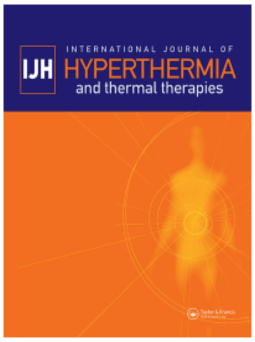

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Microwave ablation without subsequent lumpectomy versus breast-conserving surgery for early breast cancer: a propensity score matching study

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ABSTRACT

Purpose: To compare the efficacy of ultrasound-guided percutaneous microwave ablation (MWA) without subsequent lumpectomy and breast-conserving surgery (BCS) in patients with early breast cancer (BC).
Materials and methods: This retrospective cohort study enrolled 106 patients with early BC ($T_{0/1/2}$ $N_{0/1}$ M_0) treated by MWA ($n = 21$) or BCS ($n = 85$) from October 2014 to December 2020. Propensity score matching (PSM) was performed to balance the baseline characteristics between MWA and BCS groups. The tumor progression, overall survival (OS), disease-specific survival (DSS), complications, and cosmetic results were compared.
Results: After PSM, there were 21 patients with balanced baseline characteristics in each group. After a median follow-up of 43 months (range, 15–89 months), there was no significant difference in tumor progression (10% vs 2%, $p = 0.18$), OS (96% vs 99%, $p = 0.36$), DSS (100% vs 99%, $p > 0.99$), and complications (0% vs 19%, $p = 0.58$). The operation time of MWA was shorter (60 min vs 101 min, $p < 0.001$) than that of BCS. For the management of metastatic lymph nodes, five (5/21, 24%) patients with six metastatic nodes underwent ablation in the MWA group and three patients (3/21, 14%) with six metastatic nodes underwent axillary lymph node dissection in the BCS group. All the patients in the MWA group reported excellent cosmetic results, but 29% of BCS patients expressed dissatisfaction with breast asymmetry (10%) and scar formation (19%) ($p < 0.001$).
Conclusion: This pilot study indicated that in selected early BC patients, microwave ablation without subsequent lumpectomy had comparable tumor control effect with breast-conserving surgery and better cosmetic results at an intermediate follow-up.

HIGHLIGHTS

- MWA without subsequent lumpectomy has a comparable interim survival effect and better cosmetic results as BCS in the treatment of selected early breast cancer.
- MWA has the potential to be a viable and promising therapeutic option for breast cancer patients reluctant or intolerant to surgery with the advantage of minimal invasion.

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Introduction

Breast cancer (BC) is the most commonly diagnosed cancer worldwide and the second leading cause of cancer death among females [1]. As a result of the increased awareness among women and improvement in screening techniques, more patients are diagnosed with early BC [2]. Over the past decades, the treatment of early BC tends to be less invasive, with fewer complications and improved cosmetic results [3]. Breast-conserving surgery (BCS) has become the standard care for early BC and achieved comparable long-term survival to traditional mastectomy [4–7]. Even so, a small number of patients with early BC are intolerant to surgery because of their poor physical condition and 10% to 40% of patients treated with BCS reported being unsatisfied with cosmetic results for the reason of scar formation and breast asymmetry [8,9]. So it is a dilemma for surgeons to balance the oncological need for radical local resection with the desire for good cosmetic results.

There is a big potential for applying ablation techniques of BC treatment. Up to now, several studies have investigated the value of ablation techniques to treat BC, including cryoablation, laser ablation, high-intensity focused ultrasound (US), electroporation, radiofrequency ablation, and microwave ablation (MWA) [10,11]. Compared to surgery, ablation has the advantage of fewer complications, less hospitalization, and better cosmetic results without sacrificing the effect of tumor inactivation [12–14]. The majority of previous studies performed ablation with subsequent surgery and verified

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complete necrosis by the pathological result of the ablated lesions, which showed ablation techniques were effective for local tumor control and could obtain tumor-free margins [3,12,14]. Four preliminary studies have achieved short-term effects for BC control by ablation treatment without subsequent lumpectomy, which provided pilot evidence that ablation is a safe and feasible technique for the treatment of early BC [13,15–17].

Compared with other ablation techniques, MWA was proved to have a larger ablation area and higher intratumoral temperatures [14]. One preliminary study has proved that MWA without subsequent lumpectomy and nipple-sparing mastectomy achieved initially satisfactory results for BC $\leq$5.0 cm [13]. However, as a relatively recent technique in BC treatment, it remains unclear whether MWA without subsequent lumpectomy can be a potential alternative treatment for BCS. This cohort study was designed to compare the therapeutic efficacy of MWA and BCS in patients with early- BC with intermediate follow-up.

Methods

Patients

A single-center retrospective comparative study was conducted between October 2014 and December 2020, in which the electronic medical data of eligible patients were reviewed and recorded. The therapeutic protocol was jointly fully discussed by experienced surgeons, radiologists, and oncologists and determined by patients finally with full informed consent prior to treatment. The Human subjects committee approved our study and waived additional informed consent for this retrospective study (identifier number: S2021-22-01). The study was registered on *ClinicalTrials.gov* (identifier number: NCT04626986).

