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Clinical value of 3D SPECT/CT imaging for assessing jaw bone invasion in oral cancer patients

Hidetaka Miyashita [a], Tadaki Nakahara [b, *], Seiji Asoda [a], Kaori Kameyama [c], Miho Kawaida [c], Reiko Enomoto [b], Hideyuki Shiba [a], Masahiro Jinzaki [b], Hiromasa Kawana [d], Taneaki Nakagawa [a]

[a] Department of Dentistry and Oral Surgery, Keio University School of Medicine, 35 Shinanomachi, Shinjyuku-ku, Tokyo, 160-8582, Japan
[b] Department of Radiology, Keio University School of Medicine, 35 Shinanomachi, Shinjyuku-ku, Tokyo, 160-8582, Japan
[c] Department of Diagnostic Pathology, Keio University School of Medicine, 35 Shinanomachi, Shinjyuku-ku, Tokyo, 160-8582, Japan
[d] Department of Oral and Maxillofacial Implantology, Kanagawa Dental University, 82 Inaokacho, Yokosuka, Kanagawa, 238-8580, Japan

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ABSTRACT

Purpose: This study compared the diagnostic accuracy of jaw bone invasion (JBI) of oral cancer observed with three-dimensional (3D) SPECT/CT, CT, and MRI, and evaluated the clinical advantages of 3D SPECT/CT compared to conventional two-dimensional (2D) SPECT/CT.

Materials and methods: From April 2014 to January 2018, consecutive 16 oral cancer patients with suspected JBI, who had preoperatively undergone the imaging tests, were retrospectively enrolled. The likelihood of JBI was independently scored by a radiologist and oral surgeon. Using 2D or 3D SPECT/CT images, 20 oral surgeons delineated virtual surgical areas on 3D-printed jaws for 3 cases in which the extent of JBI was fully pathologically confirmed. The surgeons completed questionnaires regarding surgical planning and explanations for patients using Likert scales.

Results: JBI was found in 9 patients including 5 (56%) with initial bone invasion. 3D SPECT/CT showed very high negative predictive value (100%) and inter-observer agreement (kappa = 0.917). 3D SPECT/CT was more sensitive than CT and MRI when inconclusive findings for JBI were considered negative. Compared to 2D SPECT/CT, 3D SPECT/CT had greater clinical advantages such as surgical planning and explanation to patients ($p < 0.005$).

Conclusion: 3D SPECT/CT is useful not only for detecting JBI but also for surgical planning.

1. Introduction

In cases of oral squamous cell carcinoma (OSCC), tumor cell infiltration in the jaw bone is not uncommon, even when preoperative imaging tests show no sign of jaw bone invasion (JBI) (Abd El-Hafez et al., 2011). When JBI is suspected, either marginal or segmental jaw bone resection is performed in most cases; the latter is safer in terms of the risk of recurrence, although such extensive jaw resection can degrade the quality of life (QOL) (Schliephake et al., 1995, 1996; Namaki et al., 2004). Importantly, proactive mandibular resections only resulted in 35–78% of unnecessary mandibular resections (Gilbert et al., 1986; O'Brien et al., 1986; Ord et al., 1997). Therefore, novel imaging techniques with high accuracy may have a great impact on both the prognosis and QOL of OSCC patients.

Nuclear imaging using bone-seeking radiopharmaceuticals has developed from bone scintigraphy to SPECT and further to SPECT/CT. The image fusion of SPECT and CT provides anatomic and metabolic information simultaneously, thus making bone SPECT/CT a more accurate tool than bone SPECT alone when trying to identify JBI (Kolk et al., 2014). However, three-dimensional (3D) display methods such as maximum intensity projection and volume rendering, which are often useful for preoperative surgical planning, have been utilized only with CT; they have not been used with the CT portion of SPECT/CT. To overcome this issue, we have developed a method of displaying 3D images for SPECT/CT called 3D SPECT/CT, whereby SPECT data are projected onto the surface of the 3D volume-rendered CT data of various organs including bone

* Corresponding author. Department of Radiology, Keio University School of Medicine 35 Shinanomachi, Shinjuku-ku, Tokyo, 160-8582, Japan. fax: +81 3 3357 1593.
E-mail address: nakahara@rad.med.keio.ac.jp (T. Nakahara).

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(Nakahara et al., 2013a, 2013b, Miyashita et al., 2015; Ogata et al., 2017); we report the applications of 3D SPECT/CT for bone metastasis, osteonecrosis of the jaw, lung perfusion, and sentinel lymph nodes.

The aims of this study were to confirm the accuracy of diagnosing JBI with 3D SPECT/CT compared to the existing imaging tests (CT and MRI) and to evaluate the incremental clinical value of 3D SPECT/CT compared to conventional 2D SPECT/CT using clinical assessment scales (Likert scale).

