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Can radiological examination of mandibular bone invasion accurately predict the need for mandibular resection in oral squamous cell carcinoma?

A. DeAngelis[1], O. Breik[1], C. Angel[2], C. Goh[3], T. Iseli[4], A. Nastri[1], M. McCullough[5], D. Wiesenfeld[6]

[1]Oral and Maxillofacial Surgery, Royal Melbourne Hospital, Melbourne, Victoria, Australia; [2]Anatomical Pathology, Victorian Comprehensive Cancer Centre, Melbourne, Victoria, Australia; [3]Department of Radiology, Royal Melbourne Hospital, Melbourne, Victoria, Australia; [4]Otorhinolaryngology Head and Neck Surgery, Royal Melbourne Hospital, Melbourne, Victoria, Australia; [5]Oral Medicine, Melbourne Dental School, University of Melbourne, Melbourne, Victoria, Australia; [6]Head and Neck Tumour Stream, Victorian Comprehensive Cancer Centre, Melbourne, Victoria, Australia

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Abstract. Bone invasion by oral squamous cell carcinoma necessitates jaw resection, with preoperative imaging ideally able to guide the resection. A retrospective review of 109 patients with oral squamous cell carcinoma who underwent mandibular resection was performed. Eighty-three had preoperative computed tomography (CT) imaging and 72 underwent magnetic resonance imaging (MRI). The presence of bone invasion on imaging was compared to histopathology. Bone invasion was detected in 44 of 109 resection specimens (40.4%) and was identified on CT in 31 of 83 cases (37.4%) and on MRI in 35 of 72 cases (48.6%). The sensitivity and specificity of CT for detecting bone invasion was 69.0% and 79.6%, respectively, while for MRI was 87.1% and 80.5%, respectively. Histological detection of bone invasion was associated with greater disease-specific mortality ($P = 0.002$), as was MRI detection of bone invasion ($P = 0.027$). CT detection was not significant ($P = 0.240$). Negative prediction of bone invasion was 95% accurate for both modalities in clinically non-invaded mandibles. Survival was reduced in patients who underwent marginal mandibular resection when bone invasion was detected histologically (33.3% vs. 70.5%, $P = 0.277$) and with CT, although this was not statistically significant. More data are required to determine whether more aggressive resection is warranted when bone invasion is detected preoperatively.

Key words: squamous cell carcinoma; oral; bone invasion; computed tomography; magnetic resonance imaging.

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Historically, aggressive resection of the mandible was recommended for all oral squamous cell carcinomas (SCC) with close tumour proximity to bone, due to the belief that tumour spread into the neck occurred via lingual periosteal lymphatic channels[1–5] and that the periodontium was a direct pathway for extension into mandibular bone[6]. Subsequently, the true pathways for tumour extension have been determined and histological studies have revealed two distinct patterns of tumour invasion, confirming that the primary route of tumour entry is via direct invasion through the periosteum[5,7–9].

The aim of surgery for oral SCC with curative intent is to remove the tumour with clear margins[10]. In order to achieve this goal, resection of part of the jaw may be required. Even with modern free flap reconstructive techniques, segmental mandibular resection still results in cosmetic and functional deficits, donor site morbidity, increased risk, prolonged recovery, and increased need for postoperative rehabilitation[11]. Increased overall risk from a surgical procedure and its complications along with increased risk of perioperative complications. Marginal mandibular resection aims to maintain mandibular continuity and only remove as much bone as is necessary to obtain clear margins[6,12–14]. It is an oncologically safe procedure when performed for early tumours with limited bone invasion, especially with an erosive pattern[12,14,15].

