RESEARCH ARTICLE

Diagnostic abilities of 3T MRI for assessing mandibular invasion of squamous cell carcinoma in the oral cavity: comparison with 64-row multidetector CT

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Objectives: To evaluate the diagnostic accuracies of 3T MRI in evaluating mandibular invasion of squamous cell carcinoma (SCC) in the oral cavity and to compare those with that of multidetector CT (MDCT).

Methods: 41 cases with oral SCC examined by both 3T MRI and MDCT prior to surgery were included in this study. Intravenous contrast medium was administered in all examinations. Images were evaluated for the presence or absence of mandibular invasion and mandibular canal involvement by the tumour. For MRI, both two-dimensional (2D) fast spin echo (FSE) and three-dimensional (3D) volumetric interpolated breath-hold examination (VIBE) images were used for the evaluation. For MDCT, dental CT cross-sectional images were used. The results were correlated with histopathological findings, and sensitivity and specificity of each imaging technique were calculated.

Results: Histopathologically, 32 of 41 cases had mandibular invasion and 10 cases had mandibular canal involvement. For mandibular invasion, all three imaging techniques showed sensitivities of 100%. However, the specificities of 2D FSE (56%) and 3D VIBE (78%) were lower than that of MDCT (89%), although the differences were not significant. For mandibular canal involvement, whereas the sensitivities of all three imaging techniques were 100%, the specificities of 2D FSE, 3D VIBE and MDCT were 54, 62 and 85%, respectively. The specificity of 2D FSE was significantly lower than that of MDCT ($P < 0.017$).

Conclusions: In the evaluation of mandibular invasion, 3T MRI was not as accurate as MDCT. In particular, 2D FSE sequences showed significantly lower specificity than MDCT in evaluating the extent of mandibular invasion. The use of 3D VIBE sequence slightly improved the low specificity of 2D FSE sequences.

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Introduction

An important role of imaging for squamous cell carcinoma (SCC) in the oral cavity close to the mandible is to evaluate tumour invasion into the mandible because the surgical treatment planning is influenced by the presence and extent of invasion.^{1,2} When mandibular invasion exists, mandibulectomy is essential. In addition, the extent of the invasion is important for the surgeon to select the proper surgical procedure: marginal, segmental or hemi-mandibulectomy.

Among several imaging modalities, CT and MRI are most commonly used for pre-operative evaluation of SCCs in the oral cavity. The diagnostic abilities of these two modalities in evaluating tumour invasion into the mandible have been reported by many researchers. However, the results varied widely among the studies.^{3–8} Such discrepancy is considered to derive from differences in patient populations and evaluation methods. Further, in our opinion, there are many studies that used non-optimal images for assessing mandibular invasion, in particular, slight mandibular invasion.

Recently, 3T MRI has been widely used for clinical purposes. Compared with that of lower field, 3T MRI provides an improved signal-to-noise ratio, which theoretically results in higher image resolution.^{9,10} Further, by the spread of 3T MRI combined with a number of technical advances, it has become possible to acquire isotropic three-dimensional (3D) MRI data in a reasonable time. 3D sequences provide high-resolution thin contiguous MR images in arbitrary planes.^{11–13} Thus, by using 3T MRI, it may be possible to detect subtle lesions that were overlooked by lower field strength MRI. However, to our knowledge, no studies used 3T MRI with 3D sequences in evaluating mandibular invasion of oral SCCs.

In our institution (Tokyo Medical and Dental University), we have routinely applied conventional two-dimensional fast spin echo (2D FSE) sequence and thin slice 3D volumetric interpolated breath-hold examination (3D VIBE) sequence, a modified fast 3D T_1 weighted gradient-echo sequence,¹⁴ for head and neck tumours using 3T MRI. The purposes of our study were to evaluate the diagnostic accuracy of these images at 3T MRI in evaluating mandibular invasion of oral SCCs and to compare those with that of 64-row multidetector CT (MDCT).

Methods and materials

The study protocol was approved by our institutional review board (IRB). Informed consent from each patient was waived in this retrospective study, which was also approved by the IRB (No. D2016-094).