2. Materials and Methods

2.1. Patients and surgery

This study was performed in accordance with ethics protocols approved by the Keio University Ethics Committee (2016-0178). Sixteen OSCC patients with any clinical signs such as jaw pain and/or tumors visually attached to the surface of the jaw bone were preoperatively studied with SPECT/CT, CT, and MRI. The method of jaw bone resection was determined based on tumor extent by clinical inspection and preoperative imaging. However, 3D SPECT/CT was not used for such decision-making because the diagnostic ability of 3D SPECT/CT had not yet been established. Segmental resection was performed when mandibular invasion below the inferior alveolar canal and/or invasive tumor infiltration were suspected (Slootweg et al., 1989). Otherwise, marginal mandibulectomy was performed for patients suspected of having mandibular invasion. For patients suspected of having maxillary invasion, partial maxillectomy was performed.

For all patients, jaw bone resection was performed during surgery for the primary tumor. The presence or absence of JBI was confirmed pathologically by careful evaluation of hematoxylin and eosin (H&E)-stained sections of the resected jaw. For cases of JBI, the extent of tumor infiltration was classified as initial (i.e. invasion localized at the alveolar ridge or cortical bone) or medullary (i.e. medullary bone invasion beyond the alveolar bone).

2.2. SPECT/CT, CT, and MRI

SPECT/CT, CT, and MRI were performed as previously reported (Van Cann et al., 2008). Briefly, SPECT/CT was performed using a SPECT/CT scanner (Discovery NM/CT 670pro; GE Healthcare) 3 h after an injection of 740 MBq of ^{99m}Tc-HMDP. The CT portion of the SPECT/CT scan was used for both attenuation correction and image fusion. The slice thickness of SPECT and CT images was 4.4 mm and 0.625 mm, respectively. CT was performed after an intravenous administration of 80–100 mL of an iodine contrast agent. Reconstructed images of both soft tissue and bone windows were obtained with an average slice thickness of 1.7 mm. During MRI, T1- and T2-weighted images in the axial and coronal planes were obtained. Then, post-contrast T1-weighted images in the axial and coronal planes with fat suppression were obtained after intravenous administration of a gadolinium contrast agent at a dose of 0.1 mmol/kg of body weight. All images had a slice thickness of approximately 5 mm.

2.3. 3D SPECT/CT image generation

The process of generating 3D SPECT/CT images from the original SPECT/CT data was reported previously (Miyashita et al., 2015; Ogata et al., 2017). First, 3D volume-rendered CT images were generated from the CT portion of SPECT/CT. Then, 3D data of the bone were extracted. Second, SPECT data, which were colored based on the degree of ^{99m}Tc-HMDP uptake in the normal skull, were projected onto the surface of the 3D volume-rendered CT data. On SPECT-projected 3D CT images, blue areas indicated normal bone uptake and yellow areas indicated abnormally increased bone uptake. Finally, cross-sectional images of the 3D data from various angles (the anterior-posterior angle was usually chosen) were obtained using clip-plane editing (Ogata et al., 2017). By using this technique, surgeons can grasp abnormal uptake areas both two-dimensionally and three-dimensionally (Fig. 1 and Supplementary video).

Supplementary video related to this article can be found at https://doi.org/10.1016/j.jcms.2019.03.013

2.4. Image interpretation

3D SPECT/CT, CT, and MRI images were independently evaluated by two interpreters with knowledge of the tumor locations: a board-certified radiologist with over a 15-year experience of interpreting CT, MRI, and nuclear images, and an oral surgeon with over a 10-year experience of interpreting head and neck images for preoperative assessment of jaw surgery. During 3D SPECT/CT, tracer accumulation in the jaw was considered JBI-positive when the accumulation was adjacent to the primary tumor site and was 2.5-times greater than the accumulation of the normal skull (i.e. when the interpreter observed a yellow area in the fused images); this