Ideally, preoperative imaging is able to provide accurate information regarding the pattern and depth of bone invasion. However, the rate of non-invaded resections of the mandible in various studies still ranges between 20% and 100%[12,16–18]. While panoramic radiography is useful to determine the state of the dentition prior to radiotherapy and the residual vertical height of mandibular bone, approximately 30–50% of mineral must be lost before defects becomes visible, making it poor at detecting early bone invasion[18,19]. Computed tomography (CT) is superior to panoramic radiography for detecting bone invasion and is essential for soft tissue evaluation but increases the dose of radiation. Distortion due to scatter artefacts from metallic dental restorations, as well as beam hardening adjacent to dense cortical bone, can reduce the quality of the image and therefore its utility[20]. As with panoramic radiography, CT has a high false-negative rate for the detection of early marrow invasion and tends to underestimate bone involvement[21].

With the advent of improved magnetic resonance imaging (MRI) techniques, resolution, and mainstream use, it has become an important modality in the assessment of oral SCC. MRI does not subject the patient to ionizing radiation and suffers less from artefacts caused by metallic dental restorations[18,21]. It has been reported previously that compared to CT, MRI is less reliable at detecting cortical bone invasion, but is better at identifying perineural invasion and bone marrow spread[20,22]. MRI can overestimate the degree of bone invasion due to peri-tumoural inflammation and periodontal disease and its accuracy in this regard is debatable[21–23].

The accuracy of CT and MRI in the detection of bone invasion has been reported variably in the literature, with the sensitivity and specificity of CT ranging on average from 65% to 95% and 88% to 94%, respectively, and the sensitivity and specificity of MRI ranging on average from 75% to 90% and 75% to 88%, respectively. Despite these average figures there is wide variation, with some studies reporting sensitivity and specificity figures as low as 30–35% for CT and 55–65% for MRI and many studies reporting 100% sensitivity and specificity for both modalities[21,24,25]. Nevertheless, despite improvements in imaging techniques, the degree of bony resection still relies upon the judgement of the clinician during surgery, especially when there is significant circumferential periosteal or soft tissue involvement[3,12,14,17].

This retrospective study aimed to answer three questions: (1) Can CT and MRI accurately identify or exclude tumour invasion into bone? (2) Does marginal mandibular resection result in a worse prognosis if bone invasion is present? (3) Does the detection of bone invasion by CT or MRI suggest a poorer prognosis and therefore the need for more aggressive resection?

The aim was to answer these questions by comparing the results obtained from imaging to those obtained from histological examination of mandibular resection specimens and survival data.

Materials and methods

Recruitment

One hundred and nine patients who underwent mandibulectomy (marginal or segmental) were selected from a cohort of 287 consecutive patients who presented to the Royal Melbourne Hospital Head and Neck Tumour Stream with oral SCC between January 1, 2007 and December 31, 2012. Patients with external CT or MRI images were excluded from the analysis to ensure consistent image quality.

Treatment protocol

All patients selected for this study were treated with curative surgical intent. Neck dissection was performed for early stage (T1 and T2) tumours with a depth of invasion >3 mm and all locally advanced stage (T3 and T4) tumours. The standard protocol for adjuvant radiotherapy was 60 Gy in 30 fractions delivered in five fractions per week for patients with locally advanced tumours and positive nodal disease. Adjuvant radiotherapy was considered in patients with early stage tumours with adverse histological features including perineural or lymphovascular invasion, depth of invasion >7 mm, bone invasion, and recurrent disease.

For patients with positive margins, those with extracapsular nodal extension, and selected cases of locally advanced disease with adverse features, the standard protocol was adjuvant radiotherapy (66 Gy in 33 fractions, five fractions per week) with concurrent chemotherapy consisting of weekly cisplatin 40 mg/m^2 or carboplatin AUC2 when cisplatin was contraindicated.

CT imaging protocol

All patients underwent a contrast-enhanced multi-detector CT scan. A Siemens 128 row Somatom CT Scanner was used; 50 ml of 350 mg/ml iohexol contrast medium (Omnipaque) was injected with a delay of 45 seconds prior to the scan. Scanning was performed at 120 kVp and 210 mAs and images were reconstructed in three planes using an overlapping technique and 1-mm slices. Acquired images were then viewed in a bone window (400–1400 HU) and a soft tissue window (50–350 HU).

