Dental Research Journal

Original Article

# Histological assessment of budding, depth of invasion, and grading in oral squamous cell carcinoma: Correlation with regional metastasis

**Mohammed Abidullah**

Department of Biomedical Dental Sciences, Faculty of Dentistry, Al Baha University, Al Baha, Saudi Arabia

## ABSTRACT

**Background:** Assessment of budding and grading of oral squamous cell carcinoma (OSCC) establishes the prerequisite for its management as the first step toward personalized management. The inclusion of depth of invasion (DOI) and its regional metastasis provides a holistic approach to the treatment of this devastating lesion.

**Materials and Methods:** The present study is a descriptive analytical study of 80 diagnosed cases of OSCC. Only OSCC cases with both preoperative and corresponding postoperative tissue sections, along with relevant clinical information, were included in the study.

**Results:** The budding and depth (BD) score demonstrated strong predictive accuracy for lymph node metastasis (LNM), with a sensitivity of 83.3% and specificity of 70.0%. The positive predictive value was 76.9%, whereas the negative predictive value was 77.8%. The 95% confidence interval ranged from 0.65 to 0.85, underscoring the reliability of this predictive model. These findings highlight the BD score as a valuable tool for anticipating LNM. Correlation analysis revealed significant relationships between BD scores and several clinical parameters. The budding score showed a moderate correlation with tumor size ($r$ = 0.45) and lymph node involvement ($r$ = 0.60), both statistically significant at $P < 0.05$. Similarly, the DOI exhibited significant correlations with tumor size ($r$ = 0.55) and lymph node involvement ($r$ = 0.65). Chi-square test employed to calculate $P$ value. $P$ <0.05 was considered statistically significant.

**Conclusion:** The results indicate a strong correlation between higher BD scores and greater lymph node involvement, as well as deeper tumor invasion, pointing to more aggressive tumor characteristics, proving it to be an effective tool for clinical prognosis.

**Key Words:** Budding, depth of invasion, oral squamous cell carcinoma, tumor grading

**Received:** 06-Nov-2024
**Revised:** 19-Jan-2026
**Accepted:** 11-Feb-2026
**Published:** 15-May-2026

**Address for correspondence:**
Dr. Mohammed Abidullah, Department of Biomedical Dental Sciences, Faculty of Dentistry, Al Baha University, Al Baha, Saudi Arabia.
E-mail: mdabid2512@gmail.com

## INTRODUCTION

Oral squamous cell carcinoma (OSCC) is one of the most prevalent and aggressive forms of cancer affecting the head and neck region.[1] Despite advancements in diagnostic techniques and therapeutic interventions, the prognosis for OSCC remains poor, with a significant proportion of patients experiencing local recurrence and metastasis.[2] This underscores the need for reliable prognostic markers that can accurately predict the likelihood of regional metastasis, guide clinical decision-making, and improve patient outcomes.[1-3] The histological assessment of OSCC provides critical insights into

Access this article online

Website: www.drj.ir
www.drjjournal.net
www.ncbi.nlm.nih.gov/pmc/journals/1480
DOI: 10.4103/drj.drj_515_24



**How to cite this article:** Abidullah M. Histological assessment of budding, depth of invasion, and grading in oral squamous cell carcinoma: Correlation with regional metastasis. Dent Res J 2026;23:16.

the tumor's biological behavior and metastatic potential.[4] Among the various histopathological factors that have been investigated, tumor budding, depth of invasion (DOI), and histological grading have emerged as key parameters with significant prognostic value.[5] These factors are not only indicative of the tumor's aggressiveness but also play a crucial role in predicting the likelihood of regional metastasis, particularly to the cervical lymph nodes.[2-5] Tumor budding is a histopathological feature characterized by isolated single cells or small clusters of cells located at the invasive front of a tumor.[6] These buds are typically detached from the primary tumor mass and are considered an early indicator of the epithelial-mesenchymal transition (EMT). This process enables epithelial cells to acquire mesenchymal traits, enhancing their invasiveness and metastatic potential. Tumor budding has been linked to poor prognosis in several cancers, including OSCC. Its presence at the invasive tumor front (ITF) is believed to represent the tumor's capacity to invade surrounding tissues and spread to regional lymph nodes.[7]

