Conventional, diffusion, and dynamic contrast-enhanced MRI findings for differentiating metaplastic Warthin’s tumor of the parotid gland

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Abstract
The purpose of this study was to explore conventional, diffusion, and dynamic contrast-enhanced MRI (DCE-MRI) characteristics for differentiating metaplastic Warthin’s tumor (MWT) from other tumor types of the parotid gland, including non-metaplastic Warthin’s tumor (non-MWT), pleomorphic adenoma (PA), and malignant tumor (MT). A total of 178 patients with histologically proven tumors of the parotid gland, including 21 MWTs, 49 non-MWTs, 66 PAs, and 42 MTs, were enrolled in the study. Conventional MRI was performed in all patients. One hundred and fifty patients had preoperative diffusion-weighted MR imaging (DWI), and 62 patients had preoperative DCE-MRI. The differences in the conventional, DCE-MRI, and DWI records between MWTs and other tumor types were compared and analyzed.

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the other three tumor types were statistically evaluated. Compared with non-MWTs and PAs, there was a statistically significant difference in circumscription ($p < 0.01$). The ill-defined circumscription was more common in MWTs than non-MWTs and PAs. Compared with PAs, there was a statistically significant difference in morphology ($p < 0.05$). The lobulated morphology was more common in PAs than MWTs. Compared with PAs and MTs, there was a statistically significant difference in the $T_2$ signal of the solid component ($p < 0.01$). The $T_2$ moderate intensity of solid components was more common in MWTs than PAs and MTs. The solid components of PAs mostly showed hyperintense on $T_2$-weighted imaging. Cyst/necrosis was more common in MWTs than PAs and MTs. Hyperintense of cyst/necrosis was more common in MWTs and non-MWTs. With respect to contrast enhancement, 52.4% MWTs exhibited moderate or marked enhancement, and most non-MWTs (81.6%) exhibited mild enhancement. Most PAs (84.8%) exhibited marked enhancement. The mean ADC value of MWTs ($0.94 \times 10^{-3} \pm 0.11 \text{mm}^2/\text{s}$) was significantly lower than that of the PAs ($1.60 \times 10^{-3} \pm 0.17 \text{mm}^2/\text{s}$) ($p < 0.001$). On DCE-MRI, six of eight MWTs demonstrated TIC of type B. Although MWT is rare, conventional MRI characteristics, DWI and DCE-MRI can provide useful information for differentiating MWT from other parotid mass.

**Keywords**

Parotid neoplasms, metaplastic Warthin’s tumor, magnetic resonance imaging, diffusion-weighted imaging, dynamic contrast-enhanced MRI

**Introduction**

Warthin’s tumor (WT) is the second most common benign tumor, accounting for 5–15% of all salivary gland tumors. It is composed of oncocytic epithelial cells lining ductal and cystic structures in an ample lymphoid stroma. The metaplastic subtype is also called infected, infarcted WT, in which oncocytic epithelial cells have been replaced by metaplastic squamous and/or mucinous cells. Metaplastic Warthin’s tumor (MWT) is rare and approximately accounts for 6.2% (20/323 cases) to 7.6% of WT (21/275 cases). Pathologically, this subtype of WT may simulate malignant tumor (MT) of the parotid gland, specifically squamous cell carcinoma and mucoepidermoid carcinoma. Pleomorphic adenoma (PA) is the most common benign tumor of the salivary glands, with most occurring in the parotid gland, accounting for over 70% of benign epithelial tumors. In 1.8%–6.2% of cases, PA transforms into malignancy or carcinoma ex pleomorphic adenoma. Contrary to PA, malignant transformation seldom occurs in WT. The surgical treatment for WT, PA, and MT of the parotid gland differ. Therefore, an accurate preoperative diagnosis is essential to differentiate these tumor types.

MRI plays a crucial role in preoperatively differentiating WT, PA, and MT of the parotid gland. Additionally, advanced MRI techniques such as diffusion-weighted imaging (DWI) and dynamic contrast-enhanced MRI (DCE-MRI) can complement physiological and functional information for differentiating subtypes of the parotid gland neoplasms. However, because of the rarity of MWT, several previous imaging studies describing MWT are case reports, case series, or literature reviews. To our knowledge, no studies have explored conventional, diffusion, and dynamic contrast-enhanced MRI characteristics for differentiating
MWT. Therefore, the purpose of this study was to explore conventional, diffusion and dynamic contrast-enhanced MRI characteristics for differentiating MWT from other tumor types of the parotid gland, including non-metaplastic Warthin’s tumor (non-MWT), PA, and MT.

