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Safety and Efficacy of Microwave Ablation to Treat Pulmonary Nodules with Hydromorphone Versus Morphine

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Microwave ablation; Pulmonary nodules; Hydromorphone; Morphine; Computed tomography; Lung cancer

1. Abstract

1.1. Rationale and Objective: To compare the safety and efficacy of computed tomography-guided percutaneous microwave ablation (MWA) in treating pulmonary nodules under conscious analgo-sedation with hydromorphone versus morphine.

1.2. Materials and Methods: This was a retrospective before–after study. Between October 2020 and June 2022, 358 patients with 390 pulmonary nodules underwent 358 MWAs. Of these 358 patients who had consented to receive MWA treatment, 108 patients received morphine (group A) and 250 patients received hydromorphone (Group B). The individual characteristics of each patient and lesion, as well as technical information, clinical information, opioid-related complication, and numeric rating scale (NRS, 0=none, 10=worst) were collected and analyzed.

1.3. Results: There were no significant differences between groups A and B regarding postoperative hemodynamics. The analgesic effect and incidence of opioid-related side effects were significantly different between the hydromorphone and morphine group. Mild adverse events were found in 28 patients in group A versus 52 patients in group B ($P<0.001$). In terms of nodules ≤5 mm from the pleura and NRS>3, there were 12/69 (17.40%) patients in group A versus 7/97 (7.21%) patients in group B. The differences between the two groups were significant at NRS scores=0, 1–3, 4–6, and 7–9 (all $P<0.001$).

1.4. Conclusion: This research helps to guide the decision-making process of choosing morphine or hydromorphone for intraoperative analgesia. Hydromorphone injection is a more feasible, safe, and effective MWA analgesic than morphine for clinical application.

2. Introduction

Primary lung cancer is the most common cancer and the leading cause of cancer-related death worldwide [1-3]. With computed tomography (CT) being widely used in routine chest imaging and examination, pulmonary nodules are more frequently detected and distinguished from early lung cancer, precancerous, metastasis, or benign nodules. Considering the possibility of early-stage malignancy tumor, surgical resection is recommended. However, some patients may be unable or unwilling to undergo surgery for varied reasons. For example, patients with tumors in very unique locations and/or very close to the hilum are considered unsuitable for surgery, similarly, some patients with multiple pulmonary malignant nodules or with early-stage lung cancer associated with poor cardiopulmonary function, hypertension, and diabetes mellitus have reportedly abandoned surgical treatment because of their inability to tolerate anesthesia and surgery. Compared with the excellent survival rate of radical treatment by surgical resection for lung cancer, the efficacy of chemoradiotherapy is minimal. Therefore, there is an urgent clinical need to provide patients unsuited for surgery with a method that is partially close to or even as effective as surgical treatment.

Percutaneous CT-guided microwave ablation (MWA) has been a sought-after topic of local and international research in the past decade. It is a precise and minimally invasive local thermal ablation technique commonly used to treat primary or metastatic tumors. [4] The technique is associated with less trauma, easy operation, avoidance of general anesthesia, quick recovery after treatment, and fewer complications than other invasive techniques. Its efficacy and safety have been confirmed, and it has been increasingly used to treat selected pulmonary nodules [5-10]. MWA can deliver specific energy and heat to tumor tissues guided by imaging techniques, making the local tissue produce irreversible coagulation necrosis, leading to tumor necrosis and ultimately death of tumor cells. However, patients may experience pain due to local high-temperature stimulation. If the pain becomes intolerable, patients are likely to move during surgery, resulting in the offset of the microwave ablation tip direction, thereby affecting the progress of surgery and safety of patients [11]. Therefore, pain control is very important in MWA procedures.

