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Development and validation of nomograms for ameloblastoma recurrence prediction: a multinational, two-center study from Seoul, South Korea and Wuhan, China

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Abstract

Objective This study aimed to construct and validate region-specific nomograms to predict ameloblastoma recurrence and to investigate potential geographic differences in recurrence-related risk factors between South Korea and China.

Materials and methods A total of 816 patients with ameloblastoma treated between 2006 and 2023 were retrospectively analyzed from Yonsei University Dental Hospital ($n = 372$) and Hospital of Stomatology, Wuhan University ($n = 444$). Demographic, radiographic, and pathological variables were collected. Logistic regression analysis identified recurrence-associated predictors. Separate nomograms were developed and internally validated for each cohort. Model performance was evaluated using the area under the curve (AUC), calibration curves, and decision curve analysis.

Results The South Korean nomogram incorporated six variables, including pathological type, malignant transformation, surgical method, imaging type, tumor size, and cortical bone destruction (AUC = 0.757). The Chinese model incorporated eight predictors, including sex, root resorption, and number of involved teeth (AUC = 0.787). Calibration and decision curves indicated strong agreement between predicted and observed outcomes and favorable clinical applicability.

Conclusions Both nomograms demonstrated good predictive accuracy and highlighted regional differences in risk factors. These findings support the integration of multicenter data to enhance recurrence prediction in ameloblastoma.

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Clinical relevance The developed tools can guide individualized treatment planning and long-term follow-up, aiding clinicians in early identification of high-risk patients and optimizing surgical strategies.

Keywords Ameloblastoma, Recurrence, Multicenter study, Logistic regression, Nomogram

Introduction

Ameloblastoma is the most common odontogenic tumor, accounting for approximately 13–58% of all odontogenic tumors [1]. Although histologically benign, this tumor exhibits locally invasive characteristics that may lead to substantial facial deformity and functional deficits when inadequately managed [2]. According to the 2022 World Health Organization (WHO) classification, ameloblastomas are categorized into unicystic ameloblastoma, extraosseous ameloblastoma, conventional ameloblastoma, metastasizing ameloblastoma, and adenoid ameloblastoma, which is not categorized as a formal subtype of ameloblastoma [3]. Currently, only a limited number of adenoid ameloblastoma cases have been reported in the literature. It is recognized as a distinct epithelial odontogenic neoplasm that exhibits overlapping histopathological features with both ameloblastoma and other odontogenic lesions containing ghost cells [4]. Conventional ameloblastoma represents the most common subtype, comprising approximately 80% of cases, with a predilection for the posterior mandible [5]. Unicystic Ameloblastoma has three subtypes according to the distribution of the proliferation of the ameloblastomatous epithelium: luminal, intraluminal and mural [3]. Surgical treatment significantly impacts prognosis. For instance, recurrence rates for conventional ameloblastoma are approximately 8% following radical resection but increase to 41% with conservative management. In unicystic ameloblastoma, recurrence occurs in 3% of cases after radical treatment and 21% after conservative therapy [6]. Notably, conventional ameloblastoma and mural type unicystic ameloblastoma are recognized as more aggressive and recurrence prone [7]. Although conservative approaches such as curettage serve to preserve mandibular continuity, they are associated with recurrence rates as high as 60% for unicystic variants and up to 80% for conventional types [8].

Previous studies have investigated the risk factors associated with ameloblastoma recurrence. In a cohort of 87 patients with recurrent craniofacial ameloblastoma, Rong Yang and colleagues found that tumors larger than 6 cm and invasion into soft tissues or adjacent anatomical structures were associated with early recurrence [9]. In another single-center predictive model established by Yao-Cheng Yang et al., four independent predictors were identified: cortical bone perforation, root resorption, WHO classification, and treatment pattern [10]. However, these relatively large-sample studies were all conducted in China, and the lack of comparative data from other countries limits their generalizability in reflecting the broader characteristics of the disease.

This study aims to develop predictive models for ameloblastoma recurrence using cohorts from two East Asian dental hospitals—Hospital of Stomatology, Wuhan University (China), and Yonsei University Dental Hospital (South Korea)—providing a substantial and diverse dataset. In parallel, a dual-center comparative analysis will explore the similarities in recurrence-related factors between the two regions. The resulting models are intended to assist clinicians in tailoring surgical strategies and improving long-term patient management.

Method

Patients

This retrospective study analyzed clinical data from ameloblastoma patients treated at Yonsei University Dental Hospital and Hospital of Stomatology, Wuhan University from 2006 to 2023. Cases with incomplete medical records or treatment refusal were excluded from the analysis (Fig. 1). The dataset from Yonsei University Dental Hospital comprised 880 patient records, of which 372 met the inclusion criteria following comprehensive screening. Similarly, Hospital of Stomatology, Wuhan University obtained 1,240 patient records and retained 444 patients after screening. All included patients had pathologic diagnoses confirmed by the center's pathology departments and complete surgical records. All the candidates included granted their written consent for analyzing and revealing their treatment data. Clinical data collection and follow-up protocols were collaboratively designed by the two institutions. This retrospective study received support from both Yonsei University Dental Hospital (2-2025-0014) and Hospital of Stomatology, Wuhan University (WDKQ2024B110) and was approved by the respective Institutional Review Board.

Patient demographic characteristics and clinical data, including surgical records and diagnostic imaging results, were systematically retrieved from the electronic medical record system. Postoperative follow-up encompasses both in-hospital re-examinations and telephone consultations. The inquiries focus on the occurrence of recurrence, which necessitates imaging or a second surgical pathology assessment, as well as the time interval between recurrences. The collected data included demographic characteristics (age, gender), tumor pathological classification, malignant transformation status, and surgery interventions. Radiographic evaluation comprised imaging classification (multilocular, unilocular, or mixed

