA can be performed under US, CT, or MRI guidance and used percutaneously or during surgery(6,9). RFA generates gas bubbles within the ablation zone due to tissue heating approaching the boiling point. These gas bubble artifacts serve as acoustic markers, allowing the visualization of the heated tissue region on ultrasound, which corresponds to the ablated zone(10).

MICROWAVE ABLATION (MWA)

MWA uses electromagnetic waves to destroy tumors and is performed under US or CT guidance. This method uses heat production created by the movement of water molecules within the tissue in response to externally applied microwaves, resulting in necrosis of the targeted tissue(6). Microwave ablation is more effective at heating the targeted tissue than RFA due to differences in how the tissue is heated. In this way, microwaves can penetrate deeper tissues, which offers significant advantages over RFA(5,11).

HIGH-INTENSITY FOCUSED ULTRASOUND (HIFU)

HIFU is a non-invasive technique used for treating both benign and malignant tumors. The main benefit is that it is performed externally, meaning there is no need to place a probe or catheter inside the lesion during the procedure(12). HIFU is an ablation method where a focused ultrasound beam propagates through tissue as a high-frequency pressure wave, causing a temperature rise that leads to protein denaturation and coagulative necrosis. The HIFU beam can pass through the skin and tissues without causing damage and focus on a localized area, approximately 3-4 cm in diameter. The mechanism of this ablation method is often compared to focusing sunlight through a lens to start a fire(9). The primary principles behind HIFU tissue damage are coagulative necrosis from thermal effects and cavitation caused by ultrasound waves. Surrounding tissue remains unharmed, and no skin incisions are required. HIFU can be performed under US or MRI guidance, each with advantages and disadvantages. The US is a more affordable and accessible method, offering real-time imaging of anatomical structures. In contrast, MRI provides better visualization of morphology and soft tissue differentiation but is more expensive and time-consuming(13,14).

LASER INTERSTITIAL THERMAL ABLATION (LITT)

LITT utilizes principles similar to other thermal ablative methods. A laser fiber is inserted into the tumor, the laser is activated, and the tissue is heated to temperatures sufficient to cause necrosis (50°C). An additional probe is placed alongside the laser fiber to measure temperature, allowing precise temperature control. Laser ablation destroys the tumor by converting light into thermal energy, resulting in both direct and indirect damage to the surrounding tissue(9). Direct thermal damage occurs during heat exposure, while indirect damage happens after thermal ablation, causing progressive tissue damage, including tissue vaporization, microvascular injury, necrosis, and activation of immune cells. Laser ablation can be performed under US, CT, or MRI guidance. Three types of lasers are available: carbon dioxide, argon, and Nd-YAG(15,16).

CRYOABLATION

Cryoablation is the only technique that uses freezing instead of heat to induce tumor necrosis. A probe is placed into the tumor under US or CT guidance. By circulating liquid nitrogen or rapidly decompressing argon gas at the distal end of the probe, crystalline ice is formed. Cryotherapy causes cell damage through cycles of freezing and defrosting. Four biological damage mechanisms have been described: direct cell injury, vascular damage, ischemia, apoptosis, and immunomodu-

lation. Recent studies have shown that cell damage caused by cryoablation can increase the expression of tumor-specific antigens, potentially enhancing the immune system's ability to recognize and attack cancer cells. If cryoablation can induce a systemic tumor-specific response, it may improve tumor sensitivity to immunotherapy agents(17–19). One advantage of cryoablation over other ablation techniques is the phase change that occurs during ice formation, which can be visualized using the US, a method most applied for the procedure and treatment monitoring. Additionally, the cooling effect provides analgesia, meaning cryoablation does not require local anesthesia, unlike other ablation methods that use heat(20).

CONCLUSION

Although surgical techniques remain the gold standard in the treatment of breast tumors for now, new minimally invasive methods are achieving increasingly significant results and are becoming more integrated into the routine algorithm of breast cancer treatment. The advantages of minimally invasive methods lie in targeted tumor treatment while sparing surrounding healthy tissue, faster recovery, and shorter hospital stays. Each ablation technique shows varying results in achieving complete ablation, complications, and treatment duration, making it challenging to analyze outcomes and draw conclusions. The main disadvantage of all ablation techniques is the lack of histopathological findings, making it essential to determine pathology via biopsy before treatment and to monitor patients through imaging studies. The current level of experience is insufficient to determine one method as superior to the others definitively, and the choice of modality is typically based on the specific needs of each case and the operator's familiarity with a particular technique(5,21,22).

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Sažetak

ULOGA INTERVENCIJSKE RADIOLOGIJE KOD LIJEČENJA TUMORA DOJKI

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Radiološki intervencijski postupci minimalno su invazivne tehnike koje koriste slikovno vođenje za dijagnostiku i liječenje bolesti dojke. Obuhvaćaju različite metode ablacije koje uništavaju tumore primjenom visokih ili niskih temperatura. U ovu skupinu spadaju radiofrekvencijska ablacija (RFA), mikrovalna ablacija (MWA), fokusirani ultrazvuk visokog intenziteta (HIFU), laserska ablacija (LITT) i krioablacija. Glavna razlika među njima je izvor energije. Cilj ovih ablativnih tehnika je uništiti ili smanjiti veličinu neželjenih tvorbi uz precizno slikovno vođenje radi praćenja postupka. U usporedbi s tradicionalnim kirurškim pristupima, intervencijski postupci nude brojne prednosti, kao što su smanjena invazivnost, niže stope komplikacija, skraćeni boravak u bolnici i bolji estetski rezultati. Međutim, potrebna su dodatna istraživanja kako bi se usporedili različiti radiološki intervencijski postupci i procijenila njihova dugoročna učinkovitost i sigurnost.

KLJUČNE RIJEČI: *ablacija, dojka, intervencijska radiologija*