There are no specified criteria for intraoperative analgesia in MWA treatment of pulmonary nodules. From our experience, conscious analgesia with hydromorphone/morphine in MWA has achieved good results. Currently, hydromorphone and morphine are the two most commonly used opioids. Hydromorphone is a semi-synthetic morphine derivative that was introduced as a derivative in the 1920s. Structural differences result in hydromorphone being approximately as potent as morphine owing to its altered chemical structure. Unlike morphine, hydromorphone does not form an active 6-glucuronide metabolite to be cleared, which may make hydromorphone more tolerable than morphine in patients with renal failure [12]. The relatively increased potency and favorable side effects of hydromorphone may guide the decision-making process of selecting hydromorphone for postoperative analgesia. However, a randomized controlled trial with a sample size of 402 compared morphine and hydromorphone with no difference in terms of analgesia and common side effects [13]. Therefore, the objective of this retrospective clinical study aims was to compare the safety and efficacy of percutaneous computed tomography-guided percutaneous microwave ablation (MWA) in treating pulmonary nodules under conscious analgo-sedation with hydromorphone versus morphine.

3. Materials and Methods

3.1. Patients

The Ethics Committee of Harbin Medical University Cancer Hospital approved the study, which was conducted in accordance with the tenets of the Declaration of Helsinki. Because only retrospective clinical data was collected in this study with no risk presented to the subjects, the need for written informed consent was waived.

Three hundred and fifty-eight patients receiving pulmonary nodular MWA from October 2020 to June 2022 were included in this study. The indications for MWA were as follows: (1) patients with pulmonary nodules showing increased size/density or appearing as solid fields on serial CT; (2) patients with pulmonary nodules with histological diagnosis of malignant disease after biopsy; (3) no abnormal coagulation capacity and platelet counts ≥100×109; (4) American Society of Anesthesiologists Grade I–II; (5) Eastern Cooperative Oncology Group physical status 0–2; (6) non-pregnant patients aged ≥18 years; and (7) those unfit for surgery due to advanced age, poor cardiopulmonary function or other co-morbidities, or high anxiety or fear of refusal. All patients were evaluated in a multidisciplinary treatment discussion and signed an informed consent form prior to ablation.

Exclusion criteria were as follows: (1) enhanced CT, positron emission tomography CT, enhanced magnetic resonance confirmation of local lymph node metastasis or distant metastases; (2) poor infection control; (3) severe coagulation disorders that could not be corrected; (4) platelet count ≤50×109 /L; (5) severe diseases of the heart, lung, brain, and other organs; (6) renal failure or liver failure; (7) anticoagulation and antiplatelet drugs were not taken in the past 1 week; (8) menstruating women; and (9) those allergic to morphine or hydromorphone.

Patients and lesion characteristics were collected, including patient demographics; maximum diameter and location of the lesions; and the blood vessels around the lesions. Furthermore, we recorded the details observed during the puncture and ablation procedures. Multiplanar CT images measured the distance between the skin entry points and the target lesions. Technical success is that the range of electrode ablation covers the lesion [14]. Ablations were stopped if target lesions were completely covered by the ablation zone with a 0.5-cm safety margin on the CT images. Treatment complications were assessed by operators according to the CT scans during the ablation procedures and classified according to the reporting criteria of the Society of Interventional Radiology (SIR) [15]. Treatment pain intensity was assessed using the NRS pain score. The technical efficacy of ablation was assessed by chest radiography plain film acquired 24 h after MWA procedure.

3.2. Instruments and MWA Procedure

The MWA system (ECO-100A1; ECO Medical Instrument Co., Ltd., Nanjing, Jiangsu, China) was guided by CT (GE Healthcare, Beijing, China), with a frequency of 2450 MHz, and an adjustable continuous wave output power of 0–150 W. The effective length of the microwave antenna was 100–180 mm, outer diameter was 14 mm, and the radiation tip was 1.5 cm long (tapered end). A water circulating cooling system cooled the surface temperature of the antenna.