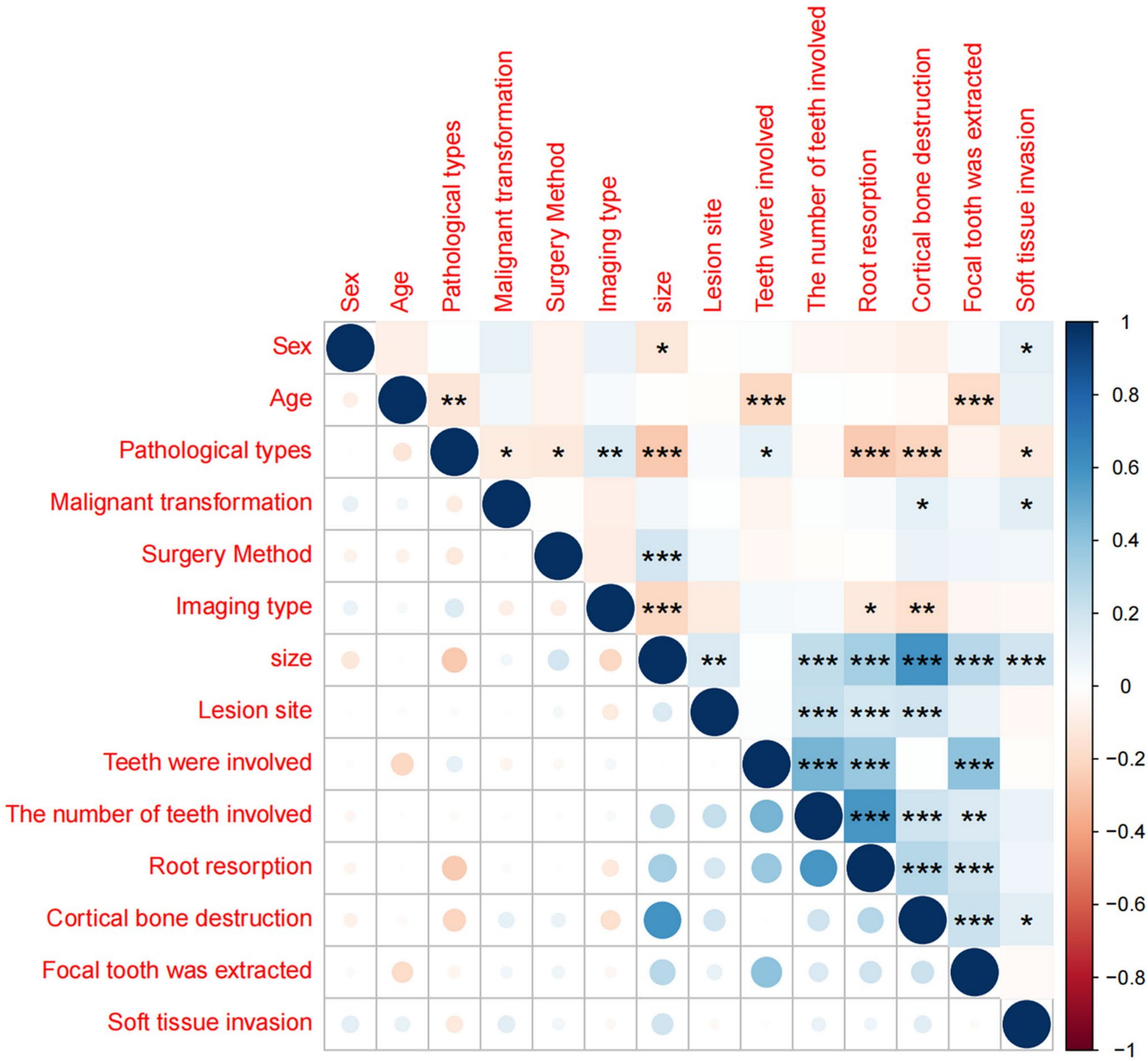

Fig. 1 Overview of inclusion and exclusion criteria for patient selection across the two centers

radiopaque–radiolucent lesion [11]), tumor dimensions, and anatomical location. Additional parameters assessed dental involvement (tooth invasion, number of affected teeth, root resorption), osseous changes (cortical bone destruction), and treatment history (extraction status of involved teeth), along with documentation of soft tissue lesions.

All patient information has been anonymized, ensuring the protection of personal privacy. The interests of patients have remained uncompromised. The data collection phase was overseen by specialized personnel to ensure optimal consistency between the two centers.

Development of the nomogram

The nomograms were developed using data from two institutions respectively. The optimal number of variables was determined by logistic regression to identify and select the influencing factors with predictive significance. Ultimately, a logistic regression nomogram was developed [12].

Evaluation of the nomogram and comparison between training and testing sets

The model performance was initially evaluated through receiver operating characteristic (ROC) analysis, with the area under the curve (AUC) serving as the primary metric. The AUC values range between 0.5, indicating no discriminative ability, and 1.0, representing perfect discrimination [13]. Subsequently, calibration curve was conducted to evaluate the agreement between predicted probabilities and observed outcomes in the logistic regression model [14]. Finally, a decision curve is developed to examine the degree of fit and similarity between the two curves created for the Seoul and Wuhan regions. This approach aims to facilitate future clinical applications of the model, enabling clinicians to determine recurrence probabilities for patients based on various influencing factors [15].

Data analysis

Statistical analysis was performed using RStudio (version 4.4.2) and relevant packages (http://www.r-project.org/). Age, ameloblastoma size, and the number of invaded teeth were identified as non-normally distributed variables, reported as mean ± standard deviation or median ± range. Categorical variables were expressed by frequencies distributions with corresponding percentages, with statistical analysis performed using chi-square test, Fisher's exact test or Mann-Whitney U test as appropriate. Logistic regression modeling was employed to identify significant predictive factors, while a correlation heatmap was constructed to visualize intervariable relationships. A decision curve was plotted, and the ROC value was extracted to create a calibration curve for model accuracy assessment. Finally, another decision curve evaluated the fit between regions in Wuhan and South Korea to determine if similar clinical decisions could be made. The baseline characteristics were compared using the "CBCgrps" package to generate a standardized table for evaluating recurrence-related factors (Zhongheng Zhang, Sir Run Run Shaw Hospital, Zhejiang University School of Medicine). The "glmnet" package facilitated elastic net regression analysis to identify significant factors affecting recurrence rates for model simplification. Additionally, the "corrplot" package enabled correlation analysis and heatmap generation to clarify relationships among various factors. Survival curves were generated with the "rms" package, while decision analysis curves were drawn using the "rmda" package.

Results

Basic characteristics

The demographic characteristics of the 372 Seoul-based patients included in this study are detailed in Table 1. The main pathological types include conventional ameloblastoma (144 cases, 39%) and unicystic ameloblastoma (209 cases, 56%). Among recurrent cases, there were 38 cases (57%) of conventional ameloblastoma and 25 cases (37%) of unicystic ameloblastoma. Regarding treatment modalities, decompression was performed in 18 patients (5%), enucleation in 87 cases (23%), and osteotomy in the

Table 1 Baseline characteristics of patients in the Yonsei university college of dentistry

Variables *n* (%)	Total (*n* = 372)	No Recurrence (*n* = 305)	Recurrence (*n* = 67)	*P* value
Gender				0.915[a]
Male	227 (61)	187 (61)	40 (60)	
Female	145 (39)	118 (39)	27 (40)	
Age (years)	37 (4, 83)	37 (4, 83)	41 (12, 78)	0.391[b]
Pathological types				0.003
Conventional/multicystic	144 (39)	106 (35)	38 (57)	
Unicystic	209 (56)	184 (60)	25 (37)	
Others	19(5)	15(5)	4(6)	
Malignant transformation				0.002
No	343 (92)	288 (94)	55 (82)	
Yes	29 (8)	17 (6)	12 (18)	
Surgery Method				0.032
Decompression	18 (5)	11 (4)	7 (10)	
Enucleation	87 (23)	69 (23)	18 (27)	
Osteotomy	226 (61)	188 (61)	38 (57)	
Combination surgeries	41 (11)	37 (12)	4 (6)	
Imaging type				0.012
Multilocular	118 (32)	88 (29)	30 (45)	
Unilocular	225 (60)	194 (64)	31 (46)	
Mixed Radiopaque–Radiolucent Lesion	29 (8)	23 (7)	6 (9)	
Size (cm)	2.5 (0.3, 13)	2.7 (0.3, 13)	2.5 (0.5, 8)	0.065
Lesion site				0.272
Anterior part of maxilla	24 (6)	22 (7)	2 (3)	
Posterior part of maxilla	15 (4)	11 (4)	4 (6)	
Ascending ramus of mandible	23 (6)	22 (7)	1 (1)	
Mandibular body	220 (59)	174 (57)	46 (70)	
Ascending ramus of mandible and body part	43 (12)	36 (12)	7 (10)	
Anterior portion of mandible	47 (13)	40 (13)	7 (10)	
Teeth were involved				0.076
No	41 (11)	30 (10)	11 (16)	
Yes	331 (89)	275 (90)	56 (84)	
The number of teeth involved,	2 (0, 10)	2 (0, 9)	2 (0, 10)	0.065
Root resorption				0.654
No	173 (47)	144 (47)	29 (43)	
Yes	199 (53)	161 (53)	38 (57)	
Cortical bone destruction				0.503
No	297 (80)	246 (81)	51 (76)	
Yes	75 (20)	59 (19)	16 (24)	
Focal tooth was extracted				0.103
No	153 (41)	119 (39)	34 (51)	
Yes	219 (59)	186 (61)	33 (49)	
Soft tissue invasion				0.833

Table 1 (continued)

Variables *n* (%)	Total (*n* = 372)	No Recurrence (*n* = 305)	Recurrence (*n* = 67)	*P* value
No	339 (91)	277 (91)	62 (93)	
Yes	33 (9)	28 (9)	5 (7)	

Age, Size, and Number of teeth involved were recorded as median and range, while categorical variables including Gender, Pathological types, Malignant transformation, Surgery method, Imaging type, Lesion site, Teeth involved, Root resorption, Cortical bone destruction, Focal tooth extraction, and Soft tissue invasion were presented as counts and percentages

majority of cases (226 cases, 61%). Combination treatments were administered to 41 patients (11%). Imaging analysis revealed multilocular ameloblastomas in 118 cases (32%), unilocular ameloblastomas in 225 cases (60%), and mixed radiopaque-radiolucent lesion in 29 cases (8%). Chi-square analysis revealed statistically significant associations between these factors and recurrence rates of ameloblastoma ($p < 0.05$).