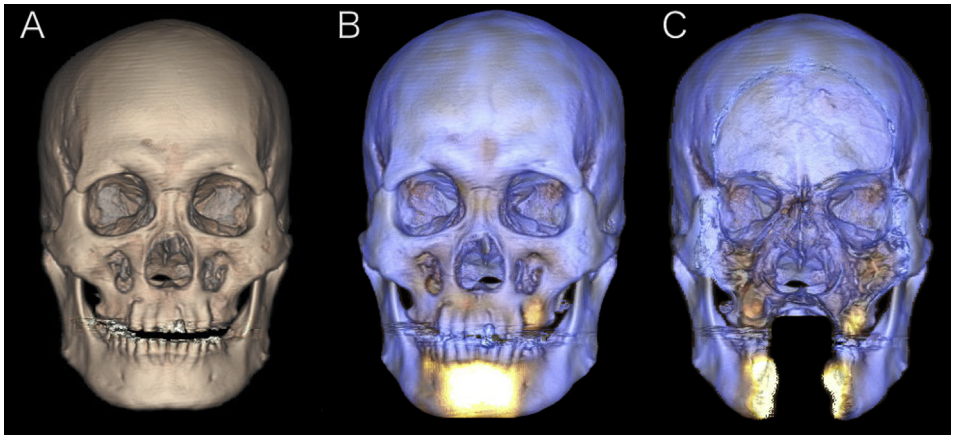


Fig. 1. Generation of 3D SPECT/CT images of a patient with jaw bone invasion (JBI) due to carcinoma of the floor of the mouth. Conventional 3D volume-rendering CT images (A) were first generated, and radioisotope uptake in the bones including the jaw bone was then displayed onto them according to the SPECT value (B). The yellow arrow indicates the hypermetabolic change caused by JBI, whereas the white arrowhead indicates periodontitis. The 3D data images can be arbitrarily cut to see cross-sectional images (C).

was based on our previous study of mandibular osteomyelitis (Miyashita et al., 2015) and our clinical case series with pathological correlations (unpublished data). During CT, the absence of cortex adjacent to the tumor on CT images was interpreted as JBI (Van Cann et al., 2008). During MRI, JBI was defined as displacement of hypointense signals of cortical bone by the signal intensity of the tumor on both T2-and T1-weighted images or replacement of normal signals of the medullary bone by tumor signal intensity (intermediate intensity on T2-weighted images, hypointensity on T1-weighted images, marked enhancement after contrast administration) (Van Cann et al., 2008).

According to these imaging criteria, the likelihood of JBI was scored as follows: 1, definitely negative; 2, probably negative; 3, inconclusive; 4, probably positive; and 5, definitely positive. Since the inflammatory process is known to cause false-positive results in any imaging modalities, a score of 4 or 5 was considered positive (a score of 3 was negative) to avoid increasing false-positives.

2.5. Assessment of the incremental value of 3D SPECT/CT compared to 2D SPECT/CT using clinical viewpoints

The clinical advantages of 3D SPECT/CT compared to 2D SPECT/CT were investigated for two reasons. At our institution, for each patient for whom bone reconstruction was potentially required during surgery, a 3D-printed model of the jaw was preoperatively prepared to determine surgical planning, such as the resection method and resection area, by comparing imaging results with the jaw anatomy. Therefore, we hypothesized that 3D imaging would be more useful than 2D imaging for jaw surgery (reason 1). In addition, it is often troublesome for oral surgeons to convince patients with suspected JBI that jaw bone resection is necessary because it is not easy for non-medical professionals to understand their disease conditions by viewing 2D medical images (reason 2).

Before comparing 2D and 3D SPECT/CT, the SPECT/CT performance itself needed to be assessed. In other words, we needed to evaluate whether areas of increased radioisotope accumulation would represent the extent of tumor invasion. Among the study population, there were three patients for whom the extent of JBI was three-dimensionally confirmed by full histopathological assessment of the resected jaw (cases 6, 8, and 16). In these cases, areas of increased radioisotope accumulation were compared with the histopathological results. Fig. 2 shows a representative case in which the hypermetabolic lesion corresponded well with the area of pathological tumor infiltration. In the other two cases, the areas of increased radioisotope accumulation were slightly wider than those of tumor involvement, although the estimated areas of tumor involvement (i.e. abnormal signal in the jaw) determined on the basis of MRI in these cases were almost consistent with ($n = 1$) or much wider than ($n = 1$) the areas of increased radioisotope accumulation.