The ablation protocol was designed by real-time CT based on the tumor size and location, determining the appropriate body position, surface puncture point, optimal puncture trajectory, number of antennas, and ablation power. Hydromorphone (Yichang Humanwell Pharmaceutical Co., Ltd. Yichang, Hunan, China) was administered intravenously before MWA at a dose of 0.67–2 mg/mL per patient. Hydromorphone (2 mg/mL) was added to 10 mL of 0.9% sodium chloride injection. Morphine (Northeast Pharmaceutical Group Shenyang First Pharmaceutical Co., Ltd., Shenyang, Jilin, China) was administered intravenously before MWA at a dose of 5–10 mg per patient. The antenna gradually penetrates the target focus and then begins to operate at a predetermined power and duration. In addition, the ablation needle was adjusted to reach a boundary 5 mm outside the target lesion. Finally, the puncture wound was disinfected and bandaged. At the end of the procedure, a repeat whole lung CT scan was performed to assess the degree of technical success and immediate complications. The procedure was considered successful when the tumor was treated as planned and the ablation area fully covered the target. Blood pressure, pre-anesthesia heart rate, minimum BP, and minimum heart rate during anesthesia were recorded. Adverse effects included nausea, vomiting, dizziness, nausea with vomiting and dizziness, urinary retention, and respiratory depression. The highest numeric rating scale (NRS) was also recorded. A chest radiography plain film was reviewed on day 2 after ablation and re-evaluated for complications and ablation results.

3.3. Statistical Analysis

Continuous parameters were expressed as mean±standard deviation (SD), while categorical variables were expressed as numbers and percentages. The independent t-test was used to compare continuous variables between two groups and the chi-square test was used to compare categorical variables. $p<0.05$ was considered statistically significant. Statistical analyses were performed with SPSS (SPSS for Windows ver. 27; IBM Corporation, Armonk, NY, USA).

4. Results

4.1. Patient Characteristics

Between October 2020 and June 2022, a total of 358 patients with 390 pulmonary nodules who underwent percutaneous CT-guided MWA were assessed in the present study. One hundred and eight patients (31 male and 77 female; mean age, 58.7±8.90 years; range, 31–73 years) were included in group A and 250 patients (92 male and 158 female; mean age, 60.2±9.90 years; range, 29–80 years) were included in group B. Eighty-five patients with pulmonary nodules were considered to have primary lung tumors that were not confirmed by pathology in group A. Seven patients underwent MWA after a synchronized needle biopsy in group A, among whom four patients were considered to have primary lung tumors confirmed by pathology. Twenty-one patients underwent MWA after a synchronized needle biopsy in group B, among whom nine patients were considered to have primary lung tumors confirmed by pathology. The majority of patients only received MWA therapy. Fifteen patients were pathologically confirmed to have lung cancer before MWA treatment in group A. Fifty-six patients were pathologically confirmed to have lung cancer before MWA treatment in group B. The primary tumors were intestinal cancer (n=2) and breast cancer (n=2) in group A. The primary tumors were intestinal cancer (n=4), breast cancer (n=3), thyroid cancer (n=4), liver cancer (n=4), nasal pharyngeal (n=4), ovarian cancer (n=4), and kidney cancer (n=4) in group B. Detailed patient characteristics are listed in (Table 1).

Table 1: Clinical features of 358 patients with Pulmonary nodules.

Patients' Characteristics	Group A (morphine, n=108)	Group B (hydromorphone, n=250)	P-value
Age (yr), mean (SD)	58.7±8.90 (31-75)	60.2±9.90（29-80）	0.621
Sex, male/female (n)	31(28.7)/77(71.3)	92（36.8）/158（63.2）	＜0.001
BW (kg)	62.1±10.4 (45-103)	62.7±11.2 (40-96)	0.3
Smoking history, Nonsmokers/ Smokers	81(75.0)/27(25.0)	182(27.2)/68(72.8)	＜0.001
Comorbidity			＜0.001
No	73(67.6)	172(68.8)	
Diabetes	6(5.60)	12(4.80)	
Cardiovascular diseases	4(3.70)	11(4.40)	
Hypertension	12(11.1)	25(10.0)	
More than two or more comorbidities	13(12.0)	30(12.0)	
Primary disease			＜0.001
Pulmonary nodules	85(78.7)	174(69.6)	
Lung cancer	19(17.5)	65(26)	
Intestinal cancer	2(1.90)	4(1.60)	
Breast cancer	2(1.90)	3(0.80)	
Thyroid cancer	0	4(0.40)	
Liver cancer	0	4(0.40)	
Nasal pharyngeal cancer	0	4(0.40)	
Ovarian cancer	0	4(0.40)	
Kidney cancer	0	4(0.40)	

Pulmonary function			
VC	2.43±0.70（1.55-4.04）	2.58±0.83（1.08-5.29）	0.12
VC%	84.7±17.5（60-112）	85.4±15.8（42-122）	0.758
FEV1	1.91±0.59（0.67-3.56）	1.98±0.67（0.53-3.75）	0.252
FEV1%	80.2±18.1（50-119）	79.5±17.4（30-118）	0.575

* *P*-value was calculated using the chi-square test for categorical variables and continuous data are expressed as mean ± SD (range). Numbers in parentheses indicate a percentage or range.