The demographic and clinicopathological characteristics of the 444 Wuhan-based patients included in this study are detailed in Table 2. There were 284 males (64%) and 160 females (36%). The main pathological types include conventional ameloblastoma (324 cases, 73%), unicystic ameloblastoma (107 cases, 24%). Among recurrent cases, there were 123 cases (83%) of conventional ameloblastoma, and 24 cases (16%) of unicystic ameloblastoma. Imaging analysis revealed multilocular ameloblastomas in 199 cases (45%), unilocular ameloblastomas in 224 cases (50%), and mixed radiopaque-radiolucent lesion in 21 cases (5%). The median tumor size was 4 cm. Tumor invasion into adjacent dentition was documented in 87% of the cases, with a median involvement of three teeth. 84% of patients got tooth extraction. Cortical bone destruction was observed in 51% of the cohort.

Correlation analysis

The interrelationships among risk factors were assessed through correlation commonality analysis, with separate analyses conducted for the Seoul and Wuhan regions (Fig. 2 and Fig. 3). This approach quantifies the degree of association between multiple contributing factors.

Establishment of logistic regression

The nomogram developed at Yonsei University Dental Hospital (Fig. 4) identified six candidate clinical variables through logistic regression analysis: pathological type, malignant transformation, surgical method, imaging type, tumor size, and cortical bone destruction ($P < 0.2$). Among these, four variables demonstrated significant predictive value ($P < 0.05$): pathological type, malignant transformation, surgical method, and tumor size.

The nomogram developed by the Hospital of Stomatology, Wuhan University (Fig. 5) identified sex, pathological types, surgery method, root resorption, imaging type, extraction of the teeth, number of teeth involved, and cortical bone destruction as significant factors associated with ameloblastoma recurrence ($P < 0.2$). Among them, pathological types, surgery method, imaging type, and cortical bone destruction showed concordance with the regional Korean nomogram.

Assessment of the nomogram

The nomogram demonstrated good predictive accuracy in both the Korean and Wuhan datasets, with concordance indices (C-index) of 0.757 and 0.787, respectively. The calibration curves showed excellent agreement between predicted and observed outcomes, indicating robust model performance in both validation cohorts (Figs. 6 and 7).

Logistic regression analysis of the Korean cohort (Table 3) systematically evaluated the included variables and identified pathological type as a significant negative predictor of recurrence. Patients with unicystic ameloblastoma exhibited a substantially reduced risk of recurrence compared to those with conventional ameloblastoma (OR = 0.28). In contrast, malignant transformation was associated with a significantly increased risk of recurrence (OR = 3.28), indicating a strong positive association. The surgical approach also played a critical role in recurrence outcomes, with osteotomy demonstrating superior efficacy over decompression in reducing recurrence (OR = 0.58). Moreover, combined surgical procedures may offer additional benefit in lowering recurrence risk. While imaging type showed a negative association with recurrence, the result was not statistically significant. Interestingly, tumor size was inversely associated with recurrence risk, with larger tumors linked to lower recurrence probability (OR = 0.36). Finally, cortical bone destruction emerged as a strong positive predictor, markedly increasing the likelihood of recurrence (OR = 2.77).

While in Wuhan cohort (Table 4), the analysis examined the relevant variables and identified gender as a significant predictor of recurrence. Male patients had a higher recurrence risk compared to female patients (OR = 1.80). Consistent with the Korean cohort, unicystic ameloblastoma was associated with a lower risk of recurrence relative to the conventional type (OR = 0.66). The surgical approach had a significant effect, with osteotomy again showing superiority over decompression (OR = 0.51), and combined procedures potentially contributing to a further reduction in recurrence. In addition, root resorption was identified as a strong risk factor, significantly elevating recurrence probability (OR = 2.93). Although imaging type exhibited a negative association with recurrence, it did not reach statistical significance. Notably, tumor-affected tooth extraction significantly reduced recurrence risk (OR = 0.26), and the extent of

Table 2 Baseline characteristics of patients in the hospital of stomatology, Wuhan university

Variables n (%)	Total (n = 444)	No Recurrence (n = 295)	Recurrence (n = 149)	*P*value
Gender				0.04
Male	284 (64)	199 (67)	85 (57)	
Female	160 (36)	96 (33)	64 (43)	
Age（years）	36 (5, 86)	36 (5, 83)	36 (9, 86)	0.824
Pathological types				0.006
Conventional/multicystic	324 (73)	201 (68)	123 (83)	324 (73)
Unicystic	107 (24)	83 (29)	24 (16)	107 (24)
Others	13 (3)	11 (3)	2 (1)	13 (3)
Malignant transformation				0.519
No	433 (98)	289 (98)	144 (97)	
Yes	11 (2)	6 (2)	5 (3)	
Surgery Method				0.218
Decompression	30 (6)	16 (5)	14 (9)	
Enucleation	185 (42)	119 (40)	66 (44)	
Osteotomy	216 (49)	152 (52)	64 (44)	
Combination surgeries	13 (3)	8 (3)	5 (3)	
Imaging type				< 0.001
Multilocular	199 (45)	117 (40)	82 (55)	
Unilocular	224 (50)	158 (53)	66 (44)	
Mixed Radiopaque–Radiolucent Lesion	21 (5)	20 (7)	1 (1)	
Size（cm）	4 (0.8, 15)	4 (0.8, 14.9)	5 (0.8, 15)	< 0.001
Lesion site				0.766
Anterior part of maxilla	20 (5)	13 (4)	7 (5)	
Posterior part of maxilla	24 (5)	17 (6)	7 (5)	
Ascending ramus of mandible	17 (4)	13 (4)	4 (3)	
Mandibular body	154 (35)	105 (36)	49 (33)	
Ascending ramus of mandible and body part	162 (36)	101 (34)	61 (40)	
Anterior portion of mandible	67 (15)	46 (16)	21 (14)	
Teeth were involved				0.002
No	57 (13)	27 (9)	30 (20)	
Yes	387 (87)	268 (91)	119 (80)	
The number of teeth involved	3 (0, 16)	3 (0, 16)	2 (0, 11)	0.004
Root resorption				0.036
No	181 (41)	131 (44)	50 (34)	
Yes	263 (59)	164 (56)	99 (66)	
Cortical bone destruction				< 0.001
No	218 (49)	178 (60)	40 (27)	
Yes	226 (51)	117 (40)	109 (73)	
Focal tooth was extracted				< 0.001
No	71 (16)	34 (12)	37 (25)	
Yes	373 (84)	261 (88)	112 (75)	
Soft tissue invasion				0.408
No	413 (93)	277 (94)	136 (91)	
Yes	31 (7)	18 (6)	13 (9)	

Age, Size, and Number of teeth involved were recorded as median and range, while categorical variables including Gender, Pathological types, Malignant transformation, Surgery method, Imaging type, Lesion site, Teeth involved, Root resorption, Cortical bone destruction, Focal tooth extraction, and Soft tissue invasion were presented as counts and percentages.

tooth extraction was inversely correlated with recurrence (OR = 0.58). As in the Korean cohort, cortical bone destruction was strongly associated with increased recurrence risk (OR = 4.08), further confirming its prognostic relevance.