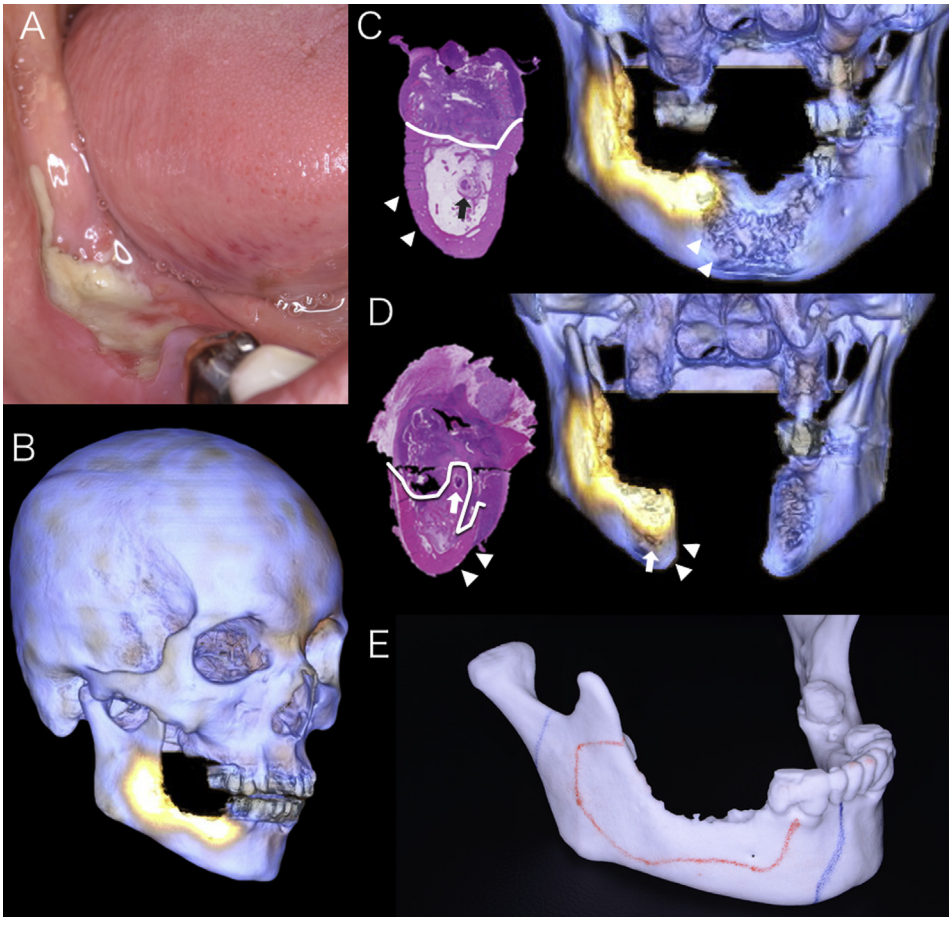


Fig. 2. Radiologic-pathologic correlation of JBI for validation of delineating the surgical area based on SPECT/CT results. A right gingival carcinoma of the mandible around the mandibular molar region is seen (A). 3D SPECT/CT image shows increased radioisotope uptake areas due to JBI (B). Coronal sections of histopathology (left) and 3D SPECT/CT (right) between the canine and first premolar teeth (C). The white line indicates a boundary of tumor infiltration. Black and white arrows indicate incisive canal and cancer-free cortical bone on the buccal side, respectively. Coronal sections of histopathology (left) and 3D SPECT/CT (right) at the level of the second molar tooth (D). White arrow and arrowheads indicate the inferior alveolar nerve and normal cortical bone at the lingual side, respectively. The histopathologic results corresponded well with those of the 3D SPECT/CT in terms of the extent of JBI. An oral surgeon drew the increased uptake area (red line) and virtual resection lines (blue lines) on the 3D-printed jaw (E).

Using the 2D and 3D SPECT/CT data of the 3 cases, 20 oral surgeons who had different clinical experience were asked to draw the surgical area (Fig. 2E). Then, the required time for delineation (TFD) was measured. The interval of each investigation (2D and 3D) was set as at least 1 month to avoid potential bias. Afterward, the surgeons were asked to complete a questionnaire using the Likert scale regarding reasons 1 and 2 (Supplementary Fig.1). The Likert scale is a well-known subjective evaluation method that can be used to assess patient-relevant outcomes and the usability of medical devices such as 3D laparoscopic surgery and 3D imaging software (Calloway et al., 2011; Buia et al., 2017). The questionnaire included confidence in delineating the disease area based on SPECT/CT images, potential changes to surgical planning if the results of SPECT/CT were added to those of CT and MRI, and potential improvement in communication with patients regarding their surgical procedures by showing them the SPECT/CT images.

After finishing both 2D and 3D SPECT/CT evaluations, all surgeons were asked to compare the 2D and 3D images and then answer a question as to whether 3D SPECT/CT is more useful than 2D SPECT/CT from diagnosis to treatment.

2.6. Statistical analysis

The diagnostic performances of SPECT/CT, CT, and MRI were based on surgical results. The weighted kappa statistic was applied to assess inter-observer agreement for the diagnosis of JBI (Crewson, 2005). A receiver-operating characteristic (ROC) analysis was performed to compare the diagnostic performances of 3D SPECT/CT, CT, and MRI. Differences in the TFD and the value of the Likert scales for the 2D and 3D evaluations were compared using the Wilcoxon signed-rank test. Two-tailed statistical tests were conducted with a significance level of 0.05.

3. Results

3.1. Diagnostic performance of SPECT/CT, CT, and MRI

Nine patients (56%) were histopathologically confirmed to have JBI; among these patients, five had initial bone invasion and four had medullary bone invasion (Table 1). Table 2 shows the diagnostic performances of 3D SPECT/CT, CT, and MRI. 3D SPECT/CT showed much higher sensitivity but relatively lower specificity than CT and MRI. Whether the radiologist or the oral surgeon interpreted the images, the accuracy of 3D SPECT/CT was 88%; however, those of CT and MRI were less than 70%. In ROC analysis, 3D SPECT/CT had a higher area under the curve (0.937 for the radiologist, 0.841 for the oral surgeon) than CT (0.762; 0.738) or MRI (0.921; 0.833), although there was no statistical significance ($p > 0.05$) (Fig. 3). Inter-observer agreements between the interpreters were 0.917 for 3D SPECT/CT, 0.833 for CT, and 0.821 for MRI (Fig. 3). Fig. 4 shows a representative case in which 3D SPECT/CT detected JBI in the periodontal space even though CT did not and MRI was inconclusive.