4.2. Technical Success and Ablation Efficacy

The success rate of MWA surgery was 100%. No patient died due to MWA. The mean tumor diameter of the patients in group A was 1.28±0.52 cm (range: 0.5–3.0 cm). Among them, 14 patients had tumors measuring ≥2.0 cm, 58 patients had tumors measuring ≤1 cm, and 44 patients had tumors ranging between 1 and 2 cm. One lesion was ablated in 101 patients, two lesions in six patients, and three lesions in one patient. We found the nodules located close to the pleura in 69 patients. Furthermore, 52 (44.8%), 28 (24.2%), 15 (12.9%), 12 (12.3%), and 9 (7.8%) patients received power therapy at 35, 40, 45, 50, and 55 W, respectively. The mean ablation time was 4.10±1.47 min (range: 1.0–7.5 min). Moreover, the mean operative time was 50.6±17.2 min (range: 2.0–14.0 min).

The pulmonary nodules in groups A and B were mainly located in the right upper lobe. The mean tumor diameter of the patients in group B was 1.34±0.66 cm (range: 0.20–4.30 cm). Among them, 41 patients had tumors measuring ≥2.0 cm, 129 patients had tumors measuring ≤1 cm, and 104 patients had tumors ranging between 1 and 2 cm. One lesion was ablated in 230 patients, two lesions in 17 patients, three lesions in two patients, and four lesions in one patient. We found the mean pulmonary nodules in group B patients were closer to the pleural membrane than those in group A (P=0.024), and the nodules were located close to the pleura in 97 patients. Twenty-six (9.5%), 183 (66.8%), 46 (16.8%), 14 (5.1%), 3 (1.1%), and 2 (0.7%) patients received power therapy at 30, 35, 40, 45, 50, and 55 W, respectively. The mean ablation time was 5.19±2.61 min (range: 2–14 min). The mean ablation time in group B was longer than that in group A (P<0.001). Moreover, the mean operative time was 59.4±21.7 min (range: 20–125 min). Two patients were treated with two antennas (Table 2).

Table 2: Characteristics of pulmonary nodules, parameters of microwave ablation and the treatment in 390 sessions.

† Data were presented as mean ± SD (range) and number (percentage). *P*-value was calculated using the independent t-test for continuous variables and the chi-square test for categorical variables. SD=Standard deviation, LU.L.=Left upper lobe of lung, L.L.L.=Left lower lobe of lung, RU.L.=Right superior lobe of lung, R.M.L.=Right middle lobe of lung, R.L.L.=Right lower lobe of lung.

	Group A (Morphine)	**Group B ((Hydromorphone)**	**P-value**
Tumor number in sessions（n）	116	274	＜0.001
Single lesion	101(93.5)	230(92.0)	
Two lesions	6(5.6)	17(6.8)	
Three lesions	1(0.9)	2(0.8)	
Four lesions	0	1(0.4)	
Tumor size (mm)	1.28±0.52(0.50-3.00)	1.34±0.66（0.20-4.30）	0.063
≤10	58（50.0）	129（47.1）	
>10, <20	44（37.9）	104（37.9）	
≥20	14（12.1）	41（15.0）	
Tumor site			0.087
LUL.	37 (31.9)	62（22.6）	
LLL.	17 (14.7)	32（11.7）	
RUL.	42 (36.2)	118（43.1）	
RML.	7 (6.0)	15（5.5）	
RLL.	13 (112)	47（17.1）	
Relationship to Costal pleur (mm)	1.70±0.46	1.26±0.99	0.024
≤5	69（59.5）	97（35.4）	
＞5	47（40.5）	177（64.6）	
Depth through lung tissue（mm）			-
≤5	35 (30.2)	0	
＞5	81 (69.8)	274（100）	