The inclusion criteria were as follows: (i) female patients; (ii) primary BC without previous treatment; (iii) breast invasive carcinoma diagnosed by histology; (iv) cTNM stage of $T_{0/1/2}N_{0/1}M_0$; (v) lesions detected clearly on the US for patients who chose to perform MWA. The exclusion criteria were as follows: (i) patients reluctant to undergo MWA or BCS; (ii) patients who underwent subsequent mammectomy after MWA or BCS; (iii) >3 multifocal or extensive carcinomas; (iv) diffuse malignant calcification; (v) inflammatory BC, Paget disease or mastitis; (vi) history of other malignancies; (vii) severe coagulopathy; (viii) pregnant or breastfeeding; (ix) loss to follow up. Patients who met all the inclusion criteria and none of the exclusion criteria were enrolled in the study.

Pre-operative evaluation

The decision of treatment modality was made by a team of experienced radiologists, breast surgeons, and oncologists based on the recommendations of National Comprehensive Cancer Network guidelines [15]. BCS is the standard practice for early BC and is recommended for patients who are willing to conserve their breasts. MWA was recommended as the treatment option for patients who were not a candidate for resection or were denied surgery. All the patients were completely informed of the potential benefits and risks before treatment. The preoperative evaluation consisted of the patient's general condition and image results (including US, contrast-enhanced ultrasound (CEUS), and contrast-enhanced magnetic resonance image (CEMRI)). The pathological diagnosis of the BCS group is based on the tissue of surgical specimens and the MWA group is based on multi-point core needle biopsies (16 G, Bard, Tempe, Ariz), which could reduce the risk of pathological diagnosis errors due to tumor heterogeneity as much as possible. All the pathologic specimens were evaluated by professional pathologists.

Treatment in the BCS Group

BCS is performed under general anesthesia by two specialized surgeons with more than 20 years of experience in breast surgery. The resection area extends 1–2 cm from the tumor margin. All the patients underwent sentinel lymph node (SLN) biopsy by the methylene blue method [16].

Treatment in the MWA Group

MWA was performed under local anesthesia by three specialized surgeons with more than 10 years of experience in the MWA. The microwave unit (KY-2000, Kangyou Medical, Nanjing, China) can produce 100 W of power at 2,450 MHz with a 16-gauge needle antenna. US guidance was performed with a GE LOGIQ E9 scanner (GE Medical Systems US & Primary Care Diagnostics, Wauwatosa, USA) with a 9.0 MHz Convex array transducer. When possible, the ablation region was expanded by at least 1 cm from the tumor margin on the US and CEUS. In addition, we prepared prophylactic ice and used saline dissection of the lesion and chest wall, nipple or skin to reduce the likelihood of thermal injury.

The status of lymph nodes was evaluated by CEUS (Sonovue, Bracco Company, Milan, Italy) or CEMRI (Signa Echo-Speed, GE Medical Systems, Milwaukee, WI, USA) before ablation and all the suspicious lymph nodes were CEUS-guided biopsied by core needle (16 G, Bard, Tempe, Ariz). When no suspicious lymph nodes were detected under CEUS and CEMRI, one SLN was percutaneously biopsied to validate the benign diagnosis. All pathologically malignant lymph nodes were ablated during the same procedure as BC ablation. The treatment details for the MWA procedure were described in our previous study [13].

Assessment and follow-up

The effect of the ablation was evaluated by CEUS immediately after MWA and CEMRI were performed within three days after MWA in patients with magnetic resonance image (MRI) tolerance. The technical success of MWA is defined as no enhancement of the entire tumor area during the arterial phase. The technical success of BCS is confirmed by the negative margins reported by post-operative pathology. All postoperative systematic therapy and radiotherapy principles are based on the National Comprehensive Cancer Network guidelines [15].

During the first year after treatment, all the patients were followed up by the US every three months and CEMRI/CEUS every six months. After the first year, patients were followed up every six months by the US and once a year by CEMRI/CEUS. Once a suspicious lesion was detected, biopsies were performed for further examination. In addition, lung computed tomography, brain MRI, abdominal contrast-enhanced computed tomography, and emission computed tomography will be performed to assess metastasis and recurrence. For the treatment of metastasis or recurrence, treatment modalities depend on patient preferences and the clinical practice of surgeons and oncologists. All the final decisions during treatment were made by consensus when a discrepancy arise.

The primary outcome was tumor progression, defined as the proportion of patients with local tumor progression, ipsilateral or contralateral breast progression, and systemic metastasis at the follow-up. Secondary outcomes included overall survival (OS) (defined as the time from the date of operation to the date of death due to any cause), disease-specific survival (DSS) (defined as survival rate after excluding death from the tumor itself and tumor treatment-related death), complication (defined as the occurrence of another disease or symptom caused by the development of disease [17]), and cosmetic result (categorized as poor, fair, good, or excellent according to American College of Surgeons and the Society of Surgical Oncology guidelines [18]). Besides, the pain intensity of patients was rated by the Numerical Rating Scale (NRS) [19].

All the clinical data (including basic characteristics, hospital information, complications, and adjuvant therapy) and follow-up information (including tumor progression, OS, DSS, and cosmetic results) were monitored by clinicians and statisticians not involved in the experimental study.

Statistical analysis

Clinical data and follow-up information were presented as percentages, means, or medians with SDs, and ranges. Differences between groups were analyzed with the $\chi 2$ test or Fisher test. Besides, propensity score matching (PSM) was performed at 1:1 with a caliper value of 0.02 to reduce bias in the evaluation of treatment effects. The variables were age, tumor size, and nodal state. Cox multivariate analysis was not performed due to the small number of outcome-related events. In this study, P values less than 0.05 were considered statistically significant. Data analyses were performed using SPSS version 26 software (IBM, Chicago, IL).