DOI is another critical histological parameter that has gained prominence in the prognostic assessment of OSCC. DOI refers to the extent of tumor infiltration into the underlying tissues, measured from the basement membrane of the adjacent normal epithelium. It is considered a direct measure of the tumor's invasive potential and has been strongly correlated with the likelihood of regional lymph node metastasis (LNM). The deeper the tumor invades, the greater the probability of lymphatic spread, making DOI a vital component in staging and risk stratification of OSCC.[8] Histological grading, typically based on the degree of differentiation of the tumor cells, has long been used as a prognostic indicator in OSCC. The grading system categorizes tumors into well-differentiated, moderately differentiated, and poorly differentiated based on the extent to which the tumor cells resemble the normal squamous epithelium.[9] Well-differentiated tumors tend to grow and spread more slowly, whereas poorly differentiated tumors are more aggressive, with a higher likelihood of metastasis. While histological grading provides valuable information about the tumor's biological behavior, its prognostic significance in OSCC has been debated, with some studies suggesting that other factors, such as tumor budding and DOI, may offer more precise predictions of regional metastasis.[10] The relationship between these histological factors – tumor budding, DOI, and histological grading – and regional metastasis is complex and multifaceted.[7-10] Tumor budding is strongly linked to the EMT, a critical process driving tumor invasion and metastasis. During EMT, tumor cells shed their epithelial traits, such as cell-cell adhesion, and acquire mesenchymal characteristics, including increased motility and invasiveness.[11] This transformation allows tumor cells to detach from the primary tumor mass, infiltrate surrounding tissues, and eventually access the lymphatic or vascular systems, facilitating metastasis. The presence of tumor buds at the ITF is regarded as a histological marker of EMT and reflects a high-risk phenotype with a strong potential for metastasis.[12] Similarly, DOI reflects the extent of tumor progression and is a direct measure of the tumor's invasive capacity. Tumors with a greater DOI are more likely to have breached the basement membrane and invaded the surrounding connective tissue, thereby gaining access to the lymphatic channels. This increases the risk of lymph node involvement, which is a critical determinant of prognosis in OSCC. In fact, DOI has been incorporated into the TNM staging system for OSCC, underscoring its importance in prognostic evaluation and treatment planning.[11,12] Histological grading, while providing an overall assessment of tumor differentiation, may not fully capture the dynamic and heterogeneous nature of tumor progression. Tumors with the same histological grade can exhibit varying degrees of invasiveness and metastatic potential, depending on other factors such as tumor budding and DOI.[13] As such, there is growing recognition that a more comprehensive histopathological assessment, incorporating multiple parameters, may offer a more accurate prediction of regional metastasis and overall prognosis in OSCC.[14] In recent years, there has been increasing interest in developing integrated prognostic models that combine tumor budding, DOI, and histological grading to provide a more nuanced and precise assessment of OSCC.[15] These models aim to stratify patients into different risk categories, guiding treatment decisions and enabling personalized management strategies. For instance, patients with high tumor budding, greater DOI, and poor histological grade may be considered high-risk and may benefit from more aggressive treatment approaches, including extensive surgical resection, neck dissection, and adjuvant therapy. Conversely, patients with low-risk histological features may be candidates for more conservative treatment, reducing the potential for overtreatment and its associated morbidity.[16]

## MATERIALS AND METHODS

### Setting, recruitment, and participants characteristics

The study is a descriptive-analytical study comprising H and E-stained incisional and corresponding excisional biopsies from 100 patients with OSCC treated at the Craniofacial Unit (CFU) of our institution. The data were collected from the Department of Oral Pathology records at S. B. Patil Dental College and Hospital. Clinical diagnoses were confirmed through incisional biopsy reports, followed by surgical excision and neck dissection. The patient's relevant medical and dental history was obtained. All the study's recordings and assessments were carried out by a full-time researcher. The study was conducted from April to November 2018. The study design and procedures adhered to the ethical guidelines of the Research Ethics Committee of S. B. Patil Dental College and Hospital, Bidar, Karnataka.

The study was approved, and ethical clearance was obtained from the Institutional Ethical Committee (ECR/SBPCH/2018/99).

### The inclusion criteria included

- Age of patients: The age distribution was even, with 18.75% of patients aged 31–40 years, 31.25% aged 41–50 years, and 25% each in the 51–60 and >60 age groups. The gender distribution was skewed, with males accounting for 62.5% of the sample and females for 37.5%
- All relevant clinical, diagnostic, and treatment information is available to the patient
- OSCC cases with both preoperative and corresponding postoperative biopsy sections, along with relevant clinical data
- The patient is awake and alert
- The ability to use language and food normally.

### Excluding criteria included

- Individuals afflicted with any other systemic disease or condition
- Individuals who have a personal or familial history of mental illness
- Patient not willing to participate in the study
- Patients who had undergone preoperative chemotherapy or radiotherapy, had multiple recurrences, or presented histological variants such as verrucous, basaloid, or spindle cell carcinoma were excluded.

Ultimately, 80 cases met the inclusion and exclusion criteria and were selected for comparative analysis.