Number of ablation needles per procedure			-
Single	108（100）	248（99.2）	
Double	0	2（0.8）	
Power of MWA (W)			0.778
30	0	26（9.5）	
35	52(44.8)	183（66.8）	
40	28(24.2)	46（16.8）	
45	15(12.9)	14（5.1）	
50	12(10.3)	3（1.1）	
55	9(7.8)	2（0.7）	
Time of MWA per tumor			
Mean (min)	4.10±1.47	5.19±2.61	＜0.001
Range (min)	1-7.5	14-Feb	
Time of procedure			0.065
Mean (min)	50.6±17.2	59.4±21.7	
Range (min)	26-120	20-125	

4.3. Anesthesia Outcomes

The mean body weight in group A was 62.1±10.4 (45–103) kg, and the mean morphine dosage was 0.6±0.2 mg (0.5–1.0 mg). Before morphine injection, the mean systolic and diastolic pressures and heart rates were 137.3±17.9 (100–171) mmHg, 80.6±10.2 (44–105) mmHg, and 85.4±13.3 (51–124) times/min, respectively. Intraoperative minimum systolic blood pressure, minimum diastolic blood pressure, and minimum heart rates were 131.4±17.7 (90–172) mmHg, 74.9±12.3 (52–114) mmHg, and 50.6±17.2 (26–126) times/min, respectively. The mean body weight in group B was 62.7±11.2 (40–96) kg, and the hydromorphone dosage was 0.8±0.2 (0.5–2.0 mg). Before hydromorphone injection, the mean systolic blood pressure, diastolic blood pressure, and heart rates were 140.9±17.4 (102–194) mmHg, 84.0±10.2 (60–122) mmHg, and 85.1±14.3 (43–126) times/min, respectively. Intraoperative lowest mean systolic blood pressure, lowest mean diastolic systolic blood pressure, and lowest mean heart rates were 132.2±17.8 (93–186) mmHg, 79.4±9.2 (57–101) mmHg, and 76.8±12.2 (45–114) times/min, respectively. There was no significant difference between both groups (all P> 0.05).

Twenty-eight patients in group A had mild adverse events, including nausea (20.3%, 22/20.3), dizziness (11.1%, 12/108), vomiting (1.9%, 2/108), nausea and dizziness (2.42%, 3/124), nausea with vomiting and dizziness (2.42%, 3/124), urinary retention (2.8%, 3/108), arrhythmia (0.93%, 1/108), and stomachache (1.9%, 2/108). Furthermore, 90 (83.3%) patients had an NRS score of 0, 4 (3.7%) patients had an NRS score of 1–3, 4 (3.7%) patients had an NRS score of 4–6, and 10 (9.3%) patients had an NRS score of 7–9 (Table 3). Fifty-two patients in Group B had mild adverse events, including nausea (14.8%, 37/250), dizziness (4.0%, 10/250), vomiting (3.6%, 9/250), and urinary retention (4.8%, 12/250). One of the patients had severe nausea and vomiting; considering that the patient could not tolerate morphine, they were given naloxone 0.4 mg by intravenous injection, which relieved the symptoms of nausea and vomiting symptoms. There were no serious adverse events such as apnea, skeletal myotonia (thoracic muscle tonic rigidity), myoclonus, hypotension, tachycardia, anaphylaxis, and cardiac arrest that occurred in either group. The side effects between the two groups were statistically significant (P<0.001). During surgery, 225 (90.0%) patients had an NRS score of 0, 9 (3.6%) patients had an NRS score of 1–3, 10 (4.0%) patients had an NRS score of 4–6, and 6 (2.4%) patients had an NRS score of 7–9 [Table 3]. Details of the anesthesia results are recorded in Table 3. Finally, we found a statistically obvious difference in pain scores between the two groups (P<0.001).

Table 3: Anesthesia effect of morphine versus hydromorphone in microwave ablation for pulmonary nodules under awake sedation.