MRI protocol

Selected patients underwent a contrast-enhanced MRI scan. A GE Medical Systems Signa 1.5 Tesla MRI scanner was used; 15 ml of 7.035 g/15 ml gadopentetate dimeglumine contrast medium (Magnevist) was injected with a delay of 45 seconds prior to the scan. Images were acquired in 0.4-mm slides using T1, T2, STIR, DWI, and fat saturation sequences and were then reconstructed in three planes using an overlapping technique prior to viewing.

Radiology protocol

A total of 83 CT images and 72 MRI scans of diagnostic quality were available for analysis. CT and MRI studies were both available for 58 patients (53.2%). All images were interpreted by a specialist head and neck radiologist who had access to clinical tumour information, but was otherwise blinded to the results of the resection and histopathology. Each modality was interpreted separately without reference to any other available imaging, and any identification of tumour invasion into bone was recorded as a positive result.

Histopathology protocol

After orientation and inking of margins, tumour resection specimens were fixed in 10% neutral buffered formalin, decalcified, and then embedded in paraffin. Representative haematoxylin and eosin stained sections of the tumour/bone interface were examined by a specialist pathologist who had access to clinical tumour information and resection, but was otherwise blinded to the results of the radiological findings. Resection margins and bone invasion were assessed by circumferential sectioning of the specimen margins followed by serial sectioning of the remaining specimen. Any identification of tumour invasion into bone was recorded as a positive result.

Statistical analysis

The statistical analysis was conducted using IBM SPSS Statistics version 19.0 (IBM Corp., Armonk, NY, USA) and GraphPad Prism version 6.01 (GraphPad Software Inc., San Diego, CA, USA). Pearson's χ^2 test and the Student *t*-test were employed for disease characteristics and demographic data. The sensitivity, specificity, positive predictive value (PPV), and negative predictive value (NPV) were calculated from the study data. Kaplan–Meier analysis and log-rank tests were used to assess univariate factors for disease-specific survival. A *P*-value of less than 0.05 was taken to be significant.

Results

Histopathology

Of the 109 patients who underwent bony resection, a total of 34 patients (31.2%) underwent marginal mandibulectomy and 75 (68.8%) underwent segmental mandible resection. Invasion into bone was detected histologically in a total of 44 patients (40.4%), with only three out of 34 (8.8%) marginal mandibulectomy specimens compared to 41 out of 75 (54.7%) segmental mandibulectomy specimens revealing invasion into bone.

The average measured tumour size was significantly larger in the bone invasion group (29.2 ± 5.1 mm) than in the non-invasion group (18.0 ± 10.5 mm) ($P < 0.001$, *t*-test). Likewise, the average measured tumour depth was significantly larger in the bone invasion group (12.1 ± 9.0 mm) than in the non-invasion group (7.3 ± 5.3 mm) ($P = 0.003$, *t*-test). There was no significant difference in bone or soft tissue margin status after resection in patients with histologically detected bone invasion ($P = 0.467$, χ^2 test) and there were no cases of tumour extending closer than 1 mm to the resection margin in bone invaded specimens (Table 1).

Comparison of disease-specific mortality over the length of this study showed that those patients who had bone invasion at the time of surgery had worse survival than those patients with no observable bone invasion on histopathological examination (65.9% vs. 87.0%, $P = 0.002$, log-rank test) (Fig. 1).

Table 1. Summary of the results of histopathological detection of bone invasion[a].

	Bone invasion detected by histopathology		
	Pathologically positive	Pathologically negative	Total
Patients	44 (40.4%)	65 (59.6%)	109 (100%)
Resection			
Marginal	3 (8.8%)	31 (91.2%)	34 (31.2%)
Segmental	41 (54.7%)	34 (45.3%)	75 (68.8%)
Tumour size	29.2 ± 5.1 mm	18.0 ± 10.5 mm	22.5 ± 12.5 mm
Tumour depth	12.1 ± 9.0 mm	7.3 ± 5.3 mm	9.3 ± 7.4 mm
Margins[b]			
>5 mm	24 (54.5%)	43 (66.2%)	67 (61.5%)
2–5 mm	15 (34.1%)	16 (24.6%)	31 (28.4%)
<2 mm	5 (11.4%)	6 (9.2%)	11 (10.1%)

[a] Results are presented as the number (percentage), or as the mean ± standard deviation.
[b] Margins are the closest resection margin (including soft tissue and bone).

