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Accuracy of magnetic resonance imaging in evaluating the depth of invasion of tongue cancer. A prospective cohort study

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ABSTRACT

Objectives: This study compared the consistency of depth of invasion (DOI) measurements by magnetic resonance imaging (MRI) and intraoperative and postoperative pathological sections due to a lack of large sample studies.

Materials and methods: From April 2015 to December 2017, patients with squamous cell carcinoma of the tongue were included in the study. Different invasion depths were measured by MRI and on intraoperative and postoperative pathological sections. The differences between two-dimensional tumor margins were analyzed using Mimics 15.0 and Geomagic Control 16.0. Statistical analyses were performed using IBM SPSS software version 25.0 (IBM Corp., Armonk, NY).

Results: This study included 150 patients, the overall difference between MRI and postoperative pathological sections (DMP) and the overall difference between intraoperative and postoperative pathological sections (DIP) based on pathological specimens were 2.32 ± 1.68 mm and 0.68 ± 0.99 mm. The overall difference between MRI and intraoperative pathological sections (DMI) based on intraoperative specimens was 1.64 ± 1.32 mm. The tumor growth pattern and T stage were significantly correlated with measurement differences. The cutoff value of MRI depth that could identify nodal metastasis was 8 mm, and were both 11 mm for OS and DSS.

Conclusion: Clinicians performing T staging on patients with tongue cancer based on MRI measurements must consider the false-positive mean depth of 2.3 mm as well as the growth pattern and specific infiltration depth. The prognostic MRI depths that enabled the identification of nodal metastasis, OS and DSS were 8 mm, 11 mm and 11 mm, respectively.

Clinical trial registration: Name: A Prospective, Observational, Real-world Study Based on the Register System of Oral and Maxillofacial Malignant Tumors. (ClinicalTrials.gov ID: NCT02395367)

Introduction

Many studies have shown that the depth of invasion (DOI) is an important independent prognostic factor for lymph node metastasis and survival in patients with tongue cancer [1–7]. The eighth edition of the American Joint Committee on Cancer (AJCC) staging manual recommends tumor invasion depths greater than 5 mm and 10 mm as the standard thresholds for T staging of oral cancer [8]. The introduction of DOI has improved the accuracy of oral cancer staging to a certain extent. However, the eighth edition of AJCC staging requires greater accuracy in data measurement because millimeter-scale errors can lead to changes in staging and treatment options.

The depth of tumor invasion can be obtained by preoperative imaging examination and analysis of intraoperative and postoperative pathological sections. However, whether 5- and 10-mm thresholds for the DOI can be used as staging criteria for each time point warrants

Abbreviations: OS, overall survival; DSS, disease-specific survival; AJCC, American Joint Committee on Cancer; DOI, depth of invasion; MRI, magnetic resonance imaging; DMP, difference between MRI and postoperative pathological sections; DMI, difference between MRI and intraoperative pathological sections; DIP, difference between intraoperative and postoperative pathological sections; TD-DMI, two-dimensional tumor margin difference between MRI and intraoperative pathological sections; TD-DMP, two-dimensional tumor margin difference between MRI and postoperative pathological sections; LoA, limit of agreement

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exploration. False-positive results on clinical images (such as MRI) and atrophy of postoperative pathological sections have been reported [9–13]. Unfortunately, no definite conclusion has been established regarding the specific value of measurement differences. Therefore, a prospective cohort study was designed to compare the consistency of DOI measured by preoperative MRI and by the analysis of intraoperative and postoperative pathological sections based on 1-mm thin-layer MRI and digital analysis techniques. The prognostic infiltration depth was also analyzed (ClinicalTrials.gov ID: NCT02395367).