Result

Patients

The baseline characteristics are shown in Table 1. From October 2014 to December 2020, a total of 106 eligible early BC patients treated with MWA ($n = 21$) or BCS ($n = 85$) were enrolled in the study (Figure 1) with a median follow-up of 43 months. Prior to PSM, the mean patient age was 19 years older in the MWA group than in BCS group. In addition, patients in the MWA group had higher body mass index ($p < 0.001$), larger tumor sizes ($p < 0.001$), and more tumors ($p < 0.001$). After PSM, 21 patients were assigned to each group with a median follow-up of 35 months. The distribution of the propensity score among patients receiving the two different treatments is shown in Figure 2. All the variables were well balanced between the MWA and BCS group, including age ($p > 0.99$), body mass index ($p = 0.08$), postmenopausal ($p = 0.28$), tumor size ($p = 0.08$), tumor number ($p = 0.22$), tumor location ($p = 0.76$), tumor stage ($p = 0.85$) and subrogate molecular subtype ($p = 0.23$). MWA achieved comparable survival even when patients in the MWA group had poorer baseline physical condition and less tolerance for post-treatment.

Treatments

In the MWA group, patients chose MWA for poor physical condition (14/21, 67%) and reluctance to surgery (7/21, 33%). Twenty-one patients with 28 lesions received 23 MWA sessions, and all achieved technique success. Six malignant lymph nodes of five patients were ablated (including four patients with one lymph node each and one patient with two). Nineteen patients underwent MWA in one session. Two patients underwent a second ablation for the residual lesions assessed by CEMRI within three days of MWA. The maximum diameter of the primary tumor was 4.9 cm and 5.0 cm in both patients. Compared to BCS, fewer patients in the MWA group received chemotherapy (before PSM: 14% vs 62%, $p = 0.004$; after PSM: 14% vs 48%, $p = 0.02$) and radiation therapy (before PSM: 14% vs 88%, $p = 0.04$; after PSM: 14% vs 81%, $p < 0.001$) for their poor tolerance (Table 2). In the BCS group, 85 patients with 86 lesions before PSM and 21 patients with 26 lesions after PSM all achieved technique success within one procedure. 24% (20/85) of patients performed axillary lymph node dissection (ALND) according to the pathological results of SLN.

Before PSM, the operation time of the MWA group was significantly shorter than that of the BCS group (median 60 min vs 101 min, $p < 0.001$) (Table 2). There was nearly no intraoperative bleeding (median 3 ml, range 1–5 ml) in the MWA group, while the average intraoperative bleeding was 34 ml (range, 5–400 ml) in the BCS group ($p < 0.001$). However, the cost of MWA was slightly higher than the BCS group (median 27,406 RMB vs 19,874 RMB, $p < 0.001$). No statistical significance was observed in the hospitalization time (median 8 days vs 9 days, $p = 0.47$) and postoperative hospitalization time (median 3 days vs 4 days, $p = 0.81$) between the two groups. After PSM, compared to BCS, patients in the MWA group had shorter operation time (median 60 min vs 105 min, $p < 0.001$), less estimated blood loss (median 3 ml vs 24 ml, $p < 0.001$) but slightly higher hospitalization cost (median 27,406 RMB vs 19,592 RMB, $p = 0.02$). The hospitalization time (median 8 days vs 9 days, $p = 0.58$) and postoperative hospitalization time (median 3 days vs 3 days, $p = 0.90$) had no statistical significance.

Table 1. Baseline Characteristics for the Total Study Cohort and Propensity Score–matched Cohort.