3.2. Delineation of the surgical area and questionnaire for comparisons between 3D and 2D SPECT/CT

TFDs and the results of the questionnaire are shown in Supplementary Figure 2. TFDs for the 3D SPECT/CT images were significantly shorter than those for 2D ($p < 0.0001$). The participating surgeons ($n = 20$) were significantly more confident using the 3D images compared to 2D images when delineating disease areas ($p < 0.01$). The additional benefit of 3D SPECT/CT compared to CT and MRI for surgical planning was greater than that of 2D SPECT/CT for 2 of the 3 cases ($p < 0.01$). 3D SPECT/CT was more effective compared with 2D SPECT/CT for explaining the necessity for and details of jaw surgery to patients ($p < 0.01$).

The 20 oral surgeons tended to consider 3D SPECT/CT more useful than 2D SPECT/CT from diagnosis to treatment (Supplementary Fig. 2). It should be noted that all surgeons supported the use of 3D SPECT/CT (i.e. Likert scale ≥ 5), and that more than 65% of them indicated a definite contribution of 3D SPECT/CT from diagnosis to treatment (case 6, 70%; case 8, 65%; case 16, 80%).

Table 1
Patient demographics (N = 16).

Age (y)	
Mean	68.1
Range	46–83
Sex	
Male	10
Female	6
Primary tumor location	
Mandibular gingiva	10
Buccal mucosa	2
Maxillary gingiva	1
Floor of the mouth	1
Others	2
TNM classification (UICC)	
pT1N0M0	5
pT2N0M0	1
pT3N0M0	1
pT4aN0M0	7
pT4bN2b	2
Jaw status around tumor	
Dentulous	7
Edentulous	9
Extent of jaw bone invasion	
Initial[a]	5
Medullary	4
Not applicable	7

[a] Localized in alveolar or/and cortical bone.

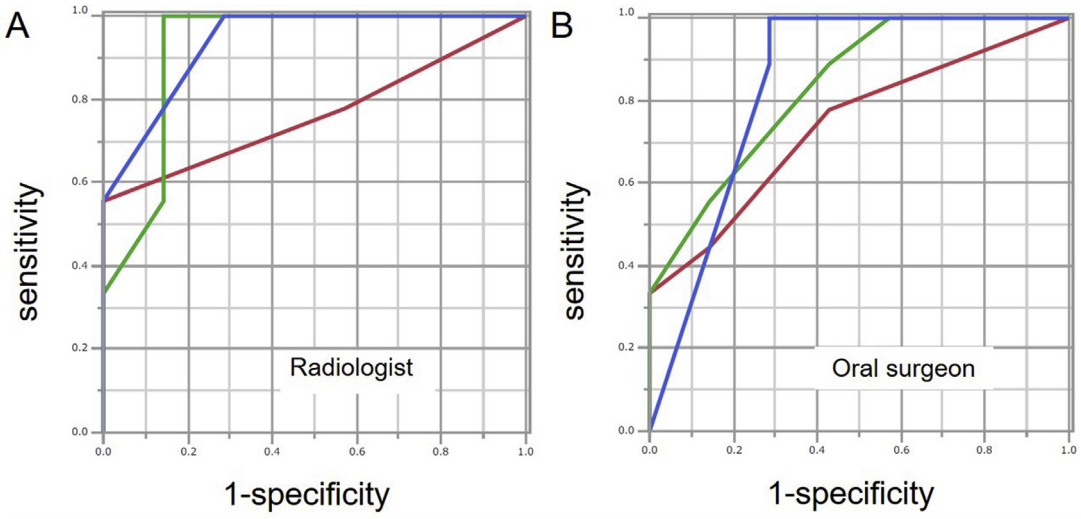
4. Discussion

3D SPECT/CT is a novel imaging technique that was developed by Nakahara et al (Ogata et al., 2017). The theory of generating the 3D

Table 2
Diagnostic performance of SPECT/CT, CT, and MRI.