Materials and methods

Patients

From April 2015 to December 2017, patients with squamous cell carcinoma of the tongue who were first diagnosed at Beijing Stomatological Hospital, Capital Medical University were included in the study. Sex and age were not restricted. Patients who were ineligible for MRI and those who had T4-stage disease or recurrent disease or who had received neoadjuvant chemotherapy or prior radiotherapy were excluded. Basic information including sex, age, tumor location, TNM stage (according to the seventh edition of AJCC), tumor morphology (invasive, exogenous, ulcerative, and necrotic), and pathological N stage was recorded. All patients underwent surgical treatment first, i.e., enlarged primary resection or enlarged en bloc resection, modified radical neck dissection for patients with cervical metastases, and selective lymph node dissection (I-III) for T2-3N0 patients; T1N0 patients were monitored and followed up.

Imaging techniques and DOI measurements via MRI were performed in patients without contraindications for MRI on a 1.5-T MR unit (Magnetom Aera, Siemens Medical Solution, Shenzhen, China), and the section thickness was 1 mm. All patients underwent preoperative MRI scanning within one week of the date of surgery. The scanning protocol included T1 (repetition time [TR] 912 ms, echo time [TE] 17 ms) and T2 (TR 5000 ms, TE 99 ms) axial, coronal, and sagittal sequences along with T2 axial and coronal sequences with fat suppression (FS) (TR 5830 ms, TE 99 ms). After intravenous injection of contrast media, T1-weighted (TR 548 ms, TE 17 ms) axial, coronal, and sagittal sequences with FS were performed. After viewing the above DICOM data with syngo.via, coronal/axial images of the maximum depth of tumor invasion were obtained by comparing the layers in T2 sequences (Fig. 1a). During the operation, the tumor specimens were dissected along a coronal/axial interval of 3 mm, and the maximum DOI was measured on a micrometer scale (Vernier caliper). An image of the tumor section was acquired and stored in JPEG format. The camera lens was positioned vertical to the tumor section during image acquisition (Fig. 1b). Then, the surgical specimens were preserved in formalin solution. Pathological sections and hematoxylin and eosin (H-E) staining were performed on the sections from which the maximum DOI was measured. The obtained sections were scanned digitally with a scanner (NanoZoomer 2.0-RS, Hamamatsu Photonics K.K., Japan). The maximum infiltration depth was measured in the software (Fig. 1c). For data comparability, the depth of tumor infiltration for these measurements was the vertical distance between the simulated normal mucosal junction and the deepest point of tumor infiltration. For exogenous tumors, the part above the mucosal surface was neglected, and for ulcerative tumors, the invaginated part was added. The depth of infiltration was measured by an experienced clinician (with over 5 years of experience) under the guidance of a more senior physician. If a disagreement occurred between the two physicians, the final decision was made after consultation with a radiologist.

Imaging analysis

Tumor images were intercepted and preserved in JPEG format from preoperative MRI, intraoperative tumor section images, and postoperative pathological section images. The above images contained a line indicating the specific depth to facilitate restoration of the true size of the image. Mimics 15.0 (Materialise Company, Belgium) was used to open the JPEG file and set the threshold, generate a mask, edit the mask, and calculate and generate entities in the Standard Template Library (STL) format. The generated STL file was imported into Geomagic Control 16.0 (Geomagic, America). The pathological data were used as the reference template for measurement, while the MRI data were used as the test object. The best fit and artificial registration were used to fit the pathological data and MRI data in the same coordinates for two-dimensional comparison. The registration criterion was the best fit for mucosal tumor morphology. After analysis, a report file was generated to record the average difference between the two-dimensional tumor margins (Fig. 2a–k). All the data were obtained with informed consent and permission from the Ethics Committee of Beijing Stomatological Hospital, Capital Medical University.

Follow-up

All patients were followed up to record local control and regional distant metastasis. The patients were followed up once every 2 months