Parameter	Total Study Cohort MWA Group (n = 21)	Total Study Cohort BCS Group (n = 85)	Total Study Cohort p Value	Propensity Score–matched Cohort MWA Group (n = 21)	Propensity Score–matched Cohort BCS Group (n = 21)	Propensity Score–matched Cohort p Value
Age (yr)[a]			0.00			>0.99
<50	2 (9.5)	51 (60.0)		2 (9.5)	2 (9.5)	
≥50	19 (90.5)	34 (40.0)		19 (90.5)	19 (90.5)	
Body mass index (kg/m^2)[a]	26.4 ± 4.1 (20.8-34.9)	23.4 ± 2.6 (17.6–31.2)	0.00	26.4 ± 4.1 (20.8–34.9)	24.4 ± 3.2 (1.6–31.2)	0.08
Postmenopausal	18 (85.7)	25 (29.4)	0.00	18 (85.7)	14 (66.7)	0.28
Mean max size (cm)[a]						
<2.0	9 (42.9)	63 (74.1)	0.01	9 (42.9)	15 (71.4)	0.32
2.1-3.0	5 (23.8)	16 (18.8)		5 (23.8)	3 (14.3)	
3.1-4.0	4 (19.0)	4 (4.7)		4 (19.0)	2 (9.5)	
4.1-5.0	3 (14.3)	2 (2.4)		3 (14.3)	1 (4.8)	
Tumor Number			0.00			0.22
1	16 (76.2)	84 (98.8)		16 (76.2)	20 (95.2)	
2	3 (14.3)	1 (1.2)		3 (14.3)	1 (4.8)	
3	2 (9.5)	0 (0.0)		2 (9.5)	0 (0.0)	
Tumor Location			0.71			0.76
left	11 (52.4)	39 (45.9)		11 (52.4)	9 (42.9)	
right	10 (47.6)	45 (52.9)		10 (47.6)	11 (52.4)	
Bilateral	0 (0.0)	1 (1.2)		0 (0.0)	1 (4.8)	
Tumor size			0.02			1.00
T1	9 (42.9)	59 (69.4)		9 (42.9)	10 (47.6)	
T2	12 (57.1)	26 (30.6)		12 (57.1)	11 (52.4)	
Nodal status			0.45			0.69
N0	16 (76.2)	73 (85.9)		16 (76.2)	18 (85.7)	
N1	5 (23.8)	12 (14.1)		5 (23.8)	3 (14.3)	
Tumor stage			0.12			0.85
T1N0M0	9 (42.9)	55 (64.7)		9 (42.9)	10 (47.6)	
T1N1M0	0 (0.0)	4 (4.7)		0 (0.0)	0 (0.0)	
T2N0M0	7 (33.3)	18 (21.2)		7 (33.3)	8 (38.1)	
T2N1M0	5 (23.8)	8 (9.4)		5 (23.8)	3 (14.3)	
Subrogate molecular subtype[b]			0.74			0.23
Luminal A	5 (23.8)	30 (35.3)		5 (23.8)	9 (42.9)	
Luminal B						
HER2 positive	9 (42.9)	27 (31.8)		9 (42.9)	6 (28.6)	
HER2 negative	1 (4.8)	6 (7.1)		1 (4.8)	1 (4.8)	
HER2 enriched (nonluminal)	0 (0.0)	3 (3.5)		0 (0.0)	2 (9.5)	
Triple negative	1 (4.8)	7 (8.2)		1 (4.8)	2 (9.5)	
Undefined	5 (23.8)	12 (14.1)		5 (23.8)	1 (4.8)	

Note.—Except where indicated, data are numbers of participants, with percentages in parentheses. MWA: microwave ablation; BCS: breast conserving surgery.
[a]Numbers in parentheses are the range.
[b]Luminal A: estrogen receptor (ER) and progesterone receptor (PR) positive, Ki67 level less than 20%, and human epidermal growth factor receptor type 2 (HER2) negative. Luminal B (HER2 negative): ER positive and HER2 negative (PR <20% or Ki67 ≥ 20%). Luminal B (HER2 positive): ER and HER2 positive (PR <20% or Ki67 ≥ 20%). HER2 enriched (nonluminal): ER and PR negative and HER2 positive. T riple negative: ER, PR, and HER2 negative.

Survival and tumor recurrence

Prior to PSM, two patients experienced a recurrence after MWA. One patient (subrogate molecular subtype: luminal A) was diagnosed with local tumor recurrence (LTR) (max diameter 1.4 cm) 42 months after MWA, but she refused any systematic treatment at 94 years old and died from pulmonary heart disease at 47 months after MWA. Another patient (subrogate molecular subtype: triple-negative, max diameter 1.2 cm) occurred three ipsilateral recurrence lesions five months after MWA and received a secondary ablation. Patients lost access to resection and adjuvant treatment for aplastic anemia. In the BCS group, one patient (subrogate molecular subtype: triple-negative, max diameter 0.6 cm) was diagnosed with ipsilateral breast progression at 13 months after BCS and received mastectomy without any recurrence during the follow-up period. Another patient (subrogate molecular subtype: luminal A, max diameter 1.9 cm) developed systemic metastasis (bone, liver, lung) at 41 months and died at 45 months after BCS. No patients were diagnosed with contralateral breast progression ($p > 0.99$) in both groups. However, the two patients were not matched in the PSM cohort. There was no significant difference in tumor progression (before PSM: 9.5% vs 2.4%, $p = 0.18$; after PSM: 9.5% vs 0.0%, $p > 0.99$), OS (before PSM: 95.5% vs 99%, $p = 0.36$; after PSM: 95.5% vs 100%, $p > 0.99$) and DSS (before PSM: 100% vs 99%, $p > 0.99$; after PSM: 100% vs 99%, $p > 0.99$) between two groups (Table 3).

Complications

No major complications occurred, but most patients developed slight skin redness and subcutaneous edema after ablation (subside within three days) or surgery (subside within one week). Before PSM, in the BCS group, six (6/85, 7%) patients developed breast hematoma (Table 3), which subside within 1–2 weeks without treatment measures. One (1/85, 1%) patient developed breast inflammation and was treated with oral antibiotics for four days. Seven (7/85, 8%) patients reported chronic pain on the surgical side of the axilla or upper arm with a median follow-up period of