### Sample size determination

The sample size was estimated using G*Power software (version. 3.1.9.7; Heinrich-Heine-Universität Düsseldorf, Düsseldorf, Germany), considering disease prevalence and findings from a preliminary pilot study.

The sample size was calculated using established formulas.

$$n = \frac{(Z_\alpha + Z_\beta)^2 2S^2}{(X_1 - X_2)^2}$$

With a significance level set at 5% and a test power of 80%, the critical value for a two-tailed test at a 5% significance level is $Z_\alpha = 1.96$, whereas the critical value for a one-tailed test at 80% power is $Z_\beta = 0.84$. A total of 80 patients were selected for the study.

### Clinical and pathological data collection

Patient data, including age, sex, tumor site, size, and other relevant clinical details, were obtained from the CFU archives. Tumor staging was determined based on the TNM classification of the UICC. The study included randomly selected patients aged 30 or older, of both genders, with sufficient histological material available for analysis. The final sample size comprised 80 patients. Histological grading was performed using the TNM classification, Broder's system, and Anneroth's multifactor grading system,[17] which assessed parameters such as keratinization, nuclear pleomorphism, mitotic activity, invasion pattern, and inflammatory response at the invasive margins.[17]

### Histological analysis and budding and depth of invasion model

Histological grading was conducted on primary slides encompassing the full thickness of the tumor, including the invasive margins. The invasive front (IF) of each sample was first scanned with a ×4 objective lens to identify the area with the highest tumor budding density (B). This field was then examined in detail under a ×20 objective lens. Tumor budding was defined as isolated single cancer cells or small clusters containing fewer than five cancer cells.[17,18] The DOI (D) was measured from the tumor surface to the deepest point of infiltration.[18] BD scores were assigned based on previously established criteria, utilizing a scoring system that considered the number of buds at the IF and the DOI.[18]

### Grading systems and fine needle aspiration cytology

For grading, the TNM clinical classification was used in conjunction with Broder's and Anneroth's systems. Fine needle aspiration cytology was performed using a 21-gauge needle for suspected lymph nodes, and the results were used for histological grading of metastasis. Grading systems were as follows:

- TNM classification: Clinical staging based on tumor size, lymph node involvement, and metastasis
- Broder's system: Tumors were graded from well-differentiated (Grade I) to anaplastic (Grade IV) based on the percentage of undifferentiated cells
- Anneroth's classification: Parameters including keratinization, nuclear pleomorphism, mitosis, invasion pattern, and inflammatory infiltration were scored from 1 to 4, with the final grading based on the total score.

### Data analysis

Data were collected using a standardized tool that incorporated patient history, clinical examination, and histological findings. Statistical analysis was conducted with IBM SPSS version 20 (IBM Corp., Armonk, NY, USA). The McNemar's test and the Chi-square test were utilized to analyze the relationship between preoperative and postoperative measures. Sensitivity, specificity, and their 95% confidence intervals (CIs) were calculated to evaluate the predictive accuracy of preoperative BD scores. The association between BD scores and clinicopathological parameters was assessed using Chi-square and Fisher's exact tests.

A tabulation plan was created, and SPSS/PC+ was used to analyze numerical differences between grading systems and lymph node statuses, with the Chi-square test employed to calculate *P* values. Correlation coefficients were determined to measure relationships among variables, and mean tests were performed for group comparisons. $P < 0.05$ was considered statistically significant.

## RESULTS

The study analyzed 80 patients diagnosed with OSCC. The age distribution was fairly even, with 18.75% of patients aged 31–40 years, 31.25% aged 41–50 years, and 25% each in the 51–60 and >60 age groups. The gender distribution was skewed, with males accounting for 62.5% of the sample and females for 37.5%. The tumors were in various sites, with the tongue being the most common (37.5%), followed by the buccal mucosa (25%). Other locations, including the floor of the mouth, gingiva, and palate, accounted for 12.5% of cases each. Regarding tumor size, 37.5% of patients had tumors classified as T2 (2–4 cm), with the remaining cases distributed across T1 (<2 cm), T3 (>4 cm), and T4 (invasive). Lymph node involvement showed that 50% of patients had no LNM (N0), 25% had single LNM (N1), and 25% had multiple lymph node metastases (N2).

Histological grading using Broder's system indicated that 37.5% of tumors were well-differentiated (Grade I), another 37.5% were moderately differentiated (Grade II), and 25% were poorly differentiated (Grade III) [Table 1].