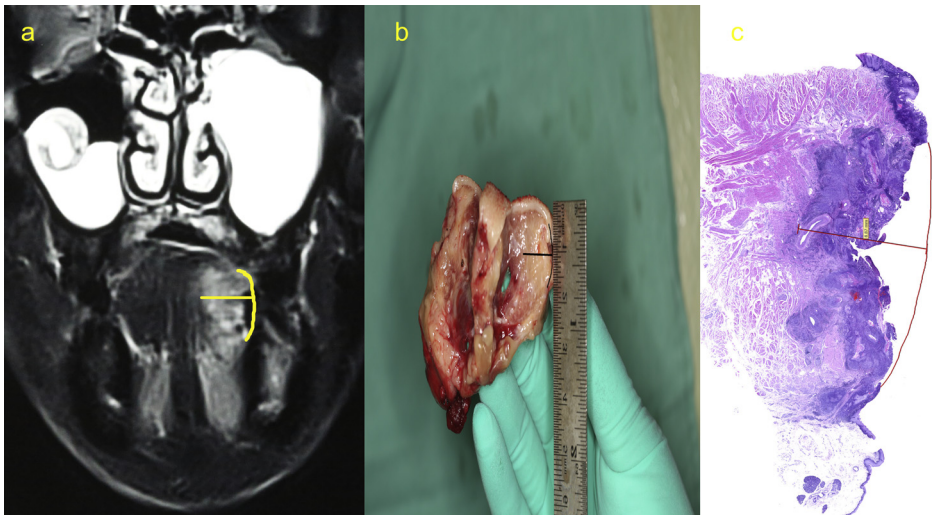

Fig. 1. Measurement of invasion depth on MRI (a), intraoperatively (b) and pathologically (c). Measurement of the DOI based on the adjacent normal mucosal junction to the deepest infiltration point.