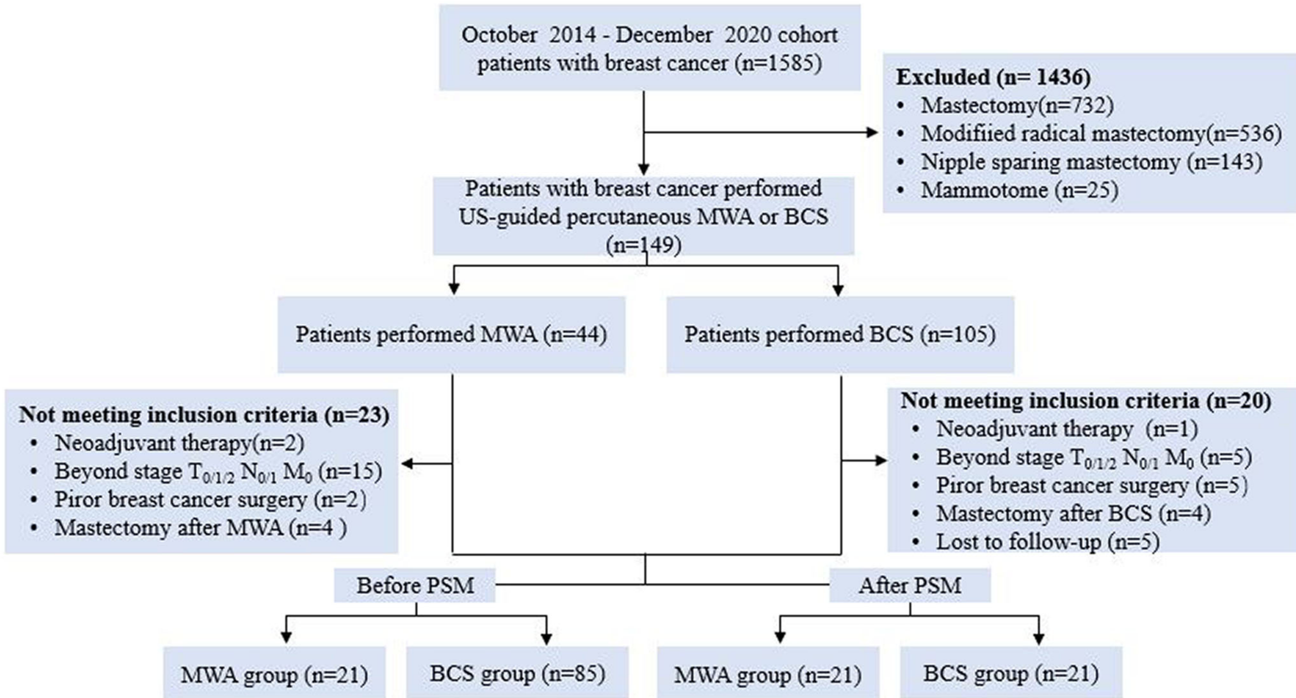

Figure 1. Flowchart shows participants in microwave ablation (MWA) and breast conserving surgery (BCS) group.

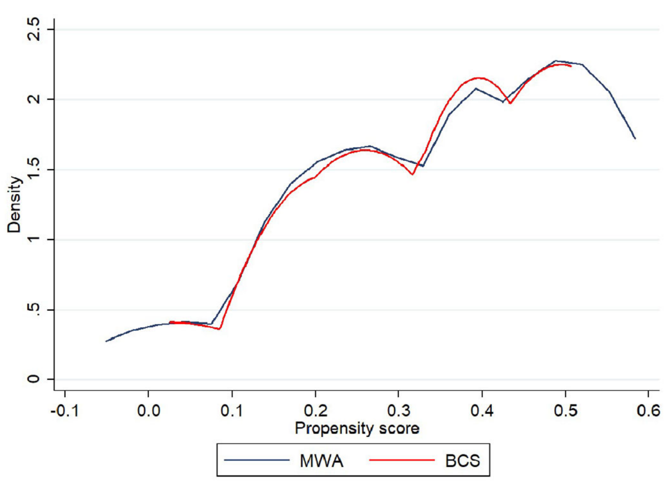

Figure 2. Distribution of the propensity score in patients who underwent MWA or BCS in the PSM population.

35 months. The mean pain intensity score was 2.3, based on NRS measurement without the need for analgesic administration. No patients in the MWA group reported complications during the follow-up. After PSM, four (4/21, 19%) patients developed minor complications (including two hematomas, one inflammation, and two pain) in the BCS group, which limited the patient's upper limb movement on the surgical side to some extent. However, there was no significant difference in minor complications both before (0% vs 17%, $p = 0.10$) and after (0% vs 19%, $p = 0.58$) PSM.

Cosmetic results

Before PSM, patients in the MWA group had better cosmetic results ($p = 0.01$) and all the patients reported excellent results (Table 4). No patients developed asymmetry or scar formation in the MWA group. In the BCS group, three (3/85, 4%) patients reported fair results, 21 (21/85, 25%) patients reported good results and 61 (61/85, 72%) patients reported excellent results. After PSM, one (1/21, 5%) patient reported fair results, five (5/21, 24%) patients reported good results and 15 (15/21, 71%) patients reported excellent cosmetic results. Patients didn't report excellent results for scar formation (29%) and breast asymmetry (10%) (Figure 3).

Discussion

For early BC, patients prefer to wipe out tumors entirely with satisfying cosmetic results [20]. Our preliminary results confirmed the hypothesis that MWA without subsequent lumpectomy can achieve the comparable effect as BCS for patients with early BC ≤5 cm. This study is the first to compare MWA without subsequent lumpectomy with BCS in the treatment of BC, achieving comparable results with an intermediate follow-up that can both explore the new therapeutic areas for MWA and expand treatment options for early BC.

To date, only four previous studies have explored ablation therapy for BC without subsequent lumpectomy, including two studies on radiofrequency ablation, one on laser ablation and one on MWA. These pilot studies achieved initially favorable effects, especially for aging female patients, which proved ablation without subsequent lumpectomy was feasible for selected BC patients [13,21–23].