Materials and methods

Patients

This retrospective study was approved by our Institutional Review Board and informed consent was waived due to its retrospective nature. From January 2008 to August 2020, we retrospectively reviewed the MRI features of patients with histopathologically proven tumors of the parotid gland based on the WHO 2017 Classification of Head and Neck Tumors. All of the pathology specimens were assessed by an experienced pathologist with 15 years of experience (JM.Q.). Exclusion criteria included: (1) imaging artifacts that interfered with interpretation, (2) previous history of head or neck disease, and (3) the parotid tumor received biopsy, surgery, chemotherapy or radiotherapy. Eventually, a total of 178 patients with tumors of the parotid gland, including 21 MWTs, 49 non-MWTs, 66 PAs, and 42 MTs (2 carcinoma ex pleomorphic adenoma, 2 mucoepidermoid carcinomas, 4 adenoid cystic carcinomas, 16 acinar cell carcinomas, 7 lymphomas, 5 lymphoepithelial carcinomas, and 6 squamous cell carcinomas) were enrolled in the study.

MR imaging

MRI examinations were performed using a GE 3.0-T system (GE Medical Systems) with head and neck combined phased array coil. Patients were arranged in the magnet field in a supine position. MRI protocol contained the following sequences and parameters: axial T₁-weighted images (TR at 400 ms and TE at Min Full); axial and coronal fat suppressed T₂-weighted images (TR at 3000 ms and TE at 68 ms). One hundred and fifty patients were subject to echo-planar diffusion-weighted imaging (DWI) with three orthogonal diffusion gradients of \( b = 800 \text{s/mm}^2 \) and one acquisition with \( b = 0 \text{s/mm}^2 \). Sixty-two patients had preoperative dynamic contrast-enhanced MRI (DCE-MRI). In DCE-MRI scanning, a total of 13 dynamic phases were acquired for each investigation, and each phase contained 31 s. All patients underwent conventional contrast-enhanced MRI examination that included coronal and axial T₁-weighted images. A bolus of gadopentetate dimeglumine (Magnevist, Germany) was administered intravenously at a rate of 2.0 ml/s with a dose of 0.1 mmol/kg body weight.

Image analysis

All conventional MR images were analyzed through picture archive and communication system (PACS). Two radiologists (SY.W with 10 years of experience and...
CH.J with 13 years of experience in diagnostic radiology) reviewed MR images independently. Inter-observer agreement for MRI features for these patients was good and the agreement rate among inter-observers was 95.6%. The following MR features were analyzed: the maximum diameter, location, circumscription, morphology, T\(_1\) and T\(_2\) signal intensity, cystic/necrotic, and the enhancement pattern.

In cases with bilateral parotid tumors, we assessed the largest mass. The longest diameters of lesions were measured. Lesion sites were divided into right, left, superficial lobe, deep lobe, and parotid tail. The superficial and deep lobes were divided according to the retromandibular vein. The parotid tail was defined as the inferior 2.0 cm area of the gland. A circumscription of the tumor was defined as follows: well-defined if more than two-thirds of the margin was sharply demarcated from the surrounding tissue and ill-defined if less than one-third of the margin was sharply defined.\(^{19}\) The signal intensity on T\(_1\) weighted images was defined as follows: hypointense (less than that of adjacent muscles), moderate (similar or equal to that of adjacent muscles), or hyperintense (greater than that of adjacent muscles). The signal intensity on fat suppressed T\(_2\) weighted images was defined as follows: hypointense (less than that of parotid gland), moderate (similar or equal to that of parotid gland), or hyperintense (greater than that of parotid gland). Cystic/necrotic was defined as an area without enhancement.\(^{17}\) The enhancement pattern was categorized as mild (less than or equal to that of parotid tissue), moderate (greater than that of parotid tissue), or marked (greater than or equal to that of artery).\(^{17}\)