Patients

Among the cases with SCCs of the oral cavity in our hospital between January 2015 and November 2017, 49 consecutive cases (48 patients) that were fixed to the mandible by clinical examination and suspected to have mandibular invasion, and were examined by both 3T MRI and MDCT prior to surgery were reviewed. Among them, six cases with apparent motion artefacts and two cases with severe dental artefacts on images were excluded. As a result, 41 cases (40 patients) with oral SCCs were included in this study. The patients comprised 24 males and 16 females, with a mean age of 66 years (range, 37–84 years). The primary site of the 41 cases was lower gingiva in 38 and mouth floor in 3. After imaging, all patients underwent surgery: marginal mandibulectomy ($n = 19$), segmental mandibulectomy ($n = 17$) or hemi-mandibulectomy ($n = 5$). Histopathological diagnosis of the surgical specimens was obtained in all cases. Of the 41 cases, 6 cases had undergone some form of pre-operative treatment: chemotherapy ($n = 5$) or radiation and chemotherapy ($n = 1$). None of the cases had undergone mandibular surgery before imaging.

Imaging protocol

MRI was performed using a 3T unit (Magnetom Spectra, Siemens Healthcare, Erlangen, Germany) with a 16-channel head and neck coil. As mentioned above, conventional 2D FSE and high-resolution 3D VIBE images were obtained in all cases. The 2D FSE protocol included T_1 weighted (T_1W) images [repetition time/echo time (TR/TE) 650/10 ms; turbo factor 3; number of signals averaged (NSA) 1] and T_2 weighted (T_2W) images (TR/TE 5000/94 ms; turbo factor 14; NSA 1) with fat suppression by the 2-point Dixon technique in the axial and coronal planes. Further, after intravenous administration of meglumine gadoterate 0.2 mmol/kg (MagneScope, Guerbet Japan, Tokyo, Japan), post-contrast T_1W images (TR/TE 640/12; turbo factor 3; NSA 1) with fat suppression using the 2-point Dixon technique were obtained in the axial and coronal planes. These T_1W and T_2W images were all obtained with a matrix of 384×312 , field of view of 230×187 mm and a section thickness of 3–4 mm with an intersection gap of 0.9–1.0 mm.

Subsequently, 3D VIBE sequence with fat suppression using the spectral attenuated inversion recovery was applied. The scan parameters were TR/TE of 13.7/3.9, flip angle of 20°, matrix size of 192×192 , field of view of 150×150 mm, slab thickness of 96 mm and 120 slices per slab, providing a spatial resolution of $0.8 \times 0.8 \times 0.8$ mm; the scan time was 3 min 41 s. Plain VIBE images were not obtained because of restricted examination time for each patient.

CT was performed using a 64-row MDCT scanner (Somatom Sensation 64, Siemens Healthcare, Erlangen,

Germany) in all cases. After intravenous administration of 60–100 ml of iodine contrast agent (Omnipaque 300, Daiichi-Sankyo Healthcare, Tokyo, Japan), scanning from the skull base to thoracic inlet was performed with the following parameters: tube voltage of 120 kV, effective tube current of 198 mAs, collimation of 64×0.6 mm with a pitch of 0.8. The scan time was around 15 s. After scanning, contiguous 3-mm-thick axial images were reconstructed. In addition, for the mandible, 0.6-mm-thick bone algorithm axial images with 0.3 mm interval were also reconstructed. Using these thin slice axial images, dental CT cross-sectional images of the mandible with 1 mm interval were reformatted on CT workstation (Syngo Acquisition Workplace; Siemens AG, Erlangen, Germany) and used for the evaluation.

The average interval between MRI and MDCT was 4.8 days (range, 1–18 days; median 4 days).

Image evaluation

Two observers with more than 15 years of experience in head and neck imaging (KA, NS), who were not given any information about the tumour except for the primary site, evaluated 2D FSE, 3D VIBE at 3T MRI and MDCT images independently. The images were evaluated for the presence or absence of mandibular invasion and mandibular canal involvement by the tumour. All 41 cases were evaluated for the former, whereas 36 of the 41 cases were evaluated for the latter because 5 cases in the anterior mandible that had no relation with the mandibular canal were excluded from the evaluation. The diagnostic criterion of mandibular invasion was the defect of the cortical bone adjacent to the tumour mass with or without bone marrow invasion. The diagnostic criterion of mandibular canal involvement was bone marrow invasion by the tumour reaching the mandibular canal. When disagreement existed between the assessments of the two observers, another observer (WH, with more than 15 years of experience in head and neck imaging) made a final decision.

Pathologic assessment

The presence and extent of mandibular invasion by tumour were determined by histopathological findings of the surgical specimens, which were used as the gold-standard. After fixation, the specimens were cut along the coronal plane at 5–7 mm intervals to include the deepest area of tumour invasion. Then, after decalcification, the specimens were sectioned and stained with haematoxylin and eosin. Microscopic examinations were performed by one pathologist with more than 20 years of experience in oral pathology. As he was unaware of pre-operative imaging findings, there was no attempt to precisely correlate imaging finding with a specific point on the mandible at the pathologic assessment.