Different from most previous studies focusing on BC ≤2cm [24], we enrolled patients with BC ≤5cm. Patients with advanced age and complex comorbidities resulted in reluctance or intolerant to standard treatment on schedule (such as surgery or adjuvant treatment), which induced gradually increasing tumor size up to 5 cm and larger. However, patients who choose to undergo BCS tended to be younger,

Table 2. Hospital Information and Adjuvant Therapy for the Total Study Cohort and Propensity Score–matched Cohort.

	Total Study Cohort			Propensity Score–matched Cohort		
Parameter	MWA Group (*n* = 21)	BCS Group (*n* = 85)	*p* Value	MWA Group (*n* = 21)	BCS Group (*n* = 21)	*p* Value
Hospital days (days)[a]	8 (2–21)	9 (2–30)	0.47	8 (2–21)	8.8 (2-30)	0.58
Postoperative hospitalization time (days)[a]	3.43 (1–15)	3.60 (1–8)	0.81	3.43 (1–15)	3.3 (1–6)	0.90
Anesthesia methods	local anesthesia	general anesthesia		local anesthesia	general anesthesia	
Operative time (mins[a]	60.0 (27–120)	101.0 (33–295)	0.00	60.0 (27–120)	105.3 (50–188)	0.00
Estimated blood loss (ml)[a]	3.19 (1–5)	33.7 (5–400)	0.00	3.19 (1–5)	24.3 (10–50)	0.00
Management of axillary lymph nodes	6 (28.6)	20 (23.5)	0.631	6 (28.6)	5 (23.8)	0.513
Contrast-enhanced evaluation						
CEMRI before treatment	14 (66.7)	7 (8.2)	0.00	14 (66.7)	2 (9.5)	0.00
CEMRI after treatment	15 (71.4)	3 (3.5)	0.00	15 (71.4)	0 (0.0)	0.00
CEUS before treatment	19 (90.5)	0 (0.0)	0.00	19 (90.5)	0 (0.0)	0.00
CEUS after treatment	6 (28.6)	0 (0.0)	0.00	6 (28.6)	0 (0.0)	0.03
Costs (RMB)[a]	27406.25 (17663.72–50090.4)	19874.71 (10414.49–52469.48)	0.00	27406.25 (17663.72–50090.4)	19592.28 (10414.49–52469.48)	0.02
Adjuvant systematic therapy						
Actual endocrine therapy	12 (57.1)	46 (54.1)	0.80	12 (57.1)	11 (52.4)	>0.99
Recommended endocrine therapy	15 (71.4)	66 (77.6)	0.753	15 (71.4)	18 (85.7)	0.452
Actual chemotherapy	3 (14.3)	53 (62.4)	0.004	3 (14.3)	10 (47.6)	0.04
Recommended chemotherapy	17 (81.0)	53 (62.4)	0.157	17 (81.0)	13 (61.9)	0.172
Actual radiation therapy	3 (14.3)	75 (88.2)	0.00	3 (14.3)	17 (81.0)	0.00
Recommended radiation therapy	21 (100.0)	85 (100.0)	>0.99	21 (100.0)	85 (100.0)	>0.99

Note.—Except where indicated, data are numbers of participants, with percentages in parentheses. MWA: microwave ablation; BCS: breast conserving surgery. CEMRI: contrast-enhanced magnetic resonance image. CEUS: contrast-enhanced ultrasound.
[a]Numbers in parentheses are the range.

Table 3. Follow-up Information and Complication for the Total Study Cohort and Propensity Score–matched Cohort.

	Total Study Cohort			Propensity Score–matched Cohort		
Parameter	MWA Group (*n* = 21)	BCS Group (*n* = 85)	*p* Value	MWA Group (*n* = 21)	BCS Group (*n* = 21)	*p* Value
Minor complication	0 (0.0)	14 (16.5)	0.10	0 (0.0)	4 (19.0)	0.58
Breast hematoma	0 (0.0)	6 (7.1)	0.47	0 (0.0)	1 (4.8)	0.29
Breast inflammation	0 (0.0)	1 (1.2)	>0.99	0 (0.0)	1 (4.8)	0.29
Chronic pain	0 (0.0)	7 (8.2)	0.38	0 (0.0)	2 (9.5)	0.08
Follow-up (mons)[a]	38 (16-59)	44 (15–89)	0.44	38 (16–59)	33 (15–81)	0.13
Tumor progression	2 (9.5)	2 (2.4)	0.18	2 (9.5)	0 (0.0)	0.48
Local tumor recurrence	1 (4.8)	0 (0.0)	0.20	1 (4.8)	0 (0.0)	>0.99
Ipsilateral breast progression	1 (4.8)	1 (1.2)	0.36	1 (4.8)	0 (0.0)	>0.99
Contralateral breast progression	0 (0.0)	0 (0.0)	>0.99	0 (0.0)	0 (0.0)	>0.99
Systematic metastasis	0 (0.0)	1 (1.2)	>0.99	0 (0.0)	0 (0.0)	>0.99
OS	20 (95.5)	84 (98.8)	0.36	20 (95.5)	21 (100.0)	>0.99
DSS	21 (100.0)	84 (98.8)	>0.99	21 (100.0)	21 (100.0)	>0.99

Note.—Except where indicated, data are numbers of participants, with percentages in parentheses. MWA: microwave ablation; BCS: breast conserving surgery; OS:overall survival; DSS: disease-specific survival.
[a]Numbers in parentheses are the range.