CT imaging

Of the 83 patients with diagnostic quality CT imaging studies available, invasion into bone was detected in a total of 31 patients (37.4%). False-positives were detected in 11 patients (13.3%) and false-negatives in nine (10.8%). When compared to histological identification of bone invasion, the sensitivity and specificity of CT imaging for the detection of bone invasion in this study was 69.0% and 79.6%, respectively. The PPV was 64.5% and the NPV was 82.7%, for an overall odds ratio (OR) of 8.69 (95% confidence interval (CI) 3.11–24.29; $P < 0.001$) (Table 2).

Bone invasion was detected radiologically in five out of 32 patients (15.6%) who underwent marginal resection with diagnostic quality CT imaging. False-positives were detected in three patients (9.3%) and false-negatives in one (3.1%), for a sensitivity and specificity of 66.7% and 89.7%, respectively. The PPV was 40.0% and the NPV was 96.3%, for an overall OR of 17.33 (95% CI 1.19–253.19; $P = 0.037$) (Table 2).

Likewise in the 51 patients who underwent segmental resection, bone invasion was detected in 26 (51.0%), with false-positives in eight patients (15.7%) and false-negatives in eight (15.7%), for a sensitivity and specificity of 69.2% and 68.0%, respectively. The PPV was 69.2% and the NPV was 68.0%, for an overall OR of 4.78 (95% CI 1.46–15.6; $P = 0.010$) (Table 2).

There was no statistically significant difference in margin status in these patients, and although disease-specific survival was reduced in patients with bone invasion detected on CT (80.6% vs. 88.5%, this was not statistically significant ($P = 0.240$, log-rank test; Fig. 2).

MRI

Of the 72 patients with diagnostic quality MRI studies available, invasion into bone was detected in a total of 35 patients (48.6%). False-positives were detected in eight patients (11.1%) and false-negatives in four (5.6%) (Table 3). Compared to histologically identified bone invasion, the sensitivity and specificity of MRI was 87.1% and 80.5%, respectively. The PPV was 77.1% and the NPV was 89.2%, for an overall OR of 27.84 (95% CI 7.56–102.53; $P < 0.001$) (Table 3).

Bone invasion was detected radiologically in three out of 22 patients (13.6%) who underwent marginal resection with diagnostic quality MRI. False-positives

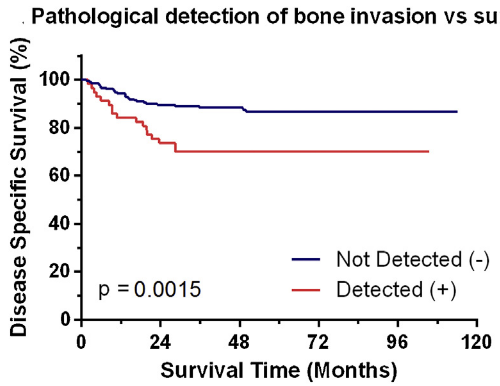

Fig. 1. Kaplan–Meier survival curve comparing patients with and without bone invasion as detected by histopathology.

were detected in two patients (9.1%) and false-negatives in one (4.5%), for a sensitivity and specificity of 50.0% and 90.0%, respectively. The PPV was 33.3% and the NPV was 94.7%, for an overall OR of 9.00 (95% CI 0.39–206.54; $P = 0.169$) (Table 3).

Of the 50 patients who underwent segmental resection, bone invasion was detected in 32 (64.0%), with false-positives in six patients (2.0%) and false-negatives in three (6.0%), for a sensitivity and specificity of 89.7% and 71.4%, respectively. The PPV was 81.3% and the NPV was 83.3%, for an overall OR of 21.67 (95% CI 4.72–99.53; $P < 0.001$) (Table 3).