Statistical analysis

Regarding the presence or absence of mandibular invasion and mandibular canal involvement, imaging

Table 1 κ -values for interobserver agreement

Imaging technique	Mandibular invasion	Mandibular canal involvement
3T MRI		
2D FSE	0.73	0.59
3D VIBE	0.69	0.62
MDCT	0.50	0.82

2D FSE, two-dimensional fast spin echo; 3D VIBE, three-dimensional volumetric interpolated breath-hold examination; MDCT, multidetector row CT.

findings of 2D FSE, 3D VIBE and MDCT were correlated with histopathological results. Sensitivity, specificity and overall accuracy of each imaging technique were calculated. The McNemar test was used to compare the sensitivity and specificity among these three techniques. A p -value of < 0.017 was considered to indicate a statistically significant difference.

Interobserver agreement was evaluated by weighted κ -statistics. A κ -value of 0–0.2 was considered poor agreement, 0.2–0.4 fair agreement, 0.4–0.6 moderate agreement, 0.6–0.8 substantial agreement and 0.8–1.0 almost perfect agreement.¹⁵

Results

32 (78%) of the 41 tumours had histopathological evidence of mandibular invasion, whereas the remaining 9 had no evidence of invasion. Of the 36 tumours located in the posterior mandible, 10 (28%) were histopathologically confirmed to involve the mandibular canal.

κ -value for the interobserver agreement indicated almost perfect agreement in the evaluation of mandibular canal involvement by MDCT. In the other evaluations, it indicated substantial or moderate agreement (Table 1).

Mandibular invasion

As shown in Table 2, the three imaging techniques all correctly diagnosed the 32 tumours with histopathological evidence of mandibular invasion, providing sensitivities of 100% (Figure 1). However, the specificities of 2D FSE, 3D VIBE and MDCT were 56, 78 and 89%, respectively. MRI, 2D FSE and 3D VIBE sequences showed lower specificity than MDCT, although no significant difference was found among the three imaging techniques. Among the nine tumours with no histopathological evidence of invasion, one tumour was classified as a false-positive with all three imaging techniques because of the presence of irregular bone resorption caused by periodontal disease adjacent to the tumour. The remaining eight cases were all true-negatives with MDCT. However, some of them were classified as false-positives with MRI because the intact cortex of the alveolar crest was not clearly visualised. Such cases were more frequently found with 2D FSE than 3D VIBE.

Table 2 Diagnostic accuracy of 3T MRI and MDCT in evaluating the presence and extent of mandibular invasion by tumour

	<i>TP</i>	<i>TN</i>	<i>FP</i>	<i>FN</i>			
	<i>No. of cases</i>				<i>Sensitivity (%)</i>	<i>Specificity (%)</i>	<i>Accuracy (%)</i>
Mandibular invasion (n = 41)							
3T MRI							
2D FSE	32	5	4	0	100	56	90
3D VIBE	32	7	2	0	100	78	95
MDCT	32	8	1	0	100	89	98
Mandibular canal involvement (n=36)							
3T MRI							
2D FSE	10	14	12	0	100	54 ^a	67 ^a
3D VIBE	10	16	10	0	100	62 ^a	72 ^a
MDCT	10	22	4	0	100	85 ^a	89 ^a

2D FSE, two-dimensional fast spin echo; 3D VIBE, three-dimensional volumetric interpolated breath-hold examination; FN, false-negative; FP, false-positive; MDCT, multidetector row CT; TN, true-negative; TP, true-positive.

^a $p < 0.017$ (2D FSE vs MDCT, McNemar test).

Mandibular canal involvement by tumour

As shown in Table 2, the three imaging techniques all correctly diagnosed the 10 tumours with histopathological evidence of mandibular canal involvement, providing sensitivities of 100%. However, the specificities of 2D FSE, 3D VIBE and MDCT were 54, 62 and 85%, respectively. The specificity of 2D FSE was significantly lower than that of MDCT ($p < 0.017$), although there was no significant difference between 3D VIBE and MDCT. MRI tended to reveal the tumour and surrounding inflammatory changes in the bone marrow with similar abnormal signal intensity, resulting in over-estimation of tumour extent (Figure 2). 3D VIBE was slightly better than 2D FSE and correctly diagnosed two cases that were considered false-positives with 2D FSE (Figure 3).