Interpreter	Modality	Sens (%)	Spec (%)	PPV (%)	NPV (%)	ACC (%)
Initial JBI						
Radiologist	SPECT/CT	100	N/A	100	N/A	100
	CT	20	N/A	100	N/A	20
	MRI	40	N/A	100	N/A	40
Oral surgeon	SPECT/CT	100	N/A	100	N/A	100
	CT	20	N/A	100	N/A	20
	MRI	20	N/A	100	N/A	20
Medullary JBI						
Radiologist	SPECT/CT	100	N/A	100	N/A	100
	CT	75	N/A	100	N/A	75
	MRI	75	N/A	100	N/A	75
Oral surgeon	SPECT/CT	100	N/A	100	N/A	100
	CT	75	N/A	100	N/A	75
	MRI	100	N/A	100	N/A	100
Total (with and without JBI)						
Radiologist	SPECT/CT	100	71	82	100	88
	CT	44	100	100	58	69
	MRI	56	86	83	60	69
Oral surgeon	SPECT/CT	100	71	82	100	88
	CT	44	86	80	55	63
	MRI	56	86	83	60	69

Sens, sensitivity; Spec, specificity; PPV, positive predictive value; NPV, negative predictive value; ACC, accuracy; N/A, not applicable.



Modalities	AUC (95% CI)		Inter-reader agreement
	Radiologist	Oral surgeon	Weighted kappa value
3D SPECT/CT	0.937 (0.751-0.986)	0.841 (0.536-0.960)	0.917
CT	0.762 (0.467-0.991)	0.738 (0.450-0.907)	0.833
MRI	0.921 (0.560-0.990)	0.833 (0.536-0.960)	0.821

Fig. 3. ROC analysis and inter-observer agreement analysis of 3D SPECT/CT, CT, and MRI for the diagnosis of JBI.

images is not complex, and 3D SPECT/CT provides almost the same information as that provided by conventional 2D SPECT/CT. In the present study, the value of 3D SPECT/CT for cases of suspected JBI was assessed from diagnosis to treatment. We found that 3D SPECT/CT had better diagnostic performance compared with that of CT and MRI. It should be noted that agreement between a radiologist and non-radiologist regarding the diagnosis of JBI was better when using 3D SPECT/CT than when using CT or MRI, probably because of the ease of

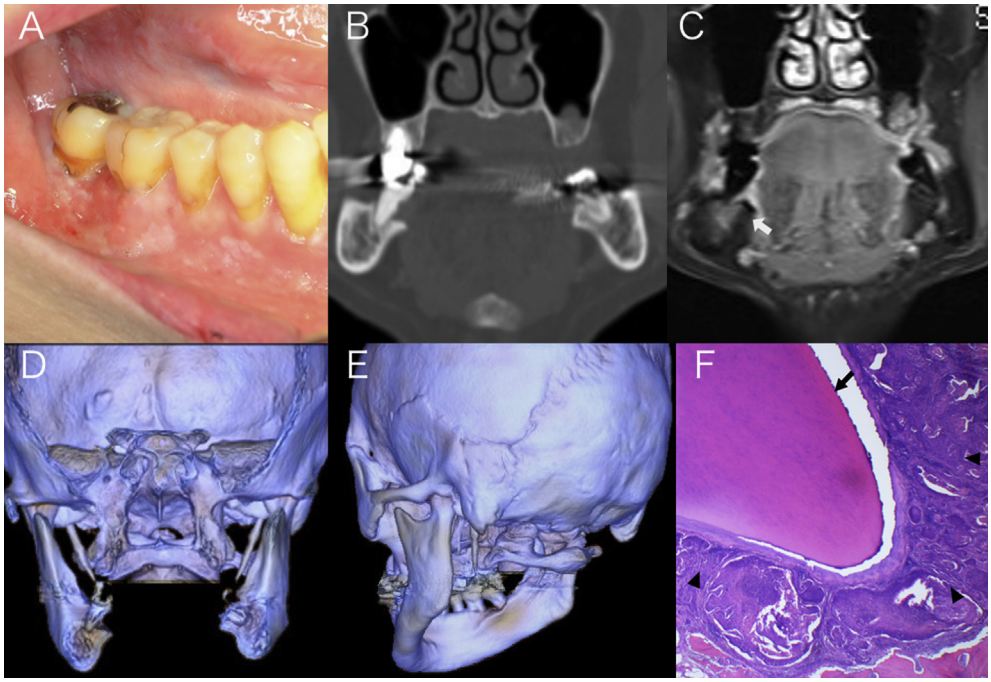


Fig. 4. A case of JBI due to carcinoma of the right mandibular gingiva around the second molar (A). CT showed no obvious structural abnormality (B). Post-contrast T1-weighted images showed faint contrast enhancement in the medulla without any cortical abnormality (C) and without any other signs of JBI on MRI images. 3D SPECT/CT showed increased radioisotope uptake areas close to the primary site (D, E). The likelihood scores of JBI were 1 with CT (definitely negative), 3 with MRI (inconclusive), and 4 with 3D SPECT/CT (probably positive) according to the image interpreters. Histopathological analysis revealed JBI localized in the periodontal space (arrowheads) just around the root of a tooth (arrow) (F).

performing visual assessments with 3D SPECT/CT. The diagnostic accuracy for JBI was expected to be similar between 2D and 3D SPECT/CT because the criterion for JBI was the presence of abnormal Tc-99m HMDP uptake in the jaw bone adjacent to the known primary tumor. However, as shown in Supplementary Figure 2, 3D SPECT/CT was clearly more effective than 2D SPECT/CT for surgical planning and explaining findings to patients from the viewpoint of surgeons. Therefore, the 3D display would have an impact on daily clinical practice compared to the 2D display.