Decision curve based on nomograms

Decision curves were plotted to assess the degree of similarity between them (Fig. 8). Upon completion, the two curves were found to exhibit a high degree of fit, indicating strong similarity. The predicted benefit ranges of both

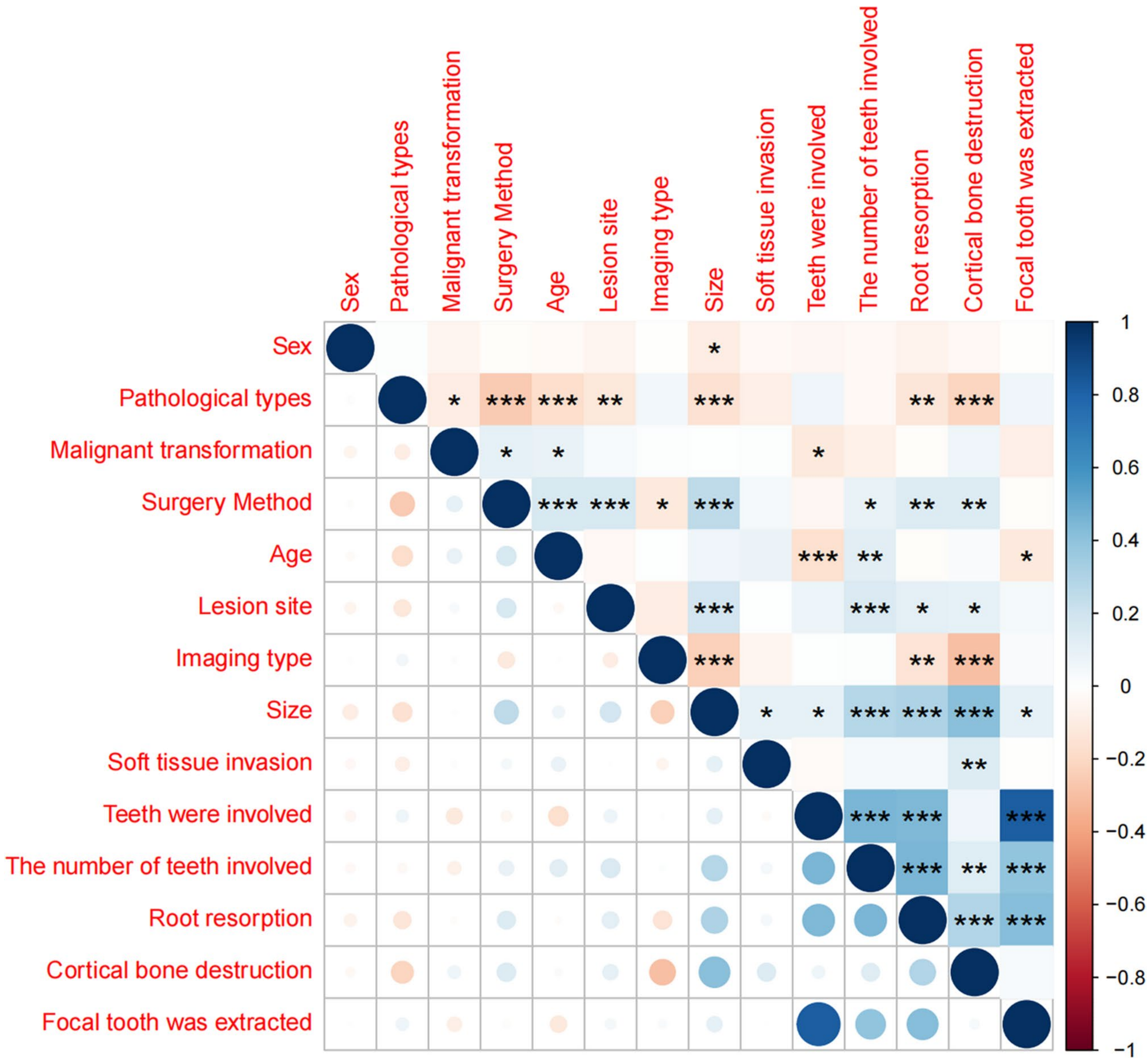

Fig. 2 Correlation analysis of clinical parameters at Yonsei university dental hospital. Color intensity and star count demonstrate positive correlation strength, with darker hues and increased star quantity representing stronger associations. Blue indicates positive correlations; red indicates negative correlation

models were from 0.2 to 0.6, and their predictive benefits were significantly enhanced compared with models incorporating all factors, suggesting that each model possesses distinct advantages.

Cross validation and development of the nomogram applicable to both regions

To further enhance the generalizability and robustness of our predictive model, we conducted a cross-validation analysis by identifying common recurrence-related predictors present in both regional datasets. A new nomogram was constructed using the Seoul cohort as the training set, while the Wuhan cohort served as the external validation set. The resulting nomogram (Supplementary File 1 & 2) achieved a concordance index (C-index) of 0.728, indicating favorable discriminative ability and stable performance across populations. These findings suggest that, despite regional and institutional differences, a unified predictive tool for ameloblastoma recurrence can be effectively developed and applied within East Asian clinical settings.

Discussion

Although ameloblastoma is a benign tumor, its high recurrence rate and locally aggressive behavior continue to pose significant therapeutic challenges. Existing