Again there was no statistically significant difference in margin status in these patients; however disease-specific survival was greatly reduced in patients with bone invasion detected on MRI (71.4% vs. 91.9%, $P = 0.027$, log-rank test), which was statistically significant (Fig. 3).

There was no difference in tumour size between modalities overall ($P = 0.338$, *t*-test) or in those where bone invasion was detected by each modality ($P = 0.459$, *t*-test).

Combined CT and MRI

Of the 58 patients with both diagnostic quality CT and MRI studies available, invasion into bone was detected in at least one study in a total of 27 patients (46.6%) and both studies were negative in 31 patients (53.4%). False-positives were detected in nine patients (15.5%) and false-negatives in four (6.9%). When compared to histological identification of bone invasion, the combined sensitivity and specificity of CT and MRI for the detection of bone invasion in this study was 81.8% and 75.0%, respectively. The PPV was 66.7% and the NPV was 87.1%, for an overall OR of 13.5 (95% CI 3.61–50.55; $P < 0.001$).

Type of resection

Overall the results showed greater survival in those treated with marginal mandibulectomy (91.1% vs. 78.7%); however these results were not statistically significant ($P = 0.105$, log-rank test) (Fig. 4). Although two out of three deaths (66.7%) in the marginal mandibulectomy group and 13 out of 16 deaths (81.3%) in the segmental mandibulectomy group occurred in patients with histologically detected bone invasion, this was also not significant. ($P = 0.570$, χ^2 test).

However, when only patients with histopathologically detected bone invasion were examined (Fig. 5A), the patients who underwent marginal mandibulectomy fared worse than those who received segmental resections (33.3% vs. 70.5%), although this did not reach statistical significance ($P = 0.\ 277$, log-rank test). When patients with bone invasion detected by CT were examined (Fig. 5B), there was a similar drop in survival for those treated with marginal resection (60.0% vs. 84.6%, $P = 0.254$, log-rank test), which was also not statistically significant, while those with bone invasion detected on MRI (Fig. 5C) treated with marginal resection showed no difference in survival (66.7% vs. 71.9%, $P = 0.990$, log-rank test).

Discussion

The accurate prediction of mandibular bone invasion prior to oral SCC resection remains an important goal to prevent the unnecessary morbidity that results from segmental mandibulectomy and subsequent reconstruction. Answers to the three questions posed in the Introduction section of this article are outlined below.

Table 2. Summary of the results of CT detection of bone invasion compared to histopathology.

Bone invasion detected by:	Bone invasion detected by histopathology						Statistics	
	Pathologically positive		Pathologically negative		Total			
CT								
Positive	20	(24.1%)	11	(13.3%)	31	(37.4%)	PPV	64.5%
Negative	9	(10.8%)	43	(51.8%)	52	(62.6%)	NPV	82.7%
Total	29	(34.9%)	54	(65.1%)	83	(100%)		
	Sensitivity	69.0%	Specificity	79.6%			OR	8.69
CT, marginal resection								
Positive	2	(6.3%)	3	(9.3%)	5	(15.6%)	PPV	40.0%
Negative	1	(3.1%)	26	(81.3%)	27	(84.4%)	NPV	96.3%
Total	3	(9.4%)	29	(90.6%)	32	(100%)		
	Sensitivity	66.7%	Specificity	89.7%			OR	17.33
CT, segmental resection								
Positive	18	(35.3%)	8	(15.7%)	26	(51.0%)	PPV	69.2%
Negative	8	(15.7%)	17	(33.3%)	25	(49.0%)	NPV	68.0%
Total	26	(51.0%)	25	(49.0%)	51	(100%)		
	Sensitivity	69.2%	Specificity	68.0%			OR	4.78

CT, computed tomography; PPV, positive predictive value; NPV, negative predictive value; OR, diagnostic odds ratio.