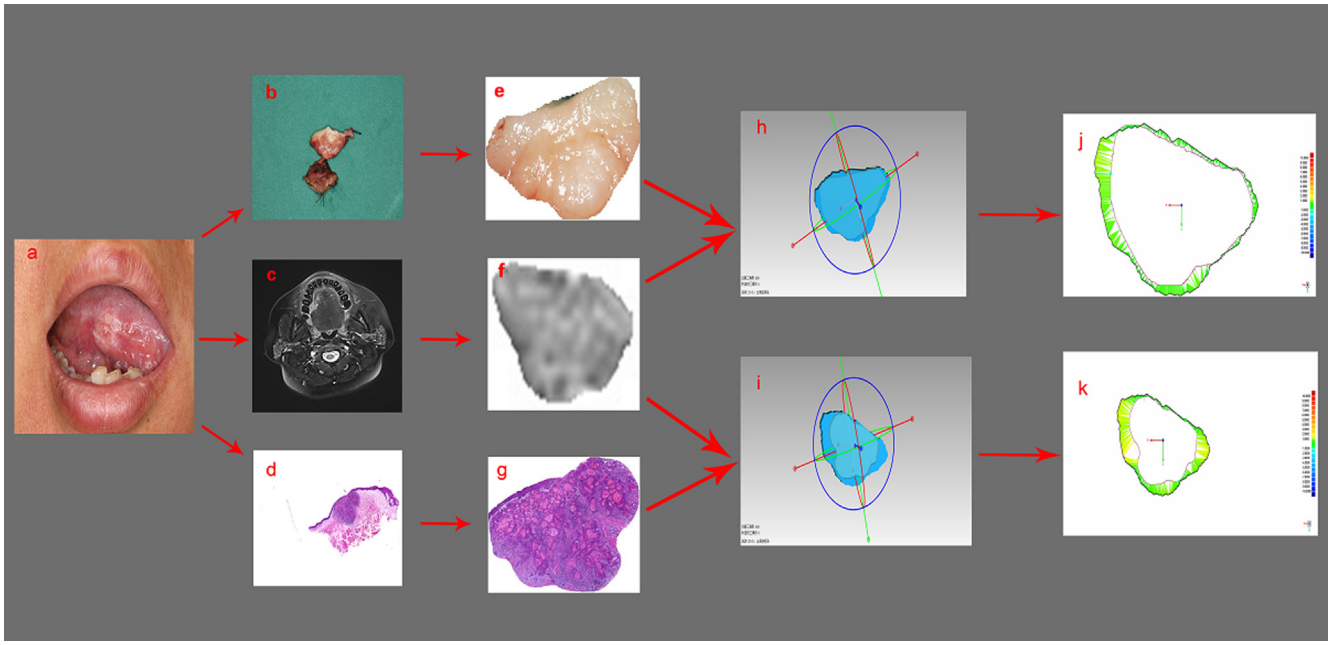

Fig. 2. Two-dimensional analysis of tumor margins. a. Preoperative intraoral image of squamous cell carcinoma of the right lingual margin. b. Intraoperative tumor section image. c. Range of the tumor on magnetic resonance imaging based on the T2 sequence. d. Postoperative pathological scan. e–g. Separation and extraction of tumor images from intraoperative, MRI and pathological images. h–i: The Best Fit and artificial registration were used to fit the MRI data and intraoperative data; the pathological data and MRI data are in the same coordinates for two-dimensional comparison. j–k. Average difference of TD-DMI and TD-DMP.

during the first year after the operation and every 3 months during the second and third years. The examination included MRI/CT, chest radiography, abdominal B ultrasound, and PET-CT when necessary.

Statistical analysis

The relationships among the DOI measurements by MRI and by analysis of the intraoperative and pathological specimens were estimated using the Bland-Altman plot, t-tests were used to analyze the agreement between the three values, and multiple linear regression was used to analyze the associated factors. The cutoff values of the DOI for predicting nodal status, overall survival (OS), and disease-specific survival (DSS) were determined using a receiver operating characteristic (ROC) curve analysis. Kaplan-Meier plots were constructed to present cumulative survival outcomes. Analyses of the relationships between clinicopathologic parameters, DOI, disease-free survival (DFS) and DSS were performed using Cox proportional hazard models. The hazard ratios (HRs) and 95% confidence intervals (CIs) were calculated. All statistical analyses were performed using IBM SPSS software version 25.0 (IBM Corp., Armonk, NY). A two-sided p value < 0.05 was considered statistically significant.

Results

This study included 150 patients with tongue squamous cell carcinoma who were treated in Beijing Stomatological Hospital Affiliated with Capital Medical University from April 2015 to December 2017. The percentage of male patients was 53.33%. The average age was 58.01 ± 12.10 years. T1-stage disease was diagnosed in 28.67% of the patients, T2-stage disease was diagnosed in 47.33% of patients, and T3-stage disease was diagnosed in 24% of patients. Invasive growth was the most common tumor growth pattern, accounting for 62.67% of the tumors, followed by ulcerative type and exogenous type, accounting for 27.33% and 10% of the tumors, respectively. The mean DOI based on MRI in all patients was 11.75 ± 6.49 mm. The mean DOI of intraoperative sections was 10.11 ± 5.90 mm, while the mean DOI based on analysis of pathological sections was 9.43 ± 5.57 mm (Table 1).

The overall difference in the DOI between MRI and pathological sections (DMP) was 2.32 ± 1.68 mm. The difference in the DOI between intraoperative and pathological sections (DIP) was 0.68 ± 0.99 mm, and the difference in the DOI between MRI and intraoperative sections (DMI) was 1.64 ± 1.32 mm (Table 2). The Bland-Altman scatter plot showed a relatively significant correlation within the 95% limits of agreement (LoA) among MRI and the analyses of intraoperative and postoperative pathological sections for the DOI at different T stages (Fig. 3) and with different tumor morphologies (Fig. 4).