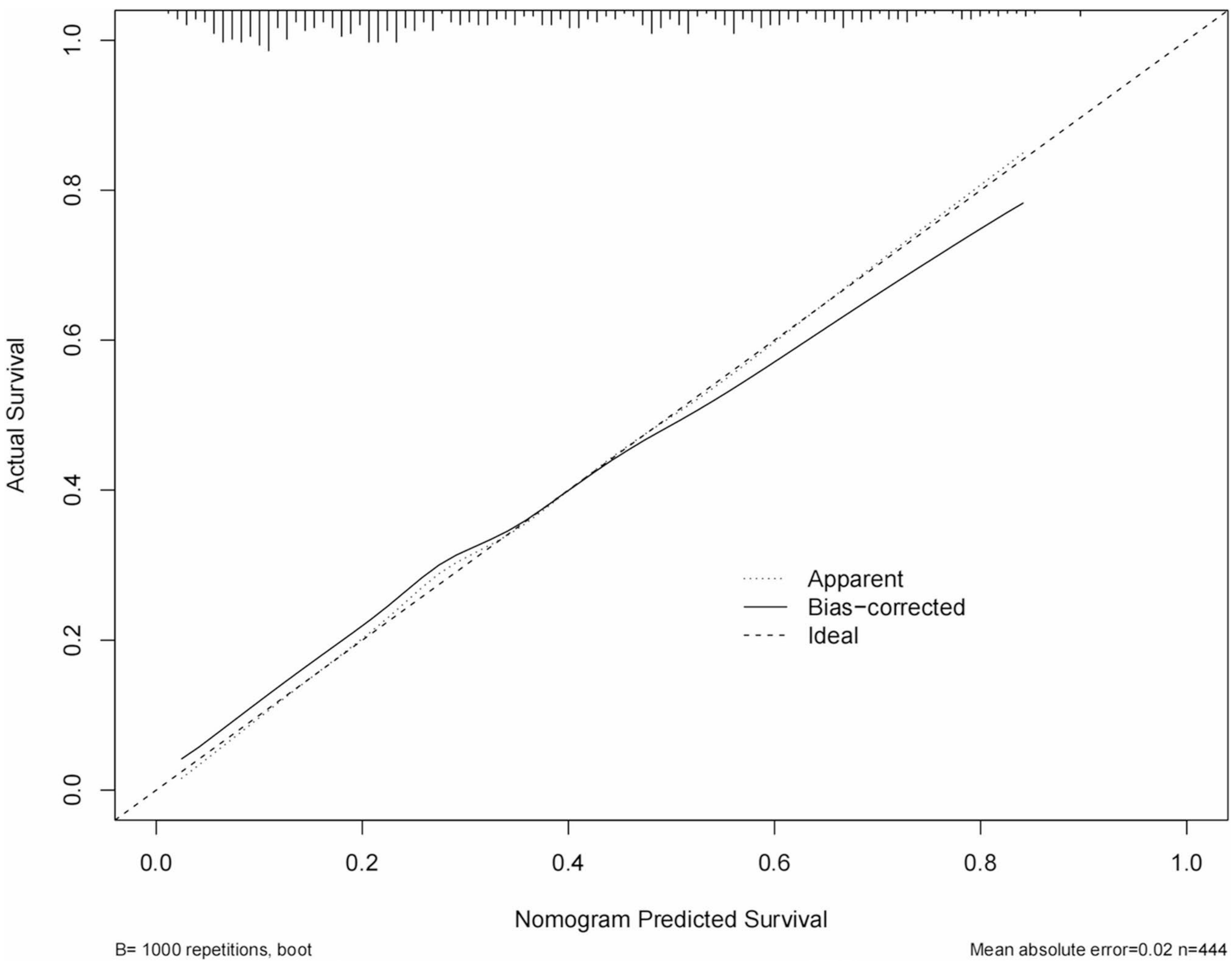

Fig. 3 Correlation analysis of clinical parameters at hospital of stomatology, Wuhan university. Color intensity and star quantity demonstrate positive correlation strength, where darker hues and higher star counts represent stronger associations. Blue indicates positive correlations; red indicates negative correlation

studies have identified multiple prognostic factors influencing ameloblastoma recurrence, including tumor site, tumor size, histopathological type and therapeutic treatment [9, 16–18]. However, these investigations neither examined potential interaction among these variables nor addressed potential geographic variations in recurrence patterns.

Our study showed that the recurrence rate of ameloblastoma was 18% in Korean area and 33.5% in the WuHan. Logistic regression calculation indicated that in Yonsei University Dental Hospital, pathological types, malignant transformation, surgery method, imaging type, size, cortical bone destruction were significant risk factors for the recurrence of ameloblastoma. In general, patients with unicystic ameloblastoma, without cortical bone destruction who undergo more aggressive treatments such as osteotomy, as well as those with larger tumors, exhibit a lower likelihood of recurrence. While in WuHan, risk factors included gender, pathological types, surgery method, root resorption, imaging type, focal tooth extraction, number involved teeth, and cortical bone destruction. To enhance generalizability, recurrence-related variables shared by both cohorts were selected. The Seoul cohort was used as the training set, while the Wuhan cohort served as the validation set. The nomogram and corresponding ROC curves are presented in Supplementary File 1 & 2. Despite inherent differences between the two cohorts, the models demonstrated strong overall consistency, supporting the feasibility of a large-scale, cross-population predictive model for ameloblastoma recurrence in East Asian populations.

Surgery is still the primary treatment for ameloblastoma. Currently, several treatment options are available for ameloblastoma, including enucleation, decompression, incision, and osteotomy (which encompasses hemi maxillectomy and maxillary bone grafting), as well as the application of Carnoy's solution [19, 20]. Existing literature demonstrates conflicting evidence regarding the

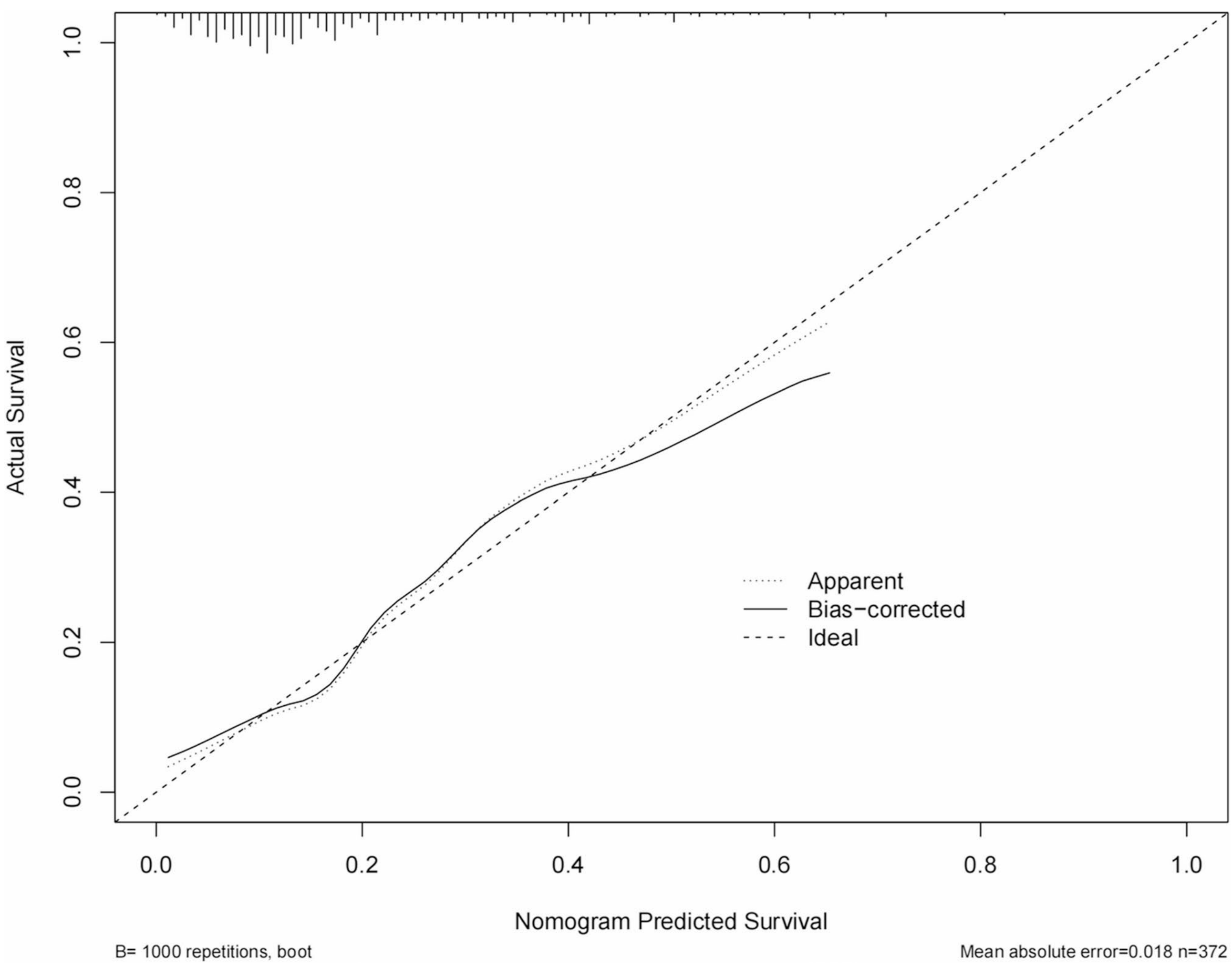

Fig. 4 Yonsei university dental hospital nomogram. LR chi^2 = 50.10, p < 0.0001, R^2 = 0.206, C (AUC) = 0.757, Dxy = 0.515, gamma = 0.516, Brier = 0.125. Pathological types (p = 0.0001), Malignant transformation (p =0.008), Surgery Method (p =0.0116), Imaging type (p =0.0514), Size (p =0.0228), Cortical bone destruction (p =0.0189). Cortical bone destruction, Malignant transformation 0=No, 1=Yes. Pathological type (1. conventional ameloblastoma 2. Unicystic ameloblastoma 3. others), Surgery method (1. Decompression 2. Enucleation 3. Osteotomy 4. Combination surgeries), Imaging type (1. multilocular ameloblastoma, 2. unilocular ameloblastoma, 3. mixed radiopaque–radiolucent lesion)