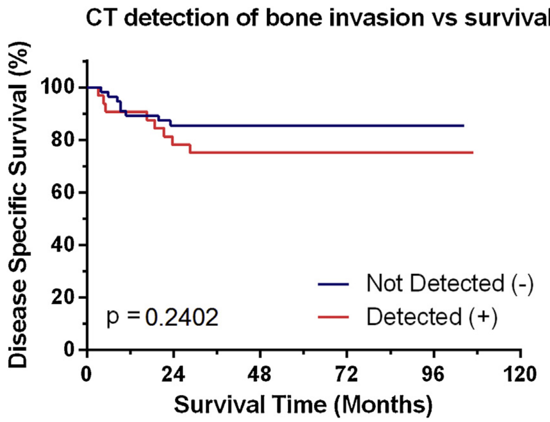

Fig. 2. Kaplan–Meier survival curve comparing patients with and without bone invasion as detected by computed tomography.

Can imaging accurately identify or exclude tumour invasion into bone?

This study represents one of the largest series to date assessing both CT ($n = 83$) and MRI ($n = 72$) and one of the few studies in which direct comparisons between the modalities could be made. In addition, this study also assessed the combined accuracy of CT and MRI ($n = 58$), as well as survival outcomes for bone invasion detected by each modality.

The imaging protocol at the study institution uses panoramic radiography to assess the dentition, CT to assess for bone invasion, and MRI for marrow contrast and enhancement. Overall, it was found that MRI was superior to CT imaging, with greater sensitivity and comparable specificity; however, neither modality was able to accurately exclude bone invasion in approximately 20% of patients. The combination of CT and MRI improved the sensitivity compared to CT imaging alone, but showed reduced sensitivity compared to MRI alone. Surprisingly the combined specificity was reduced compared to that reported for each individual modality, suggesting that additional imaging does not improve the ability to accurately identify or exclude mandibular bone invasion by oral SCC.

Approximately 85% of marginal resections in this series were performed for oncological margins without clinical or radiological evidence of bone invasion, which provided an opportunity to assess the performance of imaging in early bone invasion. Both CT and MRI were extremely accurate at excluding early bone invasion, with specificities of 96.3% and 94.7%, respectively. Neither modality, however, was able to accurately identify bone invasion in these early cases, with sensitivities of 66.7% and 50.0%, although the overall numbers were low. In cases where segmental resection was performed either due to clinically advanced disease or lack of residual mandibular height, MRI was again superior to CT imaging, with greater sensitivity and comparable specificity; however, bone invasion was again only accurately excluded in approximately 70% of patients.

Does marginal mandibular resection result in a worse prognosis if bone invasion is present?

Consistent with previous studies, the present study showed that invasion of the underlying mandibular bone was more likely to occur in larger and thicker tumours[8,9]. Although the minimum radial tumour size causing bone invasion in this study was 10 mm, bone invasion still occurred in tumours with as little as 2 mm of thickness. There was significant overlap in size and thickness of tumours that invaded bone compared to those that did not, highlighting the fact that bone invasion is related more to tumour biology and proximity than size or depth[8].

Given the overall average larger tumour size and more advanced staging of those tumours with bone invasion, it is not surprising that there was a significant survival difference seen in these patients. Similarly, larger tumours were more likely to receive segmental rather than marginal resection, accounting for the overall reduced survival seen in that population.

Despite this, there was a large drop in survival (33.3% vs. 70.5%) in those patients in whom marginal resection was performed compared to segmental resection when histological evidence of bone invasion was identified. Although these results did not reach statistical significance due to low numbers, they seem to suggest that performing a marginal resection in the setting of bone invasion may confer a

Table 3. Summary of the results of MRI detection of bone invasion compared to histopathology.