To avoid uncertainty in the selection of the baseline and maximum depths of tumor invasion and to analyze the accuracy of MRI in assessing tumor margins, the DMP and DMI were compared with the corresponding two-dimensional analysis, and their consistency was verified. The results showed that the mean two-dimensional tumor margin difference between MRI and intraoperative sections (TD-DMI) was 1.51 ± 0.90 mm, and the difference was 1.92 ± 1.41 mm between MRI and pathological sections (TD-DMP). The Bland-Altman scatter plot showed a relatively significant correlation within the 95% LoA between the DOI difference (Fig. 5) and the two-dimensional analysis result (Fig. 6). The difference between the DMP and the two-dimensional analysis result was 0.41 ± 1.10 mm, and the difference between the DMI and the two-dimensional analysis result was 0.12 ± 0.79 mm (Table 3). M Multivariate linear regression was used to investigate the factors associated with the differences in DOI measurements and the differences in the two-dimensional analysis of tumor margins (Table 4). The results suggested that the tumor growth pattern and T stage were significantly correlated with the upper differences. The difference increased with increasing T stage. For the DMP in T1 patients, the mean invasion depth was 1.48 ± 1.10 mm, while in T2 and T3 patients, the mean invasion depths were 2.08 ± 1.29 mm and 3.79 ± 2.00 mm, respectively. When the DMP was classified according to the type of tumor morphology, the results showed that the DOI of ulcerative masses was the largest at 3.72 ± 1.98 mm, followed by infiltrating and exogenic tumors at 1.83 ± 1.23 mm and 1.53 ± 0.78 mm, respectively. We find the same results for the DMI and DIP, which are listed in Table 1. Based on the above statistical

Table 2
Agreement on the infiltrating depth of a tongue tumor between MRI and intraoperative and pathological sections.

Device pairings	Mean difference ± SD	95% LoA
Overall		
MRI and pathological	2.32 ± 1.68	−0.97,5.61
Intraoperative and pathological	0.68 ± 0.99	−1.25,2.61
MRI and intraoperative	1.64 ± 1.32	−0.95,4.23
T stage		
T1		
MRI and pathological	1.48 ± 1.10	−0.67,3.63
Intraoperative and pathological	0.43 ± 0.64	−0.82,1.69
MRI and intraoperative	1.04 ± 1.14	−1.19,3.28
T2		
MRI and pathological	2.08 ± 1.29	−0.45,4.62
Intraoperative and pathological	0.68 ± 0.96	−1.20,2.56
MRI and intraoperative	1.41 ± 0.96	−0.48,3.29
T3		
MRI and pathological	3.79 ± 2.00	−0.13,7.70
Intraoperative and pathological	0.98 ± 1.28	−1.53,3.49
MRI and intraoperative	2.81 ± 1.44	−0.01,5.63
Tumor morphology		
Ulcer type		
MRI and pathological	3.72 ± 1.98	−0.16,7.60
Intraoperative and pathological	0.86 ± 1.27	−1.62,3.34
MRI and intraoperative	2.86 ± 1.33	0.26,5.47
Invasive type		
MRI and pathological	1.83 ± 1.23	−0.59,4.25
Intraoperative and pathological	0.64 ± 0.89	−1.11,2.38
MRI and intraoperative	1.19 ± 1.04	−0.85,3.24
Exogenous type		
MRI and pathological	1.53 ± 0.78	0.01,3.06
Intraoperative and pathological	0.45 ± 0.60	−0.72,1.63
MRI and intraoperative	1.08 ± 0.47	0.16,1.08

MRI: magnetic resonance imaging.
LoA: Limit of Agreement.

results, a multivariate linear regression analysis was performed to determine the exact value of the DMP when considering the infiltration depth and growth type, which had significant effects. The following calculation was performed:

DMP (mm) = 0.849 + (1.721 × ulcer type)/(0.186 × infiltration type) + (0.093 × pathological infiltration depth).

Based on the latest AJCC infiltration depth criteria of the eighth edition staging manual, when the pathological infiltration depths were 5 and 10 mm, the false-positive intervals of MRI infiltration depth were 1.314 to 3.035 mm and 1.779 to 3.5 mm, respectively, depending on the tumor morphology (Table 5).

Thirty-five patients had positive lymph nodes in the postoperative pathological report, 16 of whom were in the N1 stage and 19 in the N2 stage. During a median 13-month follow-up period (range 7–39 months), 15 patients developed cervical lymph node metastasis, and 2 patients had local recurrence. Eleven patients died, and no patients were lost to follow-up. The OS rate was 88.1%, and the overall DSS rate was 93.1%. The cutoff value of the MRI depth that could identify nodal metastasis was 8 mm. The cutoff values for OS and DSS were both 11 mm (Fig. 7a-c). In unadjusted Cox proportional hazard models, tumor DOI > 8 mm, age > 60 years, sex, tumor site, T stage, pathological nodal status, and tumor morphology were included to determine the independent effect on survival. The variables without significance, which included sex and age > 60 years, were removed from the final analysis (Table 6). After adjusting for these variables, only the tumor site was found to be predictive of both OS (p = 0.021) and DSS (p = 0.02), followed by DOI > 8 mm (OS, p = 0.085; DSS, p = 0.086). Dorsal tongue was found to be an individually significant factor associated with survival (OS, p = 0.026; DSS, p = 0.031) (Table 7).