association between surgical technique and ameloblastoma recurrence rates. While numerous investigations identify operative approach as a clinically significant prognostic factor [16–18], contradictory findings have been reported in comparable studies [9]. In this study, 226 patients (61%) from the Seoul region who underwent osteotomy, and 41patients(11%)got combination surgeries, that 87 patients (23%) received only enucleation while merely 18 patients (5%) opted decompression. The observed recurrence rates were as follows: 16.8% (38/226) for those undergoing osteotomy, 20.6% (18/87) for those receiving enucleation alone, and 38.9% (7/18) for decompression. Patients who chose combination surgical procedures exhibited the lowest recurrence rate, recorded at merely 10% (4 out of 41). The Hospital of Stomatology, Wuhan University demonstrates a clinical preference for decompression procedures, which correlates with elevated recurrence rates. Interestingly, we observed a difference in the pathological composition of ameloblastoma between the two cohorts. In the Yonsei University dataset, unicystic ameloblastomas accounted for a relatively higher proportion, a pattern that has also been reflected in previous large-scale studies comparing Korean and Chinese populations [19, 21]. Such regional variation may stem from differences in institutional characteristics and treatment preferences. In Korea, patients often place greater emphasis on postoperative facial aesthetics and may prefer less invasive options when appropriate, potentially leading to fewer conventional cases undergoing surgical treatment at medical centers. Since all diagnoses were pathologically confirmed by board-certified specialists, this variation in subtype distribution does not compromise the integrity of our predictive model. The model was constructed using individual

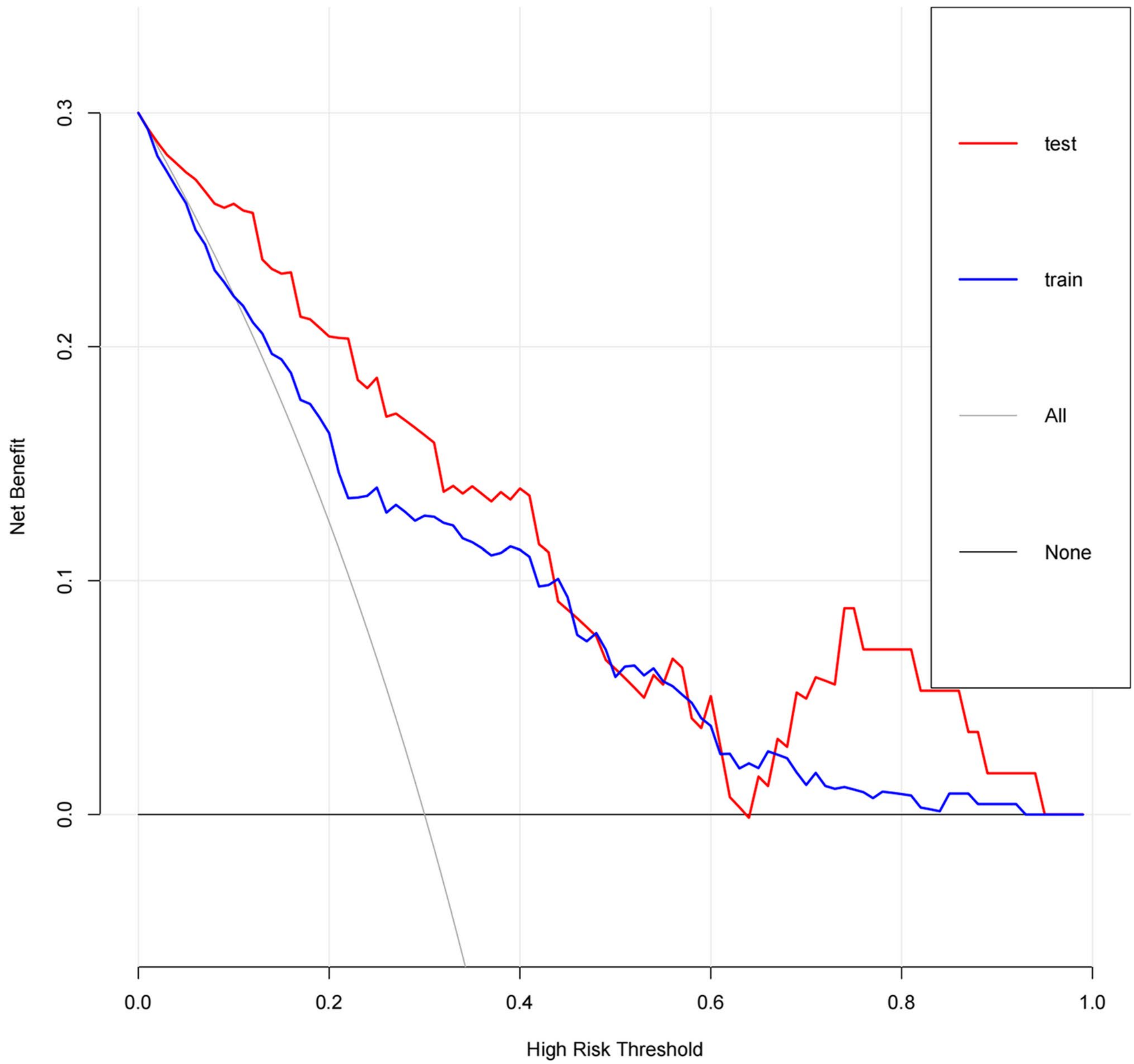

Fig. 5 WuHan nomogram. LR chi^2 = 105.61, $p < 0.0001$, R^2 = 0.294, C (AUC) = 0.787. Dxy = 0.575, gamma = 0.577, Brier = 0.173. Sex(P = 0.0137), Pathological types (p = 0.0311), Surgery Method (p = 0.0002), Root resorption (p = 0.0007), imaging type (p = 0.0602), Focal tooth was extracted(p = 0.0002), The number of teeth involved (p = 0.0022), Cortical bone destruction($p < 0.0001$). Root resorption, Focal tooth was extracted, Cortical bone destruction 0 = No, 1 = Yes. Gender (1 = Male, 2 = Female), Pathological type (1. conventional ameloblastoma 2. Unicystic ameloblastoma 3. others), Surgery method (1. Decompression 2. Enucleation 3. Osteotomy 4. Combination surgeries), Imaging type (1. multilocular ameloblastoma, 2. unilocular ameloblastoma, 3. mixed radiopaque–radiolucent lesion)

patient-level data and underwent rigorous internal validation, its performance remained stable regardless of subtype proportions within the dataset.