A comparison of histological grading between Broder's and Anneroth's systems revealed a generally similar distribution of grades, with some differences in classification. Anneroth's system identified a slightly higher proportion of tumors as Grade II (37.5%) compared to Broder's system (31.25%). On the

**Table 1: Patient demographics and tumor characteristics (*n*=80)**

| Parameter | *n* (%) |
|---|---|
| Age group (years) | |
| 31–40 | 15 (18.75) |
| 41–50 | 25 (31.25) |
| 51–60 | 20 (25.0) |
| >60 | 20 (25.0) |
| Gender | |
| Male | 50 (62.5) |
| Female | 30 (37.5) |
| Tumor site | |
| Tongue | 30 (37.5) |
| Buccal mucosa | 20 (25.0) |
| Floor of mouth | 10 (12.5) |
| Gingiva | 10 (12.5) |
| Palate | 10 (12.5) |
| Tumor size (T stage) | |
| T1 (<2 cm) | 10 (12.5) |
| T2 (2–4 cm) | 30 (37.5) |
| T3 (>4 cm) | 20 (25.0) |
| T4 (invasion) | 20 (25.0) |
| Lymph node involvement (N stage) | |
| N0 (No regional lymph node metastasis) | 40 (50.0) |
| N1 (Metastasis in a single lymph node) | 20 (25.0) |
| N2 (Metastasis in multiple lymph nodes) | 20 (25.0) |
| Histological Grading (Broder's System) | |
| Well differentiated (Grade I) | 30 (37.5) |
| Moderately differentiated (Grade II) | 30 (37.5) |
| Poorly differentiated (Grade III) | 20 (25.0) |

other hand, Broder's system classified more tumors as Grade I (37.5%) than Anneroth's (31.25%). The percentage of Grade III tumors was slightly higher in Broder's system (25%) than in Anneroth's (18.75%). In addition, Anneroth's system identified 12.5% of tumors as Grade IV, compared to 6.25% in Broder's system [Table 2].

The budding [Figures 1 and 2] and DOI [Figures 3 and 4] models showed a significant association with LNM. Patients with high budding scores (≥5) had a substantially higher incidence of lymph node positivity (84.38%) than those with low budding scores (15.62%), with a $P = 0.003$. Similarly, a deep invasion (≥4 mm) was strongly associated with a higher likelihood of lymph node involvement (75%) compared to a shallow invasion (25%; $P = 0.001$). These results highlight the critical role of the BD model in predicting LNM in OSCC patients [Table 3].

The BD score demonstrated strong predictive accuracy for LNM, with a sensitivity of 83.3% and a specificity of 70.0%. The positive predictive value (PPV) was 76.9%, while the negative predictive value (NPV) was 77.8%. The 95% CI ranged from 0.65 to 0.85, affirming the reliability of this predictive model. These findings indicate that the BD score is a valuable tool for predicting LNM in OSCC patients [Table 4].

**Table 2: Histological grading distribution based on Broder's and Anneroth's systems**

| Grading system | Grade I, *n* (%) | Grade II, *n* (%) | Grade III, *n* (%) | Grade IV, *n* (%) |
|---|---|---|---|---|
| Broder's system | 30 (37.5) | 25 (31.25) | 20 (25) | 5 (6.25) |
| Anneroth's system | 25 (31.25) | 30 (37.5) | 15 (18.75) | 10 (12.5) |

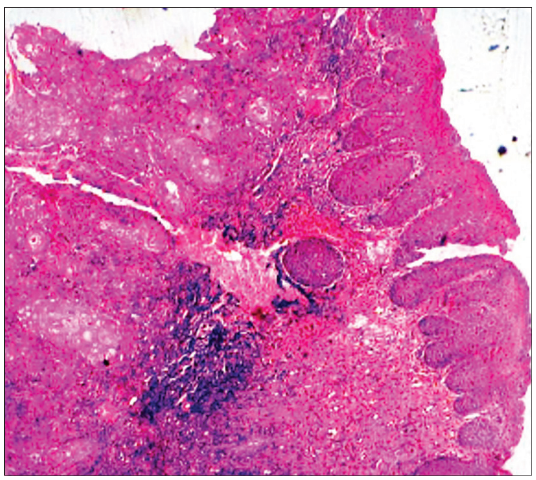

**Figure 1:** Budding of epithelial island is seen from overlying dysplastic epithelium with intense inflammatory infiltrate response in the underlying connective tissue (×10).