Discussion

The AJCC staging system has been widely adopted and applied. The latest eighth edition of the AJCC staging system adds the depth of tumor invasion to the T stage of oral cancer as a staging criterion. A clinically examined or pathologically measured DOI greater than 5 mm is stage T2, and a depth greater than 10 mm is stage T3. The depth of tumor invasion can be obtained by preoperative imaging examination and analysis of intraoperative and postoperative pathological sections. However, analyzing the consistency among invasion depths at the three time points and whether the same grading criteria apply to each time point yields interesting results. False-positive results on clinical images (such as MRI) and atrophy of postoperative pathological sections have been reported [12]. The former can lead to a decline in staging, and the latter can lead to excessive staging. The consistency and the specific differences between the three time points have become a key issue and represent the main problem that this study aims to address. One of the core concepts of the AJCC staging system is that “the general TNM principle of selecting the less advanced attribute should always be observed when the clinician

harbors doubt” [8].

MRI is an ideal method for soft tissue imaging and has been widely used for the preoperative evaluation of tongue cancer patients. However, −4.6- to 3.19-mm false-positive results have been reported, which should warrant greater attention because the clinical staging criteria use thresholds of only 5 and 10 mm. Some scholars have researched this problem. Yesuratnam et al. [9] designed a prospective study comparing preoperative MRI measurements of tumor thickness with measurements obtained from postoperative pathological sections in 81 patients. The results showed that the mean difference between histology and T2-weighted MRI measurements was 3.19 ± 4.87 mm and that the difference between histology and T1 postcontrast MRI measurements was 2.99 ± 4.41 mm. Kwon et al. [10] retrospectively

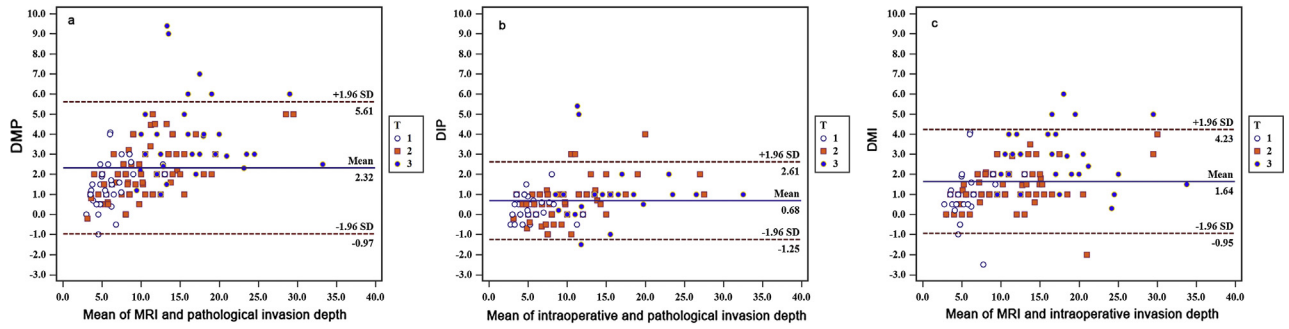

Fig. 3. Bland-Altman plots showing the agreement between MRI and intraoperative and postoperative pathological sections for measuring the infiltrating depth of a tongue tumor. Solid lines represent the bias between the two measurement methods, and dotted lines represent the 95% confidence intervals for the differences. MRI: magnetic resonance imaging.

Table 4
Factors associated with the difference between MRI and intraoperative and postoperative pathological sections in measuring the infiltrating depths of tongue tumors.