Table 4. Cosmetic Results of Total Study cohort and Matched Patients between the MWA and BCS Groups.

	Total Study cohort Patients			Propensity Score–matched Patients		
Parameter	MWA Group (*n* = 21)	BCS Group (*n* = 85)	*p* value	MWA Group (*n* = 21)	BCS Group (*n* = 21)	*p* value
Cosmetic results			0.01			0.01
Bad	0 (0.0)	0 (0.0)		0 (0.0)	0 (0.0)	
Fair	0 (0.0)	3 (3.5)		0 (0.0)	1 (4.8)	
Good	0 (0.0)	21 (24.7)		0 (0.0)	5 (23.8)	
Excellent	21 (100%)	61 (71.8)		21 (100%)	15 (71.4)	

Note.—Except where indicated, data are numbers of participants, with percentages in parentheses. MWA: microwave ablation; BCS: breast conserving surgery.

had smaller tumor sizes, better physical conditions and compliance with adjuvant treatment [25]. Thus, PSM was used to balance the bias between the two groups. We explore curative ablation indications from 2 cm to 5 cm, which will inevitably pose technical challenges for complete tumor eradication in three dimensions. In our experience, expanding the ablation boundaries, using higher powers and longer durations than benign breast tumors and timely detection of residual cancer under CEUS and CEMRI is very essential to ensure complete necrosis of malignant lesions. However, as a relatively new technique, careful pre-operative evaluation and close imaging follow-up need to performed to ensure the success of the technique, which is the reason why the cost of MWA was slightly higher than the BCS group. To our satisfaction, we achieved technique success in all the patients and comparable effects in tumor progression, OS

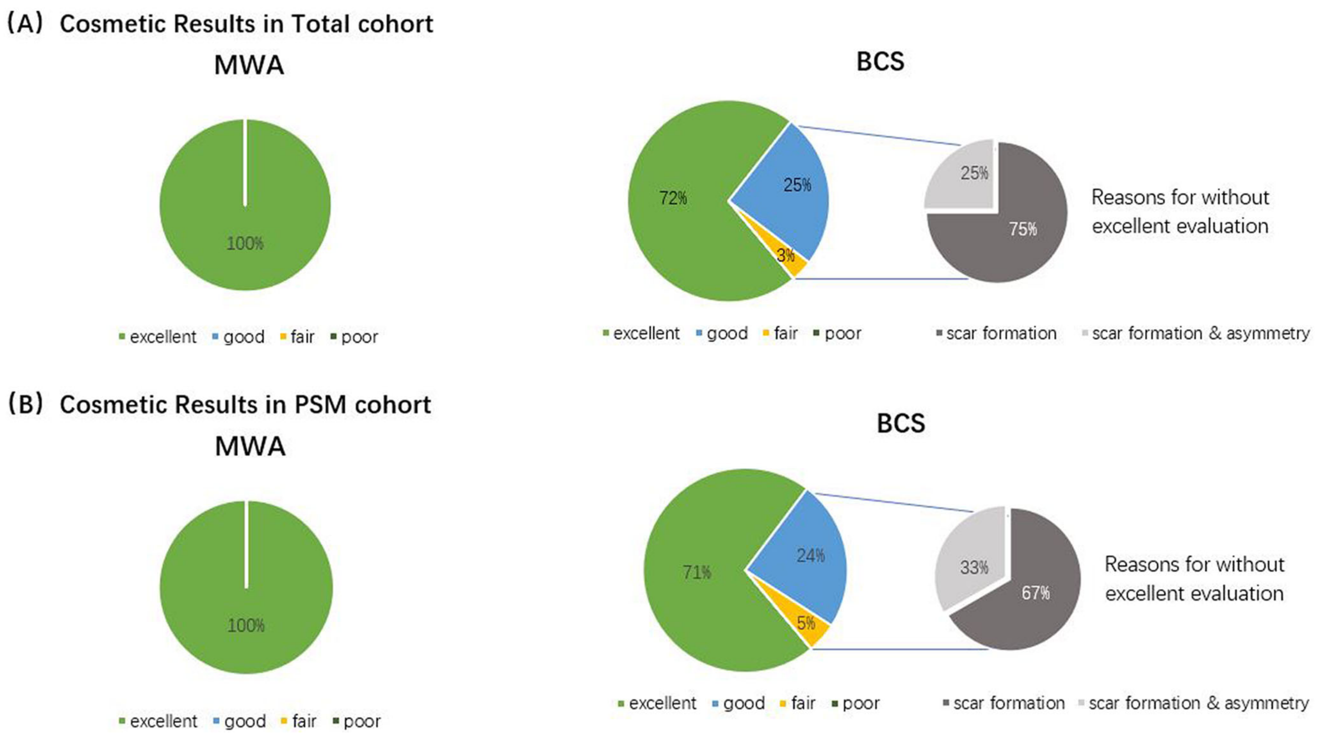

Figure 3. Cosmetic results and reasons for without excellent evaluation between ESBC patients who underwent MWA and BCS. (A) Cosmetic Results in Total cohort. (B) Cosmetic Results in PSM cohort.

and DSS between the MWA and BCS treatment with an intermediate follow-up. However, it should be pointed out that although MWA has similar prognosis to BCS statistically within a medium-term follow-up period, studies have shown that ablation tends to have a high incidence of tumor recurrence in hepatocellular carcinoma [26,27]. Further studies with larger samples and longer follow-up periods are necessary to verify the effects of MWA in early BC.