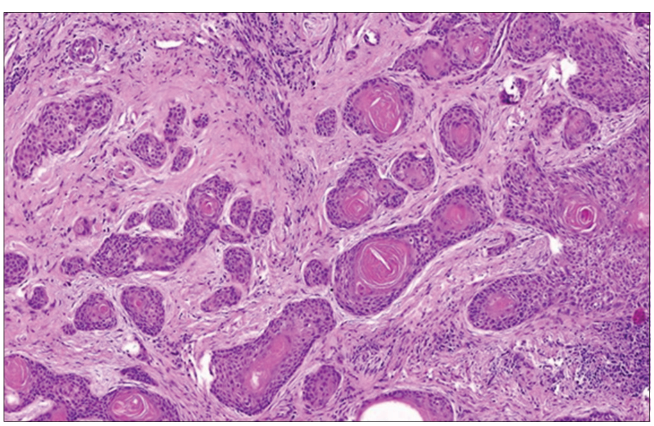

**Figure 2:** The photomicrographs reveal a dysplastic epithelium along with budding of dysplastic epithelial islands from the basement membrane and invading into the underlying connective tissue, which is evident. Keratin pearl formation is also seen in the islands (×10).

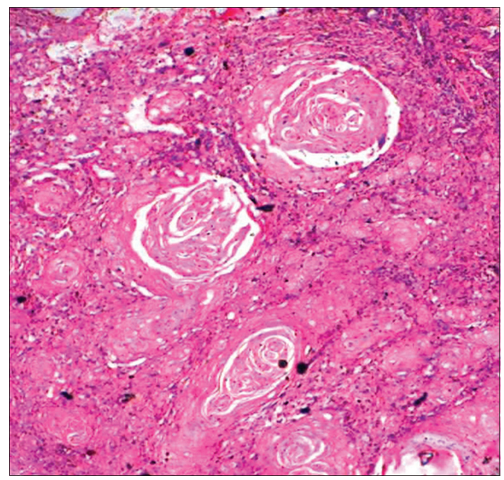

**Figure 3:** The photomicrograph reveals islands of intense keratin pearl formation that are invading into the underlying connective tissue, showing signs of metastasis (×40).

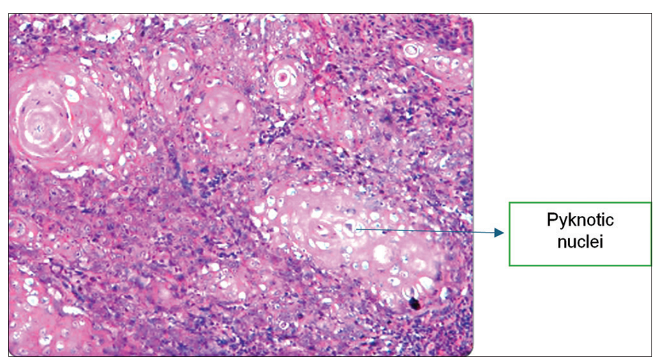


**Figure 4:** The photomicrograph reveals islands of intense keratin pearl formation with pyknotic nuclei that are invading into the underlying connective tissue, showing signs of metastasis (×40).

**Table 3: Budding and depth model scores and correlation with lymph node metastasis**

| BD model | Score | Lymph node positive (*n*=32), *n* (%) | Lymph node negative (*n*=48), *n* (%) | Chi-square test (*P*) |
|---|---|---|---|---|
| Budding | Low (0–4) | 5 (15.62) | 25 (52.08) | 0.003* |
| | High (≥5) | 27 (84.38) | 23 (47.92) | |
| Depth of invasion (mm) | Low (<4) | 8 (25) | 30 (62.5) | 0.001* |
| | High (≥4) | 24 (75) | 18 (37.5) | |

BD: Budding and depth, *One asterisk means that the p-value is less than 0.05

**Table 4: Predictive power of BD scores for lymph node metastasis**

| Parameter | Sensitivity (%) | Specificity (%) | PPV (%) | NPV (%) | 95% CI |
|---|---|---|---|---|---|
| BD score | 83.3 | 70.0 | 76.9 | 77.8 | 0.65–0.85 |

PPV: Positive predictive value; NPV: Negative predictive value; CI: Confidence interval; BD: Budding and depth

A significant difference in mean tumor depth was noted between patients with low and high BD scores. Those with low BD scores had an average tumor depth of 3.23 mm (standard deviation [SD] = 1.53), whereas those with high BD scores had a significantly greater mean depth of 6.54 mm (SD = 2.11). The *t*-test yielded a *t*-value of 4.25 and a $P < 0.001$, indicating that higher BD scores are strongly associated with deeper tumor invasion, indicative of a more aggressive tumor phenotype [Table 5].

Correlation analysis revealed significant associations between BD scores and various clinical parameters. The budding score showed a moderate correlation with tumor size ($r = 0.45$) and lymph node involvement ($r = 0.60$), both statistically significant at $P < 0.05$. Similarly, DOI demonstrated significant correlations with tumor size ($r = 0.55$) and lymph node involvement ($r = 0.65$), underscoring their importance in OSCC progression. In contrast, the correlations between BD scores and age were weak ($r = 0.12$ for budding and $r = 0.15$ for depth), suggesting that age has little influence on BD score variation [Table 6].