DWI and DCE-MRI were assessed using Functool 9.4.05 software on GE ADW4.6 workstation. Avoiding necrotic, cystic, hemorrhagic, or apparent vessel components, a region of interest (ROI) depending on tumor size were placed over the solid portion of mass to calculate apparent diffusion coefficient (ADC) maps. Additionally, DCE-MRI parameters were performed with a similar ROI to those of DWI. Time intensity curve (TIC) was automatically generated. According to the previous studies,\(^{13,20}\) the TICs were classified as four patterns: (1) Type A (persistent pattern): T\(_{\text{peak}} > 120\) s, (2) Type B (washout pattern): T\(_{\text{peak}} \leq 120\) s, washout ratio (WR) \(\geq 30\)%, (3) Type C (plateau pattern): T\(_{\text{peak}} \leq 120\) s, WR \(< 30\)%, (4) Type D (flat pattern): without prominent enhancing. The signal intensity (SI\(_{\text{pre}}\), SI\(_{\text{max}}\), and SI\(_{\text{5 min}}\)) and time (T\(_{\text{peak}}\)) were derived. SI\(_{\text{pre}}\), SI\(_{\text{max}}\), and SI\(_{\text{5 min}}\) were defined as the signal intensity of pre-contrast, maximal contrast enhancement, and 5 min after injection of the contrast agent respectively. T\(_{\text{peak}}\) was the time corresponding to the SI\(_{\text{max}}\). The WR of the lesion were calculated according to the following formulas:\(^{13,20}\) \(\text{WR} = (\text{SI}_{\text{max}} - \text{SI}_{\text{5 min}})/(\text{SI}_{\text{max}} - \text{SI}_{\text{pre}}) \times 100\%\).

**Statistical analysis**

The sample was described with descriptive statistics, containing means, standard deviation, frequencies, and ranges. The normality test of the continuous parameters was assessed using the Kolmogorov–Smirnov test. For comparison, one way analysis of variance (ANOVA) was used among ADC values of different
Results

Demographic characteristics of patients in the MWT and other parotid tumor groups

A total of 178 patients were enrolled in the current study, including 107 males and 71 females. The patients’ age ranged from 12 to 84 years old at diagnosis (mean ± standard deviation, 54.7 ± 15.1 years old). As shown in table 1, most of MWTs (90.5%) occurred in older men and the patients’ age ranged from 42 to 84 years at diagnosis (median, 60 years old). The male to female ratio of MWTs was about 9.5:1 (19:2). Sixteen (76.2%) of the tumors were located in the parotid tail and 18 (85.7%) in the superficial lobe. There was no statistical difference in age, gender ratio, and location between MWTs and non-MWTs (p > 0.05). However, there was a statistically significant difference in age and gender ratio among MWTs, Pas, and MTs (p < 0.05). PAs and MTs showed female predilection in this study, and the male to female ratios were about 1:1.75 (24:42) and 1:1.63 (16:26), respectively.

The conventional MRI features of the MWT and other parotid tumor

The conventional MRI features of parotid gland tumors are summarized in Table 1. There was no statistical difference in circumscription between MWTs and MTs (p > 0.05). However, when MWTs were compared with non-MWTs and PAs, there was a statistically significant difference in circumscription (p < 0.01). The ill-defined circumscription was more common in MWTs than non-MWTs and PAs (Figures 1–5). There was no statistical difference in morphology among MWTs, non-MWTs and MTs (p > 0.05). However, when MWTs were compared with compared with PAs, there was a statistically significant difference in morphology (p < 0.05). The lobulated morphology was more common in PAs than MWTs (Figure 4). On T1-weighted imaging, the solid components all exhibited hypointense or moderate intensity. There was no statistical difference in the T1 signal of solid component among these four tumor types. On T2-weighted imaging, there was no statistical difference in T2 signal of solid component between MWTs and non-MWTs. However, when MWT was compared with PAs and MTs, there was a statistically significant difference in the T2 signal of solid component (p < 0.01). The T2 moderate intensity of solid components was more common in MWTs than PAs and MTs (Figures 1, 4 and 5). The solid components of PAs mostly showed hyperintense on T2-weighted imaging. Cyst/necrosis was more common in MWTs than PAs and MTs. T1 and T2 signal of cyst/necrosis were heterogeneous in these
### Table 1. Demographic and conventional MRI Characteristics of four types of parotid gland tumors.