In addition, targeted therapy for ameloblastoma shows promising prospects in recent years. Among the 17 cases included in a systematic review [22], 16 experienced tumor shrinkage after targeted therapy, with only 1 case showing no response. The most common mutation was BRAF V600E (11 cases), and the corresponding targeted drug dabrafenib was the most widely used (5 cases as monotherapy, 3 cases in combination with trametinib). Among them, 1 case achieved complete remission with combination therapy, and 9 cases had partial remission. Lenvatinib and erdafitinib for FGFR2 mutations, copanlisib for PIK3CA mutations, and binimetinib for NRAS mutations also had cases of partial remission. Adverse reactions were mostly mild, such as skin problems and fatigue. This treatment can reduce surgical trauma, especially suitable for advanced or recurrent cases, but the

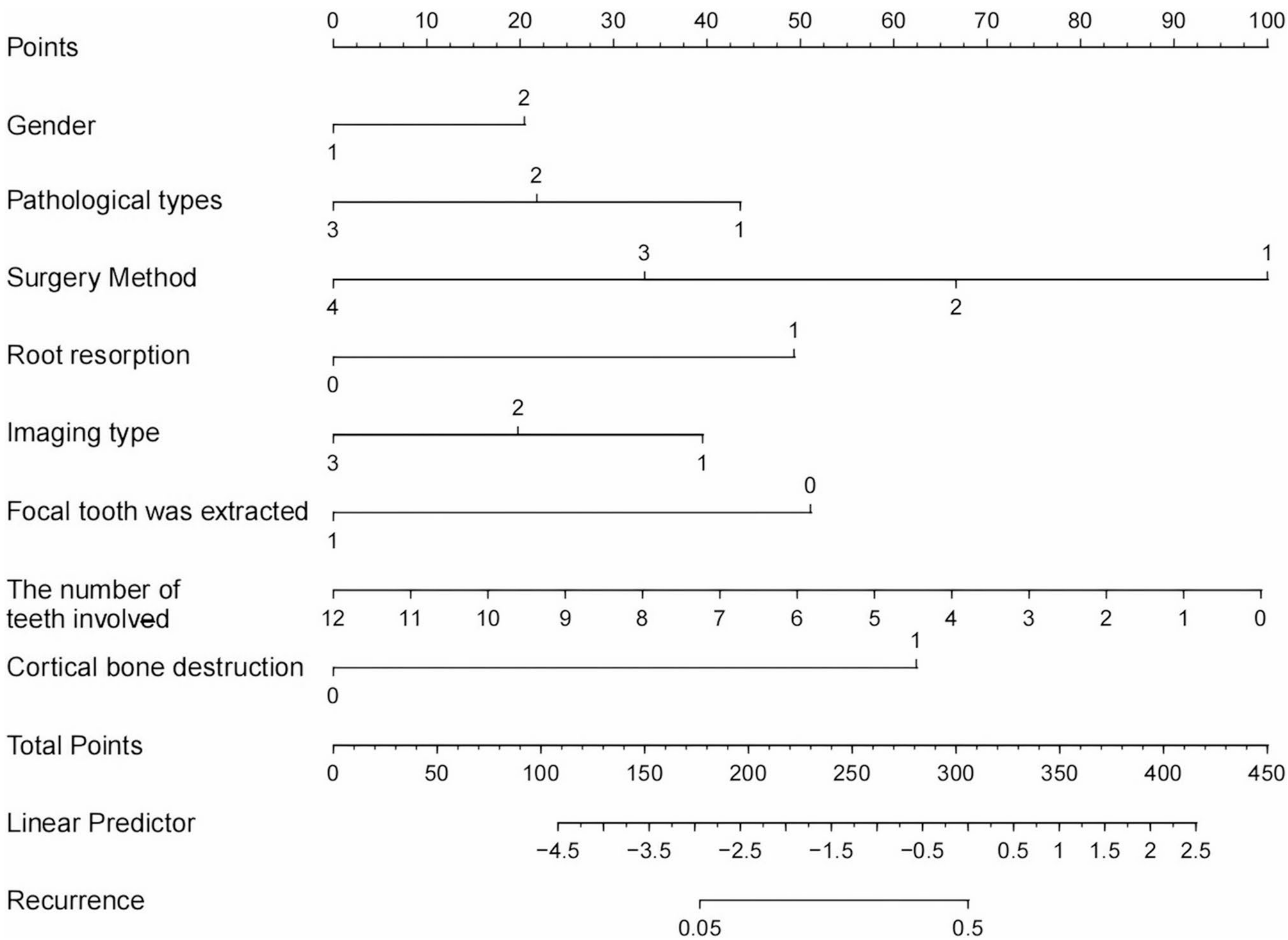

Fig. 6 Yonsei university dental hospital calibration curve (Mean absolute Error = 0.018)

choice of drugs needs to be based on the type of gene mutation.

This study indicates that malignant transformation in ameloblastoma correlates with a substantially increased recurrence probability, exhibiting approximately 3–4 times greater risk compared to benign counterparts. This increased risk may be attributed to the more invasive nature of malignant transformed ameloblastoma, which renders complete surgical excision less likely. For ameloblastoma with malignant transformation, it is crucial to expand the surgical resection margins as extensively as possible to achieve a radical excision. Concurrently, it is essential to evaluate for metastasis in other regions of the body. The clinical evidence further warrants adoption of more definitive therapeutic interventions to address the demonstrated prognostic significance of these parameters.

To our knowledge, this study represents the first development of a dual-center prognostic nomogram model for ameloblastoma in East Asia. Nonetheless, several limitations should be acknowledged. First, the study population was limited to East Asian cohorts, and external validation across diverse geographic regions is required to evaluate the broader applicability of the model. Second, incomplete clinical records led to a reduction in the number of eligible cases for model construction, suggesting that future inclusion of a larger cohort may improve predictive performance. Lastly, incorporating this nomogram with genomic or pathological markers in future research may further enhance its predictive accuracy and clinical utility.

Conclusion

In summary, the recurrence of ameloblastoma in both regions was significantly associated with pathological type, surgical method, imaging classification, and the presence or absence of cortical bone destruction. Simultaneously, this study pioneers the utilization of patient data from two East Asia centers to develop a recurrence prediction model for ameloblastoma. Future research is expected to involve broader participation from additional centers across the region to explore the homogeneity of recurrence patterns throughout East Asia. Through iterative refinement, the model can be enhanced