Variables	Model 1 [a]		Model 2 [b]		Model 3 [c]	
	Regression coefficients	P value	Regression coefficients	P value	Regression coefficients	P value
Age, mean (SD)	0.01 ± 0.01	0.23	0.003 ± 0.01	0.64	0.01 ± 0.01	0.27
Male, %	−0.04 ± 0.22	0.87	−0.20 ± 0.16	0.21	0.16 ± 0.18	0.37
Location, %						
Ventral tongue	0.27 ± 0.59	0.65	0.36 ± 0.42	0.39	−0.09 ± 0.47	0.85
Tongue border	0.53 ± 0.55	0.33	0.56 ± 0.39	0.15	−0.03 ± 0.44	0.94
Dorsal tongue	0.25 ± 0.62	0.68	0.51 ± 0.44	0.25	−0.25 ± 0.49	0.61
Tongue base	Ref		Ref		Ref	
Tumor morphology, %						
Ulcer type	1.78 ± 0.46	< 0.01	0.38 ± 0.33	0.25	1.41 ± 0.37	< 0.01
Invasive type	0.83 ± 0.41	0.04	0.48 ± 0.29	0.10	0.36 ± 0.32	0.27
Exogenous type	Ref		Ref		Ref	
T stage, %						
1	−1.50 ± 0.38	< 0.01	−0.66 ± 0.27	0.02	−0.84 ± 0.30	< 0.01
2	−0.91 ± 0.32	< 0.01	−0.22 ± 0.23	0.34	−0.69 ± 0.26	< 0.01
3	Ref		Ref		Ref	

MRI: magnetic resonance imaging.
DIP: difference between intraoperative and pathological sections.
DMP: difference between MRI and pathological sections.
DMI: difference between MRI and intraoperative sections.
[a] Model 1 used DMP as the dependent variable.
[b] Model 2 used DIP as the dependent variable.
[c] Model 3 used DMI as the dependent variable.

Table 5
Differences in the DOI between MRI and pathological sections with different tumor morphologies.

Differences in the DOI between MRI and pathological sections (mm)			
	Ulcerative	Infiltrative	Exogenous
Pathological depth = 5 mm	3.035	1.907	1.314
Pathological depth = 10 mm	3.5	2.372	1.779

DOI: Depth of invasion.

analyzed differences in tumor thickness between pathological section measurements and measurements obtained from coronal, sagittal, and axial MRI sequences. Fifty-three patients with tongue cancer were enrolled in the study. The results showed that the thickness of tumors on axial MRI was 2.2 mm greater than that measured in pathological sections, while those on coronal and sagittal images were 3.5 and 4.6 mm less than the thicknesses measured in pathological sections, respectively. Park et al. [11] retrospectively analyzed and compared the accuracy of MRI in assessing the DOI of oral/pharyngeal cancers. The DOI on T1 MRI was 1.5 mm greater than that measured in postoperative pathological sections. A total of 77 patients with oral cancer were included in the study. Lam et al. [12] performed a similar study and found that the tumor thickness measured on T1-sequence MRI was 0.8 mm greater than that measured in pathological sections, while the tumor thickness measured on T2-sequence MRI was 2 mm greater than that measured in pathological sections on average. The number of patients included in the study was small, with only 18 cases. Preda et al. [13] retrospectively analyzed 33 patients with tongue cancer and found that the tumor thickness measured on T2 MRI was 3.1 mm greater than that measured in pathological sections in patients with T1-T4-stage tongue cancer and 2 mm greater on average in patients with T1-T3-stage tongue cancer.

However, several issues affecting the establishment of a definite conclusion should be noted. First, the sample sizes of the above-mentioned studies are generally small, and avoiding inconsistencies caused by differences between research clinics is difficult. Retrospective studies are common and inevitably lead to information bias. At the same time, studies have included different tumor sites, such as the tongue and oropharynx, which will affect the consistency of results and comparability.