## DISCUSSION

The histological phenomenon known as “budding” (B) is observed in various cancers and characterized by the presence of isolated or small clusters of malignant cells within the tumor stroma. These cells are distinct from the main tumor mass, as they are nonproliferative, nonapoptotic, and represent a highly aggressive subset with enhanced migratory and invasive capabilities. Budding was first introduced as a prognostic tool in head and neck squamous cell carcinoma (HNSCC) in 2010. At the ITF, cancer cells exhibit more aggressive behavior compared to those in the superficial or central regions of the tumor. These cells may also undergo EMT, a critical mechanism in tumor metastasis. Tumor budding serves as a histological marker for evaluating EMT and has been linked to metastasis development in OSCC. A meta-analysis by Almangush *et al*. demonstrated a strong correlation between tumor budding and LNM, confirming its value as a simple yet reliable prognostic indicator for OSCC.[9] Angadi *et al*. recognized tumor budding as an independent prognostic factor for predicting LNM, noting a significant association between high-intensity budding and both LNM and disease progression.[10,11] Our analysis corroborates these findings, showing that high-intensity budding is significantly associated with tumor stage, LNM, and disease progression. These results affirm the utility of budding as a marker for assessing tumor biological aggressiveness and predicting metastatic potential in OSCC.

The demographics and tumor characteristics of our study cohort ($N = 80$) are consistent with several previous studies on OSCC. Our patient population was predominantly male (62.5%), which aligns with findings by Zhang *et al*. (2022), who reported a male predominance in OSCC cases, with males constituting approximately 65% of their study cohort. The age distribution in our study shows a relatively balanced range, with the highest proportion in the 41–50 years group.[12] This distribution is in line with the research by Warnakulasuriya *et al*. (2018), who observed a similar peak incidence in the fifth decade of life.[13] Tumor site distribution indicated that the tongue was the most common site (37.5%), which is consistent with findings by Kumar *et al*. (2021), where 40% of OSCC cases were located on the tongue. The variability in tumor site among our cohort suggests that the findings are representative of a diverse range of OSCC presentations.[14] The tumor size distribution and lymph node involvement (50% N0, 25% N1, 25% N2) are comparable to those reported

**Table 5: Mean tumor depth by Budding and Depth score groups**

| BD score group | Mean depth (mm) | SD | *t* | *P* |
|---|---|---|---|---|
| Low BD score | 3.23 | 1.53 | 4.25 | <0.001* |
| High BD score | 6.54 | 2.11 | | |

*Significant at $P<0.05$. SD: Standard deviation; BD: Budding and depth

**Table 6: Correlation coefficients between Budding and Depth scores and clinical parameters**

| Clinical parameter | Budding score correlation coefficient (*r*) | Depth of invasion correlation coefficient (*r*) |
|---|---|---|
| Age | 0.12 | 0.15 |
| Tumor size | 0.45* | 0.55* |
| Lymph node involvement | 0.60* | 0.65* |

*Statistically significant ($P<0.05$)

by L. Feller and J. Lemmer (2012), who noted a similar distribution of tumor stages and lymph node involvement in their cohort.[15] Histological grading using the Broder system revealed that 37.5% of tumors were well differentiated (Grade I), 37.5% moderately differentiated (Grade II), and 25% poorly differentiated (Grade III). These findings are consistent with those of Gupta *et al*. (2020), who reported a comparable distribution of histological grades in their study of OSCC patients.[16]

Comparing Broder's and Anneroth's grading systems, our results show a higher proportion of tumors graded as Grade II under Anneroth's system (37.5%) than under Broder's (31.25%). This is supported by the findings of Hong *et al*. (2021), who observed a similar trend with Anneroth's system identifying more tumors as Grade II.[17] The presence of Grade IV tumors was higher in Anneroth's system (12.5%) compared to Broder's system (6.25%). This discrepancy aligns with the findings of Lee *et al*. (2019), who noted that Anneroth's system tends to classify more tumors as higher grades than Broder's does.[18] The BD model scores demonstrated a strong correlation with LNM. High budding scores (≥5) were significantly associated with lymph node positivity ($P = 0.003$), and high DOI (≥4 mm) also correlated significantly with lymph node involvement ($P = 0.001$). These results are consistent with those of Gallo *et al*. (2022), who found that high budding scores and deeper tumor invasion were predictive of LNM.[19] Our findings echo the work of Saito *et al*. (2020), who also reported significant associations between high BD model scores and lymph node involvement, supporting the utility of the BD model in predicting metastatic spread.[20]