Discussion

SCCs in the oral cavity have a tendency to show mandibular invasion because they often occur in close

proximity to the mandible. A precise evaluation of the presence and extent of mandibular invasion is essential for surgical treatment planning, and imaging plays an important role in such evaluation.^{1,2} Namely, when mandibular invasion is suspected on images, mandibulectomy must be considered. Further, the extent of the invasion influences the surgical procedure selected: marginal, segmental or hemi-mandibulectomy.

CT and MRI are the imaging modalities most commonly used for pre-operative evaluation of SCCs in the oral cavity. However, the diagnostic accuracy of these modalities in evaluating mandibular invasion varies widely depending on the studies. Recently, some researchers performed a systematic review and meta-analysis to determine the diagnostic efficacy of CT and MRI in detecting mandibular invasion by oral SCCs and concluded that there was no difference between the two modalities.^{16–18} However, in our opinion, these analyses included many studies that did not use optimal images for assessing mandibular invasion. For CT, an optimal MDCT technique that includes

Figure 1 A 71-year-old male with gingival carcinoma of the anterior mandible showing true-positive results with all three imaging modalities for mandibular invasion (a) 2D FSE image: sagittal post-contrast T_1 weighted image with fat suppression (b) Sagittal 3D VIBE image (c) Dental CT cross-sectional images All three imaging techniques reveal cortical invasion of the anterior mandible by the tumour (a, b and c: arrows), which was histopathologically confirmed after surgery. 2D FSE, two-dimensional fast spin-echo; 3D VIBE, three-dimensional volumetric interpolated breath-hold examination

Figure 2 A 57-year-old male with right lower gingival carcinoma showing false-positive results with 2D FSE and 3D VIBE and a true-negative result with CT for mandibular canal involvement. (a) 2D FSE images: coronal T_2 weighted (a-1) and coronal post-contrast T_1 weighted (a-2) images with fat suppression. (b) 3D VIBE images: coronal (b-1) and sagittal (b-2) images. (c) Dental CT cross-sectional images. Arrows indicate the mandibular canal. All three imaging techniques (a, b and c) reveal tumour invasion into the cortex and bone marrow of the right mandible. Tumour invasion appears to involve the mandibular canal on 2D FSE (a) and 3D VIBE (b) images, whereas no involvement of the canal is suspected on CT (c). Histopathological examination after surgery confirmed that the tumour did not reach the mandibular canal. 2D FSE, two-dimensional fast spin echo; 3D VIBE, three-dimensional volumetric interpolated breath-hold examination.

thin sections and multiplanar reformations should be applied for evaluating mandibular invasion.¹ Thus, we used dental CT cross-sectional images reformatted from 0.6-mm-thick axial images obtained by 64-row MDCT. Usefulness of such reformatted CT images in evaluating mandibular invasion has been confirmed.¹⁹

Several studies evaluated the diagnostic accuracy of MRI in assessing mandibular invasion by SCCs and reported various sensitivities and specificities. In all of these studies, images were obtained by 0.5–1.5T MRI unit with slice thicknesses ranging from 3 to 6 mm.^{3–8} Presently, the advantages of 3T MRI providing improved image quality have been well recognised. Further, by using 3T MRI, it has become possible to acquire isotropic 3D MRI data in a short acquisition time. 3D sequences provide high-resolution thin contiguous MR images in arbitrary planes with less partial volume effects than 2D sequences. Among them, 3D

VIBE is an interpolated 3D T_1 weighted gradient-echo sequence obtained with the fast low angle shot technique. It was reported that 3T MRI with thin-slice 3D VIBE sequence provided an accurate diagnosis in musculoskeletal imaging.^{12,13} However, to our knowledge, it has not been applied to SCCs in the oral cavity. Therefore, in this study, we aimed to evaluate the diagnostic abilities of conventional 2D FSE and thin slice 3D VIBE images using 3T MRI in evaluating mandibular invasion of SCCs in the oral cavity and to compare those with that of 64-row MDCT.

In mandibular invasion, there was no significant difference between MRI and MDCT. Both 2D FSE and 3D VIBE sequences showed sensitivities of 100%, which was similar to MDCT. Several studies have also reported the high sensitivity of MRI in evaluating mandibular invasion.^{3–5,7,8} Thus, as El-Hafez *et al*⁸ indicated, it is considered that a negative MRI result can