4.1. Contribution of 3D SPECT/CT to the diagnosis of JBI

To date, CT and MRI have been widely used to preoperatively assess JBI because a gross structural change of the jaw is a definite sign of JBI. CT had the highest specificity among 3D SPECT/CT, CT, and MRI in the present study, thereby suggesting it is a valuable tool for assessing JBI (Goerres et al., 2005; Handschel et al., 2012). On the other hand, JBI at an earlier stage is unlikely to show bone destruction on CT (Van Cann et al., 2008; Gu et al., 2010; Hakim et al., 2014) because dental metal artifacts often hamper the evaluation of JBI with CT (Goerres et al., 2005; Hakim et al., 2014). Indeed, the majority of our study population showed initial bone invasion, which would account for lower sensitivity (44%) than previously reported (73%) (Qiao et al., 2018). Furthermore, Gu et al. reported a similarly low sensitivity of CT (42%) in the evaluation of JBI, and they considered that the results would be related to minimal invasion into the cortical bone (Gu et al., 2010).

In contrast, the high sensitivity of SPECT for predicting JBI has been proven in a meta-analysis (Li et al., 2015) in which sensitivity and specificity were 0.96 (95% confidence interval [CI]: 0.93–0.98) and 0.67 (95% CI: 0.61–0.73), respectively. In the present study, CT was negative for four of the five cases of initial bone invasion, whereas 3D SPECT/CT was positive for all of these cases. Therefore, SPECT has a complimentary role to CT because it can increase the sensitivity of detecting the initial bone invasion.

MRI is considered more sensitive than CT for detecting medullary bone invasion either with or without contrast agent injections because of the high contrast between the medulla and tumor tissue (Wiener et al., 2006; Van Cann et al., 2008; Gu et al., 2010), which was consistent with our results. However, the image quality of MRI is relatively low compared with CT or the CT portion of SPECT/CT due to its lower spatial resolution. In addition, motion artifacts derived from tongue movement may interfere with the image interpretation of JBI. Another weakness of MRI is that the delineation of the jaw bone cortex is difficult because of its subtle signal (Kolk et al., 2014). These reasons would account for lower likelihood scores for MRI than for 3D SPECT/CT when judging the initial JBI (data not shown; $p < 0.05$, Wilcoxon signed-rank test), resulting in low sensitivity of MRI (56%) according to our imaging criteria (Table 2). The sensitivity was similar to the aforementioned study by Gu et al. (58%), which might be due to a similar patient population (Gu et al., 2010). In addition, lower sensitivity of MRI compared with SPECT have been reported in a recently published meta-analysis (Qiao et al., 2018). However, it should be noted that better results in MRI could have been achieved when using thinner slice thickness (e.g. 3 mm) or 3D MRI technique.

In this study, increased radioisotope uptake adjacent to the primary tumor sites was a criterion for positive JBI to reduce false-positive results caused by many conditions such as dental caries. Such image interpretation is feasible with 3D SPECT/CT because it can easily grasp the anatomic relationship between primary tumors and the region of increased jaw bone uptake. Nonetheless, 3D SPECT/CT yielded false-positive results for two cases (13%) of massive inflammatory processes in the jaw near the primary sites.

4.2. Usefulness of 3D SPECT/CT for surgical planning

It was recently reported that SPECT/CT improves the determination of resection margins compared to conventional imaging modalities such as CT and MRI (Kolk et al., 2014), thereby supporting the notion that the extent of increased bone metabolism could determine the surgical area. However, because 3D surgical simulations including jaw excision and bone reconstruction are sometimes required to accomplish complicated jaw surgery, the area of tumor invasion expected from conventional 2D preoperative images is likely to be larger to avoid leaving any tumor tissues (Fig. 5). Therefore, 3D SPECT/CT serves as a useful reference for actual jaw surgery. In addition, the usefulness of 3D visualization