Second, some of the above studies focused on invasion depth, while others focused on tumor thickness, and differences existed in the definitions and measurement methods used. Moore et al. [14] recommend that DOI measurements be based on the adjacent normal mucosal junction rather than the tumor surface. Measuring the tumor surface as a reference point results in an increase in the DOI of exogenous tumors, while a decrease in the DOI occurs for ulcerative tumors.

Third, MRI slice thickness is usually 3–4 mm, and for smaller tumors, excessive scan thickness can result in an inability to measure the maximum DOI. In addition, the DOI measurement is based on either the T1 sequence or the T2 sequence, but the DOI measurement based on the T1 enhancement sequence may overestimate the invasion depth due to inflammation or local tissue swelling after biopsy. Therefore, the T2 sequence is better for tumor depth measurements [15].

Finally, and most importantly, studies have shown that the difference in invasion depth between MRI analysis and analysis of pathological sections is smaller in patients with lower-stage disease [13], although few studies have analyzed the relative factors contributing to MRI differences.

In this study, for MRI measurements, 1-mm thin-slice scanning was used to obtain the maximum invasion depth of the tumors, and all measurements were based on T2 MRI sequences, which ensured consistency across the measured data. At the same time, preoperative MRI localization using an intraoperative section interval of 3 mm and postoperative pathological section scanning ensured the comparability of the DOIs obtained between MRI analysis and intraoperative and postoperative pathological sections. To avoid uncertainty regarding baseline reconstruction and selection of the maximum depth of tumor invasion, a two-dimensional analysis of the difference in the tumor anterior margin was added in this study to verify the consistency between DOI measurements and two-dimensional data. The results showed that the DOI measured on MRI was in good agreement with those measured in intraoperative and pathological sections. The Bland-Altman scatter plot also shows that the difference in infiltration depth is in good agreement with the difference in the two-dimensional edge,

thus verifying the validity of the DOI measurement from the side.

Multivariate linear regression showed that tumor morphology and T stage significantly affected the DMP, DMI, and DIP, which increased with increasing T stage, and ulcerative masses had the largest values, followed by infiltrating and exogenic tumors. These findings may be due to severe local inflammation and edema, resulting in false-positive MRI results due to necrosis. Moreover, pathological specimens of patients with ulcerative necrosis can be substantially deformed after soaking in paraformaldehyde, which can lead to underestimation of the infiltration depth on pathological sections. The increased difference with increasing T stage may be related to the fact that with an increase in T stage, the depth of tumor infiltration increases, and the proportion of atrophy of pathological specimens after immersion remains unchanged, but increased specimen shrinkage will lead to differences in the analysis of the pathological specimens harvested. Thus, as the actual amount of shrinkage increases, the difference in tumor depth measurements increases [16,17].

In the eighth edition of the AJCC manual, values of 5 and 10 mm were used as staging criteria, which are of universal significance. However, because of differences in race, geographic region, tumor etiology, and the sites of oral cancer, the extent of the prognostic value of the invasive depth of tongue cancer still warrants further exploration. The ROC curve analysis in this study revealed that MRI-measured depths of invasion of 8, 11, and 11 mm were predictive of lymph node positivity, OS, and DSS, respectively. However, the correlation between DOI and prognosis had a p value higher than 0.05, possibly because the follow-up time was too short considering that the average follow-up time is less than 2 years, resulting in the absence of positive results in some patients and leading to a reduction in the effectiveness and specificity of invasion depth. The large proportion of early-stage patients in this study may be another reason. To obtain a prognostic range of invasion depths, a large sample size and a long follow-up are necessary.

Conclusion

Clinicians performing T staging on patients with tongue cancer based on MRI measurements must consider the false-positive mean depth of 2.3 mm as well as the growth pattern and specific infiltration depth. MRI has an average 1.92-mm false-positive measurement error in evaluating the two-dimensional edge of a tumor. The depth of infiltration measured on MRI associated with lymph node-positive tongue cancer was 8 mm. The depth of infiltration on MRI that correlated with both OS and DSS was 11 mm.

Conflict of interest

None declared.

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Appendix A. Supplementary material

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