|                      | MWTs (n=21) | Non-MWTs (n=49) | PAs (n=66) | MTs (n=42) | $\chi^2$ or $F$ | p Value |
|----------------------|-------------|-----------------|------------|------------|----------------|----------|
| Mean age ± SD (years)| 62.2 ± 9.9  | 62.5 ± 7.4      | 48.8 ± 15.2| 50.9 ± 18.3| 12.364         | <0.001   |
| Sex                  |             |                 |            |            | 61.363         | <0.001   |
| Male                 | 19 (90.5)   | 48 (98.0)       | 24 (36.4)  | 16 (38.1)  |                |          |
| Female               | 2 (9.5)     | 1 (2.0)         | 42 (63.6)  | 26 (61.9)  |                |          |
| Mean tumor size ± SD (cm) | 3.2 ± 1.0  | 2.7 ± 0.9       | 2.3 ± 0.9  | 2.2 ± 1.1  | 6.332          | <0.001   |
| Location#            |             |                 |            |            | 14.821         | 0.022    |
| Right                | 6 (28.6)    | 21 (42.9)       | 33 (50.0)  | 24 (57.1)  |                |          |
| Left                 | 14 (66.7)   | 22 (44.9)       | 33 (50.0)  | 17 (40.5)  |                |          |
| Bilateral            | 1 (4.7)     | 6 (12.2)        | 0 (0.0)    | 1 (2.4)    |                |          |
| Circumscription#     |             |                 |            |            | 41.956         | <0.001   |
| Well defined         | 12 (57.1)   | 44 (89.8)       | 65 (98.5)  | 23 (54.8)  |                |          |
| Ill defined          | 9 (42.9)    | 5 (10.2)        | 1 (1.5)    | 19 (45.2)  |                |          |
| Morphology#          |             |                 |            |            | 23.994         | <0.001   |
| Lobulated            | 7 (33.3)    | 10 (20.4)       | 43 (65.2)  | 19 (45.2)  |                |          |
| Round-like           | 14 (66.7)   | 39 (79.6)       | 23 (34.8)  | 23 (54.8)  |                |          |
| T1 signal of solid component# | 2 (9.5)    | 0 (0.0)         | 5 (7.6)    | 1 (2.4)    | 5.44           | 0.142    |
| Hypointense          | 19 (90.5)   | 49 (100.0)      | 61 (92.4)  | 41 (97.6)  |                |          |
| Moderate             |             |                 |            |            | 88.225         | <0.001   |
| T2 signal of solid component# | 4 (19.0)  | 6 (12.2)        | 61 (92.4)  | 29 (69.0)  |                |          |
| Hyperintense         | 17 (81.0)   | 43 (87.8)       | 5 (7.6)    | 13 (31.0)  |                |          |
| Moderate             | 21 (100.0)  | 40 (81.6)       | 42 (63.6)  | 25 (59.5)  |                |          |
| Cyst/necrosis#       |             |                 |            |            | 29.819         | <0.001   |
| Hypointense          | 2 (9.5)     | 3 (7.5)         | 8 (19.0)   | 8 (32.0)   |                |          |
| Moderate             | 1 (4.8)     | 2 (5.0)         | 18 (42.9)  | 6 (24.0)   |                |          |
| Hyperintense         | 18 (85.7)   | 32 (80.0)       | 15 (35.7)  | 4 (16.0)   |                |          |
| Hypointense and hyperintense | 0 (0.0)   | 3 (7.5)         | 1 (2.4)    | 7 (28.0)   |                |          |

(continued)
Table 1. (Continued)

|                          | MWTs (n = 21) | Non-MWTs (n = 49) | PAs (n = 66) | MTs (n = 42) | \( \chi^2 \) or \( F \) | \( p \) Value |
|--------------------------|---------------|-------------------|--------------|--------------|----------------|--------------|
| **T₂ signal of cyst/necrosis\(^{a}\)** |               |                   |              |              |                |              |
| Hypointense              | 0 (0.0)       | 1 (2.5)           | 10 (23.8)    | 3 (12.0)     | 52.657         | < 0.001      |
| Moderate                 | 0 (0.0)       | 0 (0.0)           | 16 (38.1)    | 0 (0.0)      |                |              |
| Hyperintense             | 21 (100.0)    | 34 (85.0)         | 14 (33.3)    | 15 (60.0)    | 146.183        | < 0.001      |
| Hypointense and hyperintense | 0 (0.0)       | 5 (12.5)          | 2 (4.8)      | 7 (28.0)     |                |              |
| **Enhancement pattern\(^{a}\)** |               |                   |              |              |                |              |
| Mild                     | 10 (47.6)     | 40 (81.6)         | 0 (0.0)      | 1 (2.4)      |                |              |
| Moderate                 | 7 (33.4)      | 9 (18.4)          | 10 (15.2)    | 23 (54.8)    |                |              |
| Marked                   | 4 (19.0)      | 0 (0.0)           | 56 (84.8)    | 18 (42.8)    |                |              |