Another vital treatment strategy to ensure MWA effect is the management of axillary lymph node (ALN), which is a vital disputation for ablation of BC. We used both CEUS and CEMRI to detect the malignant lymph nodes and verified the diagnosis with percutaneous biopsies. After ablating all the malignant ALN and SLN based on the pathology results, no lymph node progression was detected during the follow-up. In addition, MWA did not induce the complications after lymph node therapy, while in the BCS group, seven patients reported that they still felt pain on the surgical side of the axilla or upper arm in their daily life at a median follow-up of 35 months. There has been evidence that ALND is not necessary when the tumor burden in the sentinel nodes is minimal or moderate in patients with early BC [28]. These provide potentially supportive evidence that, compared to ALND, ablating the malignant lymph nodes does sacrifice efficiency and leads to a higher quality of life, especially for patients with clinical oligometastatic imaging assessment. However, this needs further study with longer time to verify.

In addition to local treatment, postoperative treatment (including endocrine therapy, chemotherapy and radiation therapy) is an essential measure to reduce the recurrence of BC. However, only three patients in our study in the MWA group received both systemic and radiotherapy after ablation. Only two patients developed tumor progression, which might be related to relatively older patients (68 years, range 33-90 years) with lower speed of tumor growth [29,30]. The only LTR occurred in the first ablated case treated in 2014 and LTR occurred at 42 months after MWA, which may be attributed to the limited experience of radiologists to enlarge the ablation area at the beginning of the technique application and the elderly patient losing the chance of systematic treatment. However, there was no restriction on the prognosis with LTR, and the patient died of pulmonary heart disease at 47 months after MWA at the age of 94. No LTR occurred in BCS group, which might be attributed to good manipulation techniques with a history of almost four decades of application. However, the triple-negative subrogate molecular subtype is a challenge for BC progression after local treatment. In both groups, one patient developed ipsilateral breast progression despite receiving systemic therapy. Therefore, further exploration of the treatment of triple-negative BC is an important direction.

The most common risks following MWA for BC are skin burns and fat necrosis, but no complications occurred in our study due to the precise ablation technique and application of saline dissection. While no statistical significance was observed, BCS showed a higher percentage of minor complications. After BCS, in patients with early BC, removal of the lesion increases the incidence of postoperative complications such as pain, breast edema, hematoma, inflammation. In terms of cosmetic results, MWA eradicates tumors *in situ* with a spot-sized wound. However, after BCS, even for this minimally invasive surgery, it leaves surgical scars of 4–15 cm in length or asymmetry for the rest of life. As a result, MWA can provide an excellent option for patients with higher demanding cosmetic requirements.

There are several limitations to our study. First, it was a single-center, small-sample retrospective cohort study with unavoidable potential selection and indication biases. Thus, PSM is used to balance all the baseline variables. Second, more than half of the patients in the MWA group did not receive the standard post-operative treatment they should have because of their advanced age and poor physical condition. However, no difference in recurrence in our results suggests that MWA is feasible and effective for elderly female patients who have lost the opportunity for adjuvant therapy. Thirdly, we rely on CEUS and CEMRI to evaluate the success of MWA. Nevertheless, the CEMRI and the combined use of CEUS and CEMRI have been proven to have a decent diagnostic performance in BC diagnosis and BC ablation effect evaluation currently [31]. Finally, imaging examination of ALNs may result in false negatives. Although no progression of lymph nodes was observed during follow-up, it is necessary to explore better management of lymph nodes to balance the reduced quality of life caused by ALND with the complete elimination of carcinoma.

In conclusion, our study shows that MWA without subsequent lumpectomy has comparable effects to BCS in terms of selected early BC treatment and better cosmetic results. MWA has the potential to be a feasible and favorable option for patients who are reluctant or intolerant of BCS, especially for older women with a relatively minimal invasion advantage, although this preliminary result requires further investigation.

Author contributions

Dr Yu had full access to all of the data in the study and takes responsibility for the integrity of the data and the accuracy of the data analysis. Study concept and design: Yu-qing Dai, Ping Liang, Jie Yu; Acquisition of data: Yu-qing Dai, Ping Liang, Xiao-Ling Yu, Zhi-Yu Han, Fang-yi Liu, Xin Li, Shui-lian Tan, Zhen Wang, Chong Wu, Jian-ming Li, Jie Yu; Analysis and interpretation of data: Yu-qing Dai, Yan-chun Luo, Jie Yu; Drafting of the manuscript: Yu-qing Dai, Jie Yu; Critical revision of the manuscript for important intellectual content: Yu-qing Dai, Jie Yu.

Disclosure statement

We declare that the submitted manuscript does not contain previously published material, and are not under consideration for publication elsewhere. Each author has made an important scientific contribution to the study and is thoroughly familiar with the primary data. All authors listed have read the complete manuscript and have approved the submission of the paper. The manuscript is truthful original work without fabrication, fraud or plagiarism. All authors declare that there is no conflict of interest.

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Data availability statement

We understand the terms of the share upon reasonable request data policy and our data generated or analyzed during the study are available from the corresponding author by request.

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