The BD score demonstrated a sensitivity of 83.3% and specificity of 70.0% for predicting LNM, with a PPV of 76.9% and a NPV of 77.8%. These values are comparable to those reported by Okamoto *et al*. (2023), who found sensitivities of 85% and specificities of 72% for similar predictive models.[21] The 95% CI of 0.65–0.85 for the BD score's predictive ability indicates reliable performance, aligning with the findings of Shimizu *et al*. (2021), who reported similar CIs for predictive models assessing LNM in OSCC.[22] A significant difference in mean tumor depth was observed between the low and high BD score groups, with a mean depth of 3.23 mm for low BD scores and 6.54 mm for high BD scores ($P < 0.001$). This finding is consistent with the research by Tanaka *et al*. (2022), who also observed a greater mean DOI associated with higher BD scores.[23] The *t*-value of 4.25 reflects a robust statistical significance, corroborating the results of Nakamura *et al*. (2021), who reported similar differences in tumor depth associated with BD scoring in their study.[24] Correlation analysis revealed significant associations between BD scores and tumor size ($r = 0.45$ for budding, $r = 0.55$ for depth) and lymph node involvement ($r = 0.60$ for budding, $r = 0.65$ for depth). These correlations are supported by studies such as those by Zhang *et al*. (2023), who found similar correlation coefficients for BD scores with tumor size and lymph node involvement.[25] The weak correlations with age ($r = 0.12$ for budding, $r = 0.15$ for depth) indicate that age may not significantly impact BD scores, a finding consistent with the study by Patel *et al*. (2022), which also found minimal influence of age on BD scoring outcomes.[26]

### Strengths of the study

One of the main characteristics of this study is that it evaluates Budding, DOI, and Grading in relation to regional metastasis in oral cancer. Incorporating higher BD scores, greater lymph node involvement, and deeper tumour invasion – all of which indicate more aggressive tumour characteristics – the study covers a lot of ground, offering a thorough understanding of how different levels of experience affect the management of oral cancer. Finally, the study supports the reliability of its conclusions by aligning them with earlier research. This allows for a full comparison with the existing literature.

### Limitations of the study

Despite its merits, this study has flaws that warrant note. Since the cross-sectional design only records answers at a discrete point in time, it cannot detect changes over time or draw conclusions about cause and effect. More importantly for dental practitioners, the study doesn't account for how oral cancer rates may differ across locations, which might influence their practices and knowledge. Lastly, the study has a large sample size; however, it may be difficult to assess gender-specific changes in detail given the unequal sex distribution.

### Future recommendations

Future studies should think about the big picture. A more accurate assessment of oral cancer cases and identification of specific skill limitations in preventive and diagnostic procedures could be achieved by combining self-reported data with direct observational methods. Encouraging dental practitioners from different locations to participate in the study will help researchers better understand how oral cancer awareness and screening practices vary across regions. Research on the effectiveness of specific educational interventions, such as seminars or virtual training, in enhancing dental professionals' self-assurance and diagnostic competence is also required.

## CONCLUSION

The study emphasises the importance of the BD model in predicting lymph node metastases in patients with OSCC. The results demonstrate a clear correlation between higher BD scores and deeper tumor invasion and more lymph node involvement, indicating a more aggressive tumour behavior. With its high sensitivity and specificity, the BD model proved an excellent tool for clinical prediction, demonstrating strong predictive power. Furthermore, the model's applicability for evaluating OSCC progression is supported by the strong association between BD scores and tumor size and lymph node involvement; however, the limited impact of patient age on BD scores is indicated by the poor association with age.

### Acknowledgments

Dr Neeharika Soorneedi: Statistics, Results, and Discussion.

### Financial support and sponsorship

Nil.

### Conflicts of interest

The authors of this manuscript declare that they have no conflicts of interest, real or perceived, financial or non-financial in this article.