Bone invasion detected by:	Bone invasion detected by histopathology						Statistics	
	Pathologically positive		Pathologically negative		Total			
MRI								
Positive	27	(37.5%)	8	(11.1%)	35	(48.6%)	PPV	77.1%
Negative	4	(5.6%)	33	(45.8%)	37	(51.4%)	NPV	89.2%
Total	31	(43.1%)	41	(56.9%)	72	(100%)		
	Sensitivity	87.1%	Specificity	80.5%			OR	27.84
MRI, marginal resection								
Positive	1	(4.5%)	2	(9.1%)	3	(13.6%)	PPV	33.3%
Negative	1	(4.5%)	18	(81.9%)	19	(86.4%)	NPV	94.7%
Total	2	(9.1%)	20	(90.9%)	22	(100%)		
	Sensitivity	50.0%	Specificity	90.0%			OR	9.00
MRI, segmental resection								
Positive	26	(52.0%)	6	(12.%)	32	(64.0%)	PPV	81.3%
Negative	3	(6.0%)	15	(30.0%)	18	(36.0%)	NPV	83.3%
Total	29	(58.0%)	21	(42.2%)	51	(100%)		
	Sensitivity	89.7%	Specificity	71.4%			OR	21.67

MRI, magnetic resonance imaging; PPV, positive predictive value; NPV, negative predictive value; OR, diagnostic odds ratio.

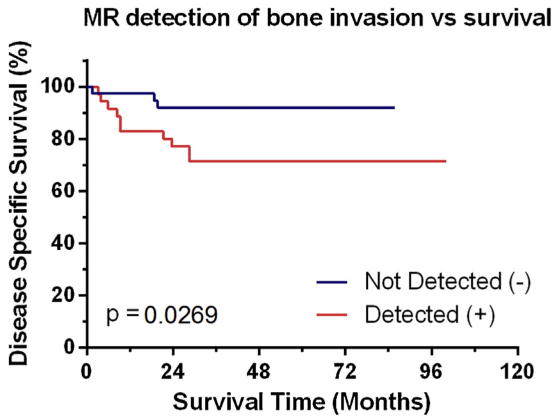

Fig. 3. Kaplan–Meier survival curve comparing patients with and without bone invasion as detected by magnetic resonance imaging.

survival disadvantage to the patient and this may justify more aggressive resection.

Does imaging detection of bone invasion suggest a poorer prognosis and therefore the need for more aggressive resection?

It is interesting to note that MRI detection of bone invasion showed greater disease-specific mortality in the present study, while CT detection of bone invasion did not, despite no significant differences in tumour size or depth between the two modalities. It is most likely that this observed difference in survival is related to the poorer sensitivity of CT seen in this study. Potentially the use of finer 0.65-mm slices available on more modern scanners may have altered these results and should be considered for use in future prospective studies.

Again, despite not reaching statistical significance, the survival of patients who underwent marginal as opposed to segmental resection was reduced (60.0% vs. 84.6%) when CT evidence of bone invasion was detected preoperatively. No similar difference was seen for MRI, although the numbers of cases involved was extremely low with a total of three patients. If this trend were to be seen in larger numbers, it would suggest more aggressive bony resection when bone invasion is detected by imaging studies.

There are a number of important limitations and considerations with regard to this study. First, although this was a retrospective study, it is unlikely that a true randomized controlled study to evaluate marginal vs. segmental reconstruction could ever ethically be performed. Second, while histology is the accepted gold standard, it is prone to sampling error, especially in microscopic bone invasion. It may well be possible that some of the false-positives observed for imaging could actually be false-negatives from histology. This might be improved by prospective serial sectioning and examination of a greater number of slices beneath the tumour, which was not possible in the present retrospective study.

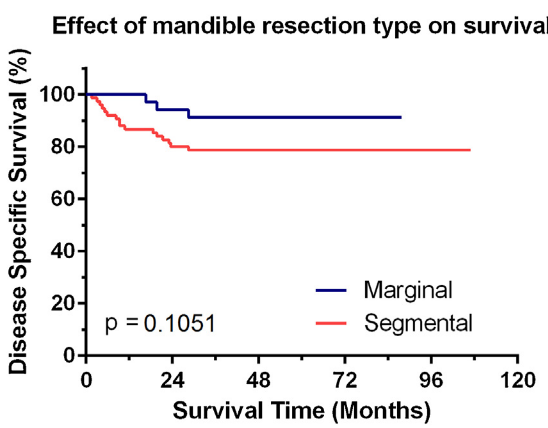

Fig. 4. Kaplan–Meier survival curve comparing patients who underwent segmental mandibular resection vs. marginal mandibular resection.