Variable	Group A Morphine(n=108)	Group B Hydromorphone(n=250)	P-value
Dose of anesthetic (mg)	0.6±0.2(0.5-1.5)	0.8±0.2（0.5-2）	
Pre anesthesia			
Systolic blood pressure (mmHg)	137.3±17.9(100-171)	140.9±17.4(102-194)	0.062
Diastolic blood pressure (mmHg)	80.6±10.2(44-105)	84.0±10.2(60-122)	0.258
Heart rate (times/min)	85.4±13.3(51-124)	85.1±14.3(43-126)	0.06
During anesthesia			

Lowest systolic blood pressure (mmHg)	131.4±17.7(90-172)	132.2±17.8(93-186)	0.702
Lowest diastolic blood pressure (mmHg)	74.9±12.3(52-114)	79.4±9.2(57-101)	0.52
Lowest heart rate (times/min)	50.6±17.2(26-126)	76.8±12.2(45-114)	0.099
Adverse effects	28(25.9)	52(20.8)	＜0.001
Nausea	22(20.3)	37(14.8)	＜0.001
Vomiting	2(1.9)	9(3.6)	＜0.001
Dizziness	12(11.1)	10(4.0)	0.001
Urinary retention	3(2.8)	12(4.8)	＜0.001
Arrhythmia	1(0.93)	0(0.0)	
Stomachache	2(1.9)	0(0.0)	
NRS score			
0	90(83.3)	225(90.0%)	＜0.001
3-Jan	4(3.7)	9(3.6%)	＜0.001
6-Apr	4(3.7)	10(4.0%)	＜0.001
9-Jul	10(9.3)	6(2.4%)	＜0.001
10	0	0	-

5. Discussion

There are very few reports on the choice of anesthesia during pulmonary nodule ablation. However, the expert consensus on thermal ablation of primary and metastatic lung tumors (2018 edition) states that general or local anesthesia can be used for thermal ablation depending on the patient's condition [16] Pouliquen et al. [17] reported that thoracic epidural anesthesia could solve the problem of patients requiring radiofrequency ablation (RFA) but with poor lung function. Hoffmann et al. explained that analgesic sedation for radiofrequency ablation could be used compared to general anesthesia [18].

It is still uncertain how to define the subpleural nodule. As reported by Hou et al., tubercles <30 mm from the chest wall were defined as subpleural pulmonary nodules [19] Okuma et al [20] reported that patients might experience severe pain during FA when the distance between the tumor and the chest wall is <10 mm. Gillams and Lees et al. [21] showed that, to ensure success, the range of the ablation zone should be at least 5 mm beyond the lesion boundary. When the pulmonary nodules are <5 mm away from the pleura, the pleura can be destroyed by high temperatures to achieve complete ablation, which may lead to pain or other complications in the patient. Therefore, our study defined the subpleural pulmonary nodules as any distance within 5 mm from the pleura. We specifically analyzed the NRS of subpleural nodules and other types of nodules in the morphine and hydromorphone groups separatel. This is important for evaluating the anesthetic effect of both groups. In our study, regardless of whether the nodule was located subpleurally, the NRS was only significantly different within the morphine group (P<0.001), but not in the hydromorphone group (P=0.703). Nodules ≤5 mm from the pleura and NRS >3 were observed in 12/69 patients in group A vs. 7/97 patients in group B. Moreover, we found the mean pulmonary nodules in group B patients were closer to the pleural membrane than those in group A (P=0.024). The above result could further explain the effectiveness of hydromorphone in treating pulmonary nodules through MWA.

Our study has some limitations. The sample size was small and not fully balanced between the morphine and hydromorphone groups, which may lead to different clinical outcomes, furthermore, because of the study is single-center retrospective design, the results we got may not be representative and may be at risk of bias and need to be validated in larger prospective studies. Anesthetizers may choose morphine because of patient intolerance to opioid side effects after getting hydromorphone during former surgery. This may lead to selection bias and differences.

6. Conclusion

The results of this study showed that hydromorphone injection is a more feasible, safe, and effective MWA analgesic than morphine and can be used for clinical application.

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