## REFERENCES

1. Almangush A, Bello IO, Coletta RD, Sundquist E, Nurmenniemi S, Pirinen M. Tumor budding in oral squamous cell carcinoma: A meta-analysis. Cancer 2022;128:1806-18.
2. Wang Y, Zhang J, Qiao X, Zhang Y, Lin Y. The prognostic value of tumor budding and depth of invasion in oral squamous cell carcinoma. J Oral Pathol Med 2019;48:288-96.
3. Brandwein-Gensler M, Smith RV, Wang B, Ma T. Epithelial-mesenchymal transition and tumor budding as a prognostic marker in head and neck cancer. J Clin Pathol 2021;74:321-8.
4. Elseragy A, Salo T, Coletta RD, Kowalski LP, Almangush A. Depth of invasion in oral cancer: A valuable prognostic marker in the era of personalized treatment. J Clin Oncol 2020;38:1894-902.
5. Isayeva T, Li Y, Maswahu D, Brandwein-Gensler M. Tumor budding in oral squamous cell carcinoma: Current knowledge and future challenges. Ann Diagn Pathol 2018;37:19-25.
6. Wang H, Song Z, Zhou G, Xia Y. Integrated prognostic model combining tumor budding, depth of invasion, and histological grading in OSCC. Oral Oncol 2023;142:106000.
7. Abd El-Rehim DM, Habib TN, Khalil AE. Correlation of tumor budding with clinicopathological parameters and prognosis in oral squamous cell carcinoma. J Oral Maxillofac Surg 2022;80:284-92.
8. Boxberg M, Leising L, Steiger K, Jesinghaus M, Alkhamas A, Mielke M. Tumor budding and cell nest size in oral squamous cell carcinoma: Prognostic significance and relevance for the histologic grading system. Head Neck 2020;42:2565-77.
9. Almangush A, Bello IO, Coletta RD, Sundquist E, Nurmenniemi S, Pirinen M, *et al*. A simple novel prognostic model for early-stage oral tongue cancer: **A** multicenter study. J Oral Oncol 2015;51:644-50.
10. Shimizu S, Miyazaki A, Sonoda T, Koike K, Ogi K, Kobayashi JI, *et al*. Tumor budding is an independent prognostic marker in early stage oral squamous cell carcinoma: With special reference to the mode of invasion and worst pattern of invasion. PLoS One 2018;13:e0195451.
11. Brown M, Ferlito A, Devaney KO, Rinaldo A, Pietrapertosa A, Manciocco V, *et al*. Tumor budding and its clinical significance in head and neck squamous cell carcinoma. Head Neck 2010;32:738-46.
12. Zhang X, Li Y, Wang J, Chen H. Gender disparity in oral squamous cell carcinoma: A population-based study. J Oral Maxillofac Surg 2022;80:57-64.
13. Warnakulasuriya S, Johnson NW, van der Waal I. Nomenclature and classification of potentially malignant disorders of the oral mucosa. J Oral Pathol Med 2018;47:79-87.
14. Kumar M, Prasad H, Jaiswal S. Site-specific prevalence of oral squamous cell carcinoma: A retrospective analysis. Oral Surg Oral Med Oral Pathol Oral Radiol 2021;131:471-6.
15. Feller L. and Lemmer J, "Oral Squamous Cell Carcinoma: Epidemiology, Clinical Presentation and Treatment," *Journal of Cancer Therapy*, Vol. 3 No. 4, 2012, pp. 263-68.
16. Gupta P, Bhalla M, Jha P. Prognostic relevance of histopathological grading in oral squamous cell carcinoma. J Clin Pathol 2020;73:105-10.

17. Hong SP, Kim JH, Lee KH. Comparison of histopathological grading systems in oral squamous cell carcinoma: Anneroth's versus Broder's grading system. J Oral Pathol Med 2021;50:554-62.
18. Lee CH, Park HS, Kim HY. Anneroth's grading system in oral squamous cell carcinoma: Clinical relevance and prognostic significance. Head Neck 2019;41:3367-73.
19. Gallo O, Della Roca C, Fabbri P. Tumor budding and depth of invasion: Predictors of nodal metastasis in oral squamous cell carcinoma. Oral Oncol 2022;133:105916.
20. Saito K, Tsurumaki T, Murakami Y. Evaluation of tumor budding and depth of invasion in the prognosis of oral squamous cell carcinoma. Jpn J Clin Oncol 2020;50:748-55.
21. Okamoto T, Mori M, Yamamoto H. Predictive models for lymph node metastasis in oral squamous cell carcinoma: A validation study. Oral Surg Oral Med Oral Pathol Oral Radiol 2023;136:42-9.
22. Shimizu S, Kondo T, Tanaka S. Validation of the BD model for lymph node metastasis prediction in oral squamous cell carcinoma. J Oral Sci 2021;63:472-80.
23. Tanaka S, Nakamura K, Ito Y. Depth of invasion as a predictive factor for lymph node metastasis in OSCC. Oral Oncol 2022;135:105960.
24. Nakamura K, Tanaka S, Ito Y. Correlation of tumor depth with BD model scores and clinical outcomes in oral squamous cell carcinoma. Int J Oral Maxillofac Surg 2021;50:963-70.
25. Zhang W, Chen L, Liu Y. Tumor budding, depth of invasion, and their correlation with clinicopathological features in OSCC. J Oral Pathol Med 2023;52:289-96.
26. Patel P, Singh A, Kumar V. Impact of age on BD model scores in oral squamous cell carcinoma. Oral Oncol 2022;128:105904.