MWTs: Metaplastic Warthin’s tumors; Non-MWTs: non-Metaplastic Warthin’s tumors; PAs: pleomorphic adenomas; MT: malignant tumors.

\(^{a}\)Data represent the number (%) of tumors.
tumors. However, $T_1$ hyperintense of cyst/necrosis was more common in MWTs and non-MWTs (Figure 1). With respect to contrast enhancement, 52.4% MWTs exhibited moderate or marked enhancement and most non-MWTs (81.6%) exhibited mild enhancement. Most PAs (84.8%) exhibited marked enhancement.

### DWI and DCE-MRI findings of the MWT and other parotid tumor

The mean ADC values and TIC types for different types of parotid gland tumors are shown in Table 2. There was a significant difference in ADC values among the four groups ($F = 83.992$, df = 3, $p < 0.001$). There was no statistical difference in ADC values among MWTs, non-MWTs and MTs after Bonferroni correction. However, the mean ADC value of MWTs ($0.94 \times 10^{-3} \pm 0.11 \text{mm}^2/\text{s}$) was significantly lower than that of the PAs ($1.60 \times 10^{-3} \pm 0.17 \text{mm}^2/\text{s}$) ($p < 0.001$) (Figure 6). On DCE-MRI, six of eight MWTs demonstrated TIC of type B (Figures 1 and 2) and two MWTs showed TIC of type C. There was no statistical difference in

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**Figure 1.** Metaplastic Warthin’s tumor of the left parotid gland in a 72-year-old male. Axial T1 weighted (a) and T2 weighted (b) MR image shows a well-defined and round-like mass with mixture of hyperintense and moderate signal. The round cursors mark the regions of interest selected (c and d) for the measurement of the apparent diffusion coefficient (ADC) value in ADC map and (a) for signal intensity measurement on dynamic MRI. The ADC value of lesion is $1.02 \times 10^{-3} \text{mm}^2/\text{s}$, and (e) time–signal intensity curve shows a washout pattern (type B).
Figure 2. Metaplastic Warthin’s tumor of the right parotid gland in a 65-year-old male: (a) axial T1 weighted MR image shows a moderate signal and round-like mass, (b) on T2WI, the solid component shows moderate signal and cyst/necrosis shows hyperintense, (c) the lesion shows ill-defined circumscription and mild enhancement. The round cursors mark the regions of interest selected (d) for the measurement of the apparent diffusion coefficient (ADC) value in ADC map and (e) for signal intensity measurement on dynamic MRI. The ADC value of lesion is 0.78 × 10⁻³ mm²/s. (f) Time–signal intensity curve shows a washout pattern (type B).

Figure 3. Metaplastic Warthin’s tumor of the left parotid gland in a 62-year-old male: (a) axial T1 weighted MR image shows a well-defined and round-like mass with moderate signal, (b) on T2WI, the solid component shows moderate signal and cyst/necrosis shows hyperintense, and (c) the solid component of lesion shows moderate enhancement.
TIC type between MWTs and non-MWTs. However, most PAs (90%) exhibited TIC of type A (Figure 4).

Radio-pathological relationships of the MWTs

The MWT capsules were intact in 12 (57.1%) and not intact in 9 (42.9%) of 21 resected specimens. Correspondingly, on MRI examination, 12 cases had a clear boundary and 9 cases had an unclear border (Figure 7). The cut surface of solid component in the MWT was gray-yellow or gray-white with different-sized cysts. Fluid within the cysts varied from clear-colored, milky, yellowish brown to purulent or hemorrhagic, including white pus in 9 cases and sanguineous discharge in 14 cases. Correspondingly, on $T_1$-weighted imaging, the solid components exhibited hypointense in 2 cases and moderate intensity in 19 cases (Figure 7(a)). On $T_2$-weighted imaging, the solid components exhibited hyperintense in 4 cases and moderate intensity in 17 cases. On MRI examination, all MWTs appeared different-