In addition, although it was attempted to classify bone invasion into erosive and infiltrative patterns, as defined by Slootweg and Müller[7], in order to identify differences in survival and imaging detection rates, it was not always possible to confidently exclude infiltration from the available slides, especially for patients with edentulous alveolar ridges. Likewise measurements of total, cortical, and depth of marrow invasion were impossible in severely invaded mandibles when there were no adjacent sections to determine the original bone height.

Finally, although the results appear to suggest that patients treated with marginal resection in whom bone invasion is identified by histology and imaging have a worse prognosis than those treated with segmental resection, the current study is likely underpowered to answer that question.

In conclusion, the results of this study showed that MRI is more sensitive than CT imaging for the detection of bone invasion by oral SCC, while both modalities are similar in their specificity, suggesting that the findings of MRI may be taken with higher levels of assurance than previously thought.

In early disease where bone invasion is not suspected on clinical grounds, both modalities are highly accurate at ruling out invasion, suggesting marginal mandibulectomy is more appropriate for these patients. Despite this, in clinically advanced disease, neither imaging modality was able to confidently exclude bone invasion, with approximately 20% of histologically detected invasion going undetected.

As such, while imaging studies remain an important part of the oncological workup for disease staging and to guide resection margins, negative imaging studies should not preclude an oncologically safe bony resection if indicated on clinical grounds. More data are required to determine whether more aggressive resection is warranted in cases of early disease when imaging suggests the presence of bone invasion.

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Ethical approval

Ethics approval was obtained from the Royal Melbourne Hospital Human Research & Ethics Committee (Reference: QA2015101).

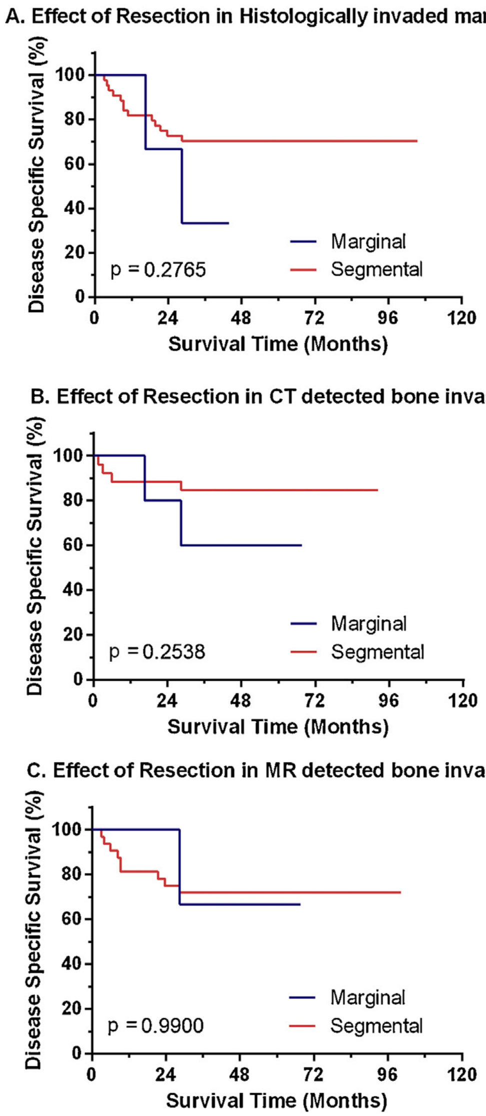

Fig. 5. Kaplan–Meier survival curves comparing patients who underwent segmental mandibular resection vs. marginal mandibular resection with bone invasion detected by (A) histopathology, (B) computed tomography, and (C) magnetic resonance imaging.

Competing interests

None.

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Address:
Adrian DeAngelis
Oral and Maxillofacial Surgery
Royal Melbourne Hospital
Melbourne
Victoria
Australia
E-mail: ADeAngelis1@gmail.com