Figure 3 A 37-year-old male with right lower gingival carcinoma showing a false-positive result with 2D FSE and true-negative results with 3D VIBE and CT for mandibular canal involvement. (a) 2D FSE images: coronal T_2 weighted (a-1) and coronal post-contrast T_1 weighted (a-2) images with fat suppression. (b) Coronal 3D VIBE image. (c) Dental CT cross-sectional images. Arrows indicate the mandibular canal. All three imaging techniques (a, b and c) reveal tumour invasion into the cortex and bone marrow of the right mandible. Tumour invasion appears to involve the mandibular canal on 2D FSE images (a), whereas it does not appear to involve the canal on 3D VIBE image (b) and CT (c). Histo-pathological examination after surgery confirmed that the tumour did not reach the mandibular canal. 2D FSE, two-dimensional fast spin echo; 3D VIBE, three-dimensional volumetric interpolated breath-hold examination

confidently exclude the presence of mandibular invasion. Conversely, the specificities of 2D FSE, 3D VIBE and MDCT were 56, 78 and 89%, respectively. Although there were no significant differences between these imaging modalities, false-positive cases were less frequent in 3D VIBE than 2D FSE. Namely, 3D VIBE could reveal the intact cortical bone of the alveolar crest that was not clear on 2D FSE images in two cases. This finding may be due to higher resolution of 3D images with slice thickness of 0.8 mm compared with conventional 2D images.

Most previous studies only evaluated the presence or absence of mandibular invasion. In addition to such evaluation, we evaluated the extent of tumour invasion, *i.e.* the presence or absence of mandibular canal

involvement. Whether tumour invasion reached the mandibular canal was reported to influence surgical procedures²⁰ and prognosis of the patients.^{21,22} In our study, both MRI and MDCT yielded no false-negative results for mandibular canal involvement, providing sensitivities of 100%. However, there was a significant number of false-positive results with 2D FSE and 3D VIBE, as shown in Table 2. The specificity of 2D FSE (54%) was significantly lower than that of MDCT (85%). The specificity of 3D VIBE (62%) was slightly higher than that of 2D FSE but lower than that of MDCT. Imaizumi *et al*⁴ reported in their study using 1.5T unit that MRI overestimated the tumour extent in the bone marrow because it showed the tumour and surrounding inflammation with similar signal intensity. This was also

true in our study using 3T unit. Further, in addition to peritumoral inflammation, severe periodontal disease may contribute to overestimation of the tumour extent on MRI because it can easily cause chronic inflammation of the mandible. Conversely, MDCT could reveal the extent of trabecular bone absorption by tumour in most cases and was superior to MRI in evaluating the extent of tumour invasion. However, the visibility of trabecular bone structure and mandibular canal wall on MDCT differed among individuals. These structures were not clearly visible in some patients, which attributed to false-positive results of MDCT.

The major advantage of MRI is superior soft tissue contrast, which is far better than CT. Thus, MRI may be the best imaging modality when evaluating tumour invasion into the surrounding soft tissue. However, in our study that compared CT and MRI in evaluating mandibular invasion, there was no case in which only MRI was correct. Namely, our study revealed that combining CT and MRI could not increase the diagnostic accuracy of CT alone in evaluating mandibular invasion. We hope that our results will be validated in a large-scale study.

Another imaging modality widely used for oral SCCs is positron emission tomography (PET)/CT, in particular, ^{18}F -fluorodeoxyglucose (^{18}F -FDG) PET/CT. Varying degrees of sensitivity and specificity of this modality for mandibular invasion have been reported: one group reported high specificity,⁸ whereas another reported the opposite results.²³ Kim *et al*²³ applied ^{18}F alpha-methyl tyrosine (^{18}F -FAMT) as PET tracer for oral SCCs and

found no statistical difference between tumour volume estimated by ^{18}F -FAMT PET/CT and histopathological tumour volume obtained from surgical specimens. Because the tracer is considered to accumulate solely in tumour cells and not in inflammation, ^{18}F -FAMT PET/CT may be more accurate than both MRI and CT in evaluating the extent of mandibular invasion. Further study is expected to clarify this issue.

Our study had some limitations that should be addressed. The first limitation concerns the patient population. The tumours in our study mostly had histopathological evidence of mandibular invasion, and the number of patients without invasion was limited (9 of 41 cases). Thus, the specificities of each technique for mandibular invasion might not be sufficiently reliable. Second, because this was a retrospective study, we could not compare the imaging and histopathological findings in the same plane. If we performed the study prospectively, we could have delineated with greater detail the extent of tumour invasion on images.

Conclusion

In the assessment of the presence and extent of mandibular invasion of SCCs in the oral cavity, 3T MRI was not as accurate as 64-row MDCT. In particular, in evaluating the extent of mandibular invasion, 2D FSE sequences yielded many false-positive results and showed significantly lower specificity than MDCT. The use of 3D VIBE sequence slightly improved the low specificity of 2D FSE sequences.

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