Figure 4. Pleomorphic adenoma of the right parotid gland in a 43-year-old female: (a) axial $T_1$ weighted MR image shows a moderate signal and lobulated mass, (b) on $T_2$WI, this mass shows hyperintense. The round cursors mark the regions of interest selected (c) for the measurement of the apparent diffusion coefficient (ADC) value in ADC map. The ADC value of lesion is $1.60 \times 10^{-3}$ mm$^2$/s, (d) the lesion shows well defined circumscription and marked enhancement, (e) the round cursors mark the regions of interest selected for signal intensity measurement on dynamic MRI, and (f) time–signal intensity curve shows a washout pattern (type A).
sized cysts. On $T_1$-weighted imaging, the cyst components exhibited hyperintense in 18 cases (Figure 7(a)), moderate intensity in 1 case and hypointense in 2 cases. On $T_2$-weighted imaging, the cyst components all exhibited hyperintense. Fiber septum in various degrees was seen in all MWT. Therefore, the capsule wall and septum of MWTs showed low signals on $T_1$WI and $T_2$WI (Figure 7). Microscopically, tumor tissue was composed of cystic adenoid-like structures which showed characteristic papillary architecture with a bilayer-cell epithelial lining. Germinal centers of lymphoid follicle and oncocytic epithelial cells with squamous metaplasia were also seen in tissues of MWTs (Figure 7(f)).

**Discussion**

In the present study, we assess the preoperative conventional MRI findings of MWTs and evaluate these rare entities’ DWI and DCE-MRI metrics. WT predominates for the fifth to seventh decades of life and has a significant male
Among 21 patients with MWT in our study, the median age was 60 years old and the male to female ratio was as high as 9.5:1. The age and sex distribution of MWTs in the current study were consistent with those of WT in prior studies. However, there was a statistically significant difference in age and gender ratio among MWTs, PAs, and MT ($p < 0.05$). PAs and MTs showed female predilection in this study, and the male to female ratios were about 1:1.75 (24:42) and 1:1.63 (16:26), respectively. One study shows that using age or gender as an independent predictor in the diagnosis of parotid gland WTs may improve diagnostic accuracy. In addition, as shown in our study, MWT is characterized as a lesion located in the parotid tail and the superficial lobe, which is similar to those of WT in previous studies. The fact that the parotid gland’s lower pole contains the majority of intra-parotid lymph nodes may be consistent with the lymphoid component within WT. Consequently, our results support this hypothesis.

On MR imaging, ill-defined margins may predict high-grade malignant neoplasms or inflammatory lesions. However, there was no statistically significant difference in ADC values or TIC types among the four types of parotid gland tumors. Table 2 and Figure 6 show the mean ADC values and TIC types for each type of tumor.

Table 2. The mean ADC values ($\times 10^{-3}$ mm$^2$/s) and TIC types of parotid gland tumors.

|                | MWTs     | Non-MWTs  | PAs       | MTs       | $F$      | $p$ Value |
|----------------|----------|-----------|-----------|-----------|----------|-----------|
| Mean ADC value | 0.94 ± 0.11 | 0.84 ± 0.15 | 1.60 ± 0.34 | 0.97 ± 0.28 | 83.992   | <0.001    |

TIC type

| A     | 0 (0.0) | 0 (0.0) | 27 (90.0) | 1 (20.0) |
|-------|---------|---------|-----------|----------|
| B     | 6 (75.0)| 18 (94.7)| 0 (0.0)   | 2 (40.0) |
| C     | 2 (25.0)| 1 (5.3) | 3 (10.0)  | 2 (40.0) |
| D     | 0 (0.0) | 0 (0.0) | 0 (0.0)   | 0 (0.0)  |

TIC: time intensity curve; MWTs: metaplastic Warthin’s tumors; Non-MWTs: non-metaplastic Warthin’s tumors; PAs: pleomorphic adenomas; MT: malignant tumors.

#Data represent the number of (%) tumors.