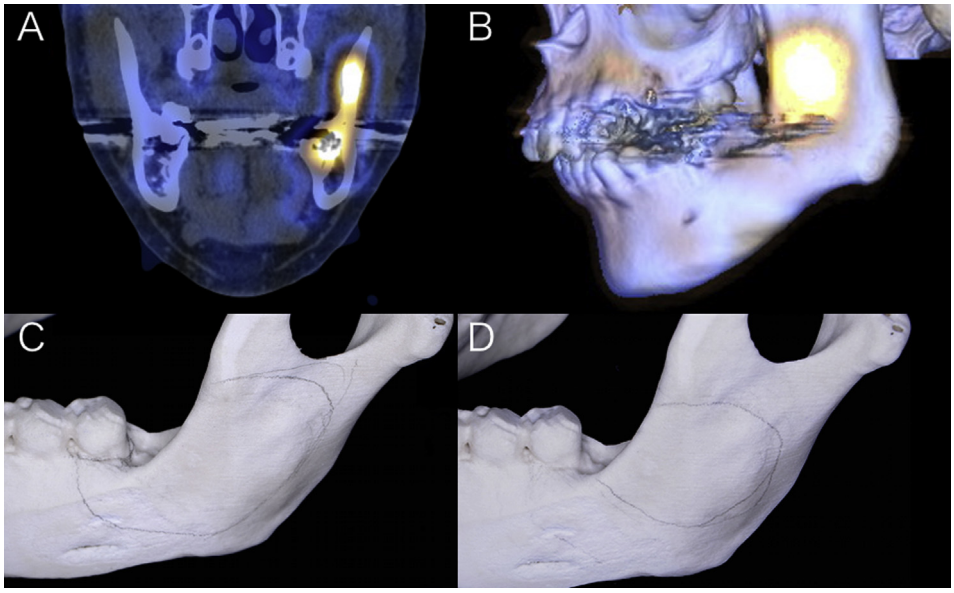


Fig. 5. Delineation of the disease area onto 3D-printed jaws by an oral surgeon using references to 2D (A) and 3D SPECT/CT (B) for a patient with carcinoma of the left mandibular gingiva. The same surgeon delineated the virtual disease areas using references to 2D (C) and 3D images (D) with an interval of more than 1 month.

has been reported for other surgical purposes (Albes et al., 2001; Calloway et al., 2011; Buia et al., 2017). For example, Buia et al. evaluated the advantage of 3D imaging for laparoscopic surgery using Likert scales that showed increased "personal felt safety" and "task efficiency" of the surgeon using 3D imaging compared to 2D imaging (Buia et al., 2017).

4.3. Usefulness of 3D SPECT/CT for explaining findings to patients

Similar to other oncologic patients, head and neck cancer patients expect their attending surgeons to intelligibly explain both the necessity for and method of surgery before they undergo surgeries that can affect QOL, such as postoperative dysphagia (Bozec et al., 2016). Some studies reported that supplying information to cancer patients before surgery is closely linked to postoperative QOL (Davies et al., 2008; Lamers et al., 2016). Due to the complex anatomy and close proximity to critical areas, the lack of a preoperative discussion regarding the potential complications and alternative treatment increases the risk of otolaryngology malpractice litigation (Svider et al., 2013). Our questionnaire revealed that many surgeons thought highly of 3D SPECT/CT as an informative tool for patients compared to 2D SPECT/CT. Furthermore, the clarity of 3D SPECT/CT could reduce the possibility of misunderstandings regarding disease conditions among medical staff, including oral and plastic surgeons, and patients.

4.4. Limitations

This study had some limitations. First, we investigated only three cases in which pathological tumor infiltration was three-dimensionally confirmed to allow correlation with increased radioisotope accumulation. Therefore, it is uncertain whether 2D or 3D SPECT/CT is superior to MRI in determining the extent of jaw surgery although MRI was reported to have a limited value (Imaizumi et al., 2006). However, our scope was not to compare between 3D SPECT/CT, CT, and MRI for determining the extent of JBI, but to compare between 3D and 2D SPECT/CT as an adjunct to CT and MRI for the diagnosis, surgical planning, or explanation to patients. In addition, it was practically difficult to perform a full 3D correlation analysis of SPECT and histopathology for all cases. Second, the patients did not complete a questionnaire. Therefore, the opinion of patients regarding the impact of 3D SPECT/CT is unknown. Third, Bone SPECT can only depict bone metabolism, and it therefore has no impact on detection of soft tissue infiltration and cervical lymph node metastasis. Therefore, SPECT/CT cannot replace CT or MRI for clinical evaluation of oral cancers.

5. Conclusions

3D SPECT/CT showed high sensitivity and high inter-reader agreement compared to CT and MRI when used to detect JBI. 3D SPECT/CT is more useful compared with 2D SPECT/CT not only for determining a treatment strategy for JBI but also for explaining the details of jaw surgery to patients and convincing them of its necessity.

Conflicts of interest

One of the authors (T.N.) received a research grant by the Development of Medical Devices through Collaboration between Medicine and Industry from Japan Agency for Medical Research and Development (AMED). The other authors declare that they have no conflict of interest.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jcms.2019.03.013.

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