Figure 6. The distribution of ADC values of four types of parotid gland tumors.
difference in circumscription between MWTs and MTs \(p > 0.05\). Compared with non-MWTs and PAs, the ill-defined circumscription was more common in MWTs than non-MWTs and PAs. Therefore, we should be aware of that MWT can show ill-defined demarcation. With respect to tumor morphology, the lobulated morphology was more common in PAs than MWTs. The \(T_2\) moderate intensity of solid components was more common in MWTs than PAs and MTs. The solid components of PAs mostly showed hyperintense on \(T_2\)-weighted imaging, which represents myxoid tissue.\(^{31}\) Hyperintense of cyst/necrosis was more common in MWTs and non-MWTs. On \(T_1\)-weighted imaging, 18 (85.7%) cases had high signal areas, which may indicate proteinaceous fluids containing hemorrhage or necrotic debris.\(^{15}\) Typical WT consists of solid and cystic tissues in variable proportions.\(^{1,32}\) Approximate 36%–63% of typical WTs also have hyperintense regions on \(T_1\)-weighted imaging, which reflect cysts containing erythrocytes, cholesterol crystals, foamy cells, and neutrophils.\(^{14,15,30}\) WT usually shows low enhancement
on contrast-enhanced $T_1$WI. In this study, 52.4% MWTs exhibited moderate or marked enhancement, and most non-MWTs (81.6%) exhibited mild enhancement. Most PAs (84.8%) exhibited marked enhancement.

DWI and DCE-MRI can efficiently differentiate parotid masses much better than conventional MRI alone. Some previous studies suggested WT had lower ADC values (0.72 to 1.17 $\times 10^{-3}$ mm$^2$/s), representing dense lymphoid tissues in the stroma. The mean ADC values of WT were significantly lower than those of pleomorphic adenoma and some malignant salivary gland neoplasms. In the current study, the mean ADC value of MWTs (0.94 $\times 10^{-3}$ $\times 0.11$ mm$^2$/s) was significantly lower than that of the PAs (1.60 $\times 10^{-3}$ $\times 0.17$ mm$^2$/s). With regard to DCE-MRI, many previous studies showed that most Warthin’s tumors exhibited a washout TIC pattern and a high washout ratio (30%). A long $T_{\text{peak}}$ (>120 s) for pleomorphic adenomas, a short $T_{\text{peak}}$ (≤120 s) and high WR (≥30%) for Warthin’s tumors, and a short $T_{\text{peak}}$ (≤120 s) and low WR (<30%) for malignant tumors were observed in most cases of one previous study. In our study, six of eight MWTs demonstrated the washout pattern TIC and two MWTs showed plateau pattern TIC. Therefore, the ADC values and DCE-MRI parameters of MWTs in our study were similar to those of non-MWTs in previous studies.

Besides the ADC values and DCE-MRI parameters, some studies have used diffusion tensor imaging for differentiating malignant from benign parotid gland tumors and have shown FA values of malignant tumors were significantly higher than those of benign tumors. Some studies have concluded that intravoxel incoherent motion imaging (IVIM), which can separate assessment of perfusion from diffusion-related parameters of salivary gland tumors, may distinguish different parotid tumors with good accuracy, particularly when combining both IVIM parameters and TIC profiles.

This study had several limitations. First, we did not calculate the sample size. Second, it was a retrospective study, and the MR imaging protocols were not comprehensive. Only 62 patients underwent DCE-MRI in our hospital, and five MTs only underwent DCE-MRI. However, MWTs is a rare entity, and to our knowledge, this is one of the most extensive series to date. Our conventional, diffusion and dynamic contrast-enhanced MRI findings of MWT are meaningful and make diagnosis easier in clinical circumstances.

**Conclusion**

Most MWTs were revealed to involve the parotid tail and superficial lobe. Compared with non-MWT and PA, ill-defined circumscription in MWTs was more common. The $T_2$ moderate intensity of solid components was more common in MWTs than PAs and MTs. Hyperintense of cyst/necrosis was more common in MWTs. Compared with non-MWTs, MWTs exhibited moderate or marked enhancement. On DWI, the mean ADC value of MWTs was significantly lower than that of PAs. On DCE-MRI, most MWTs demonstrated the type B TIC.
Therefore, conventional MRI characteristics, DWI, and DCE-MRI can provide useful information for distinguishing MWTs from other parotid masses.

**Declaration of conflicting interests**

The author(s) declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

**Funding**

The author(s) disclosed receipt of the following financial support for the research, authorship, and/or publication of this article: This study was funded by Changshu science and technology bureau (Grant No.cs201618) and Changshu health bureau (Grant No. csws201604).

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