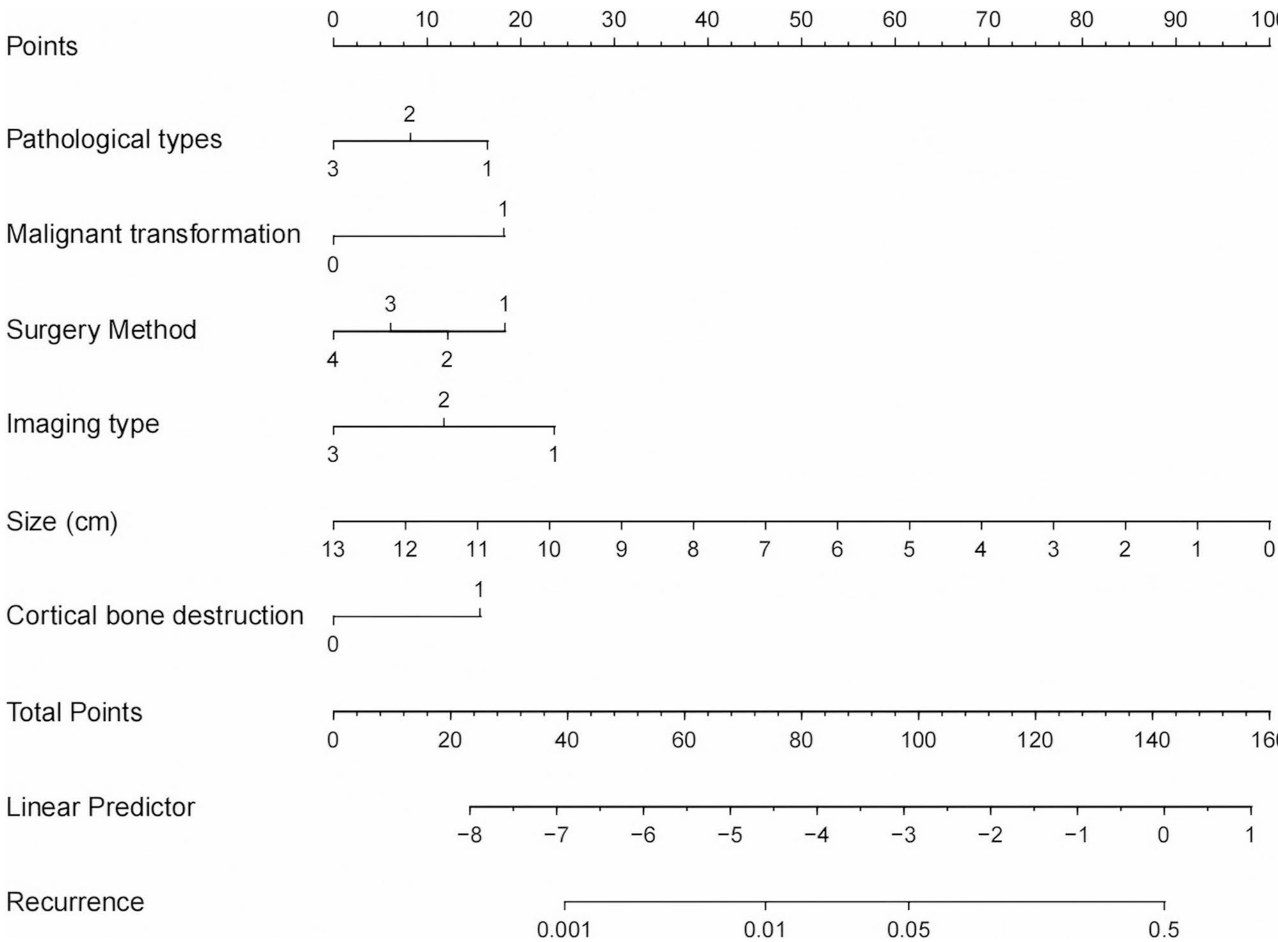

Fig. 7 Hospital of stomatology, Wuhan university calibration curve (Mean absolute Error = 0.02)

Table 3 Yonsei university dental hospital nomogram variables

Factor	Low	High	Effect	S.E.	OR	95% CI
Pathological types	1	4	−1.274	0.328	0.280	[−1.916, −0.632]
Surgery Method	2	3	−0.553	0.219	0.575	[−0.982, −0.124]
Imaging type	1	3	−1.030	0.529	0.357	[−2.066, 0.006]
Size	1.675	4	−1.018	0.279	0.361	[−1.565, −0.470]
Cortical bone destruction	0	1	1.018	0.447	2.769	[0.142, 1.8949]
Malignant transformation	0	1	1.088	0.448	3.279	[0.310, 3.279]

Cortical bone destruction, Malignant transformation 0 = No, 1 = Yes. Pathological type (1. conventional ameloblastoma 2. Unicystic ameloblastoma 3. others), Surgery method (1. Decompression 2. Enucleation 3. Osteotomy 4.Combination surgeries), Imaging type (1. multilocular ameloblastoma, 2. unilocular ameloblastoma, 3. mixed radiopaque–radiolucent lesion)

to exhibit improved predictive capacity and broader representativeness.

Table 4 WuHan nomogram variables

Factor	Low	High	Effect	S.E.	OR	95% CI
Gender	1	2	0.586	0.238	1.797	[0.120, 1.053]
Pathological types	1	3	−0.424	0.197	0.655	[−0.809, −0.038]
Surgery Method	2	3	−0.675	0.182	0.509	[−1.030, −0.319]
Root resorption	0	1	1.075	0.316	2.930	[0.456, 1.694]
Imaging type	1	3	−0.812	0.432	0.444	[−1.659, 0.035]
Focal tooth was extracted	0	1	−1.356	0.366	0.258	[−2.074, −0.638]
The number of teeth involved	1	4	−0.552	0.180	0.576	[−0.906, −0.199]
Cortical bone destruction	0	1	1.405	0.257	4.075	[0.902, 1.908]

Root resorption, Focal tooth was extracted, Cortical bone destruction 0 = No, 1 = Yes. Gender (1 = Male, 2 = Female), Pathological type (1. conventional ameloblastoma 2. Unicystic ameloblastoma 3. others), Surgery method (1. Decompression 2. Enucleation 3. Osteotomy 4. Combination surgeries), Imaging type (1. multilocular ameloblastoma, 2. unilocular ameloblastoma, 3. mixed radiopaque–radiolucent lesion)

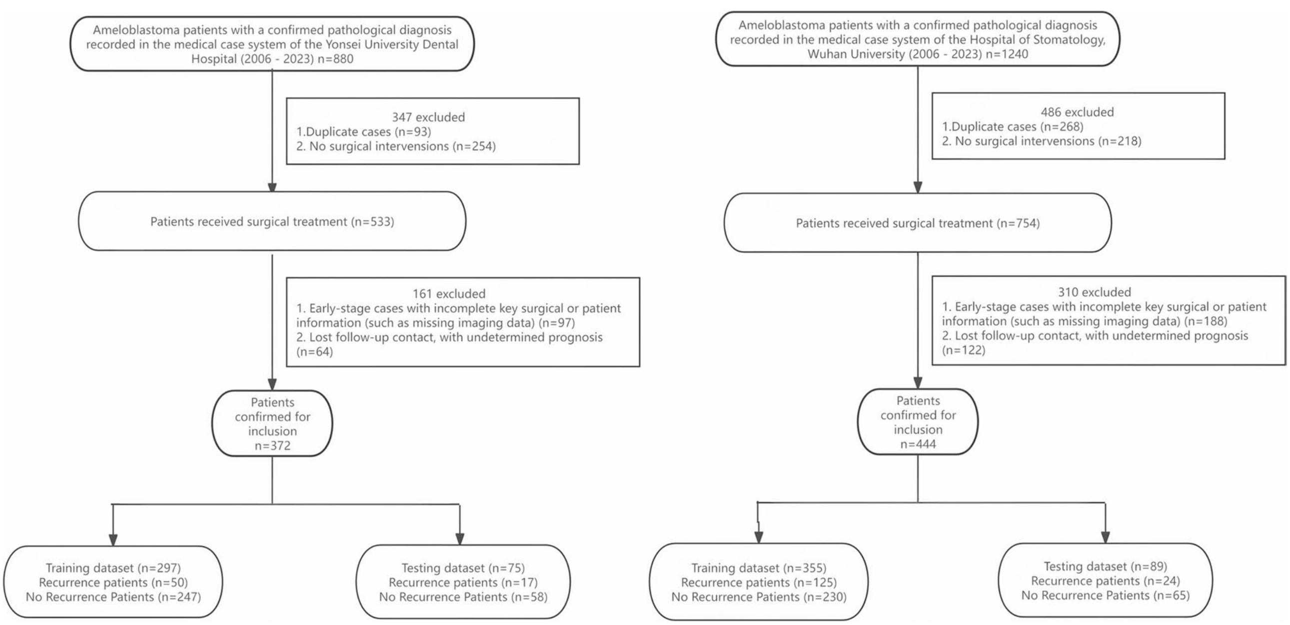

Fig. 8 Decision curve analysis both models show good fitting performance

Abbreviations

AUC Area Under the Curve
ROC Receiver Operating Characteristic curve
CI Confidence Interval
OR Odds Ratio

Supplementary Information

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Supplementary Material 1.

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Authors' contributions

Clinical data collection was conducted by Derong Zou and Hao Lin. Quality control of the data and algorithms was performed by Derong Zou, Hao Lin and Junxu Chen. Statistical analysis was carried out by Derong Zou, Hao Lin and Junxu Chen. The article was written and edited by Tianfu Wu, while the study design was developed by Bing Liu and Hyung Jun Kim.

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Data availability

The data will be available from the corresponding author on request.

Declarations

Ethics approval and consent to participate

All participants provided written informed consent to participate in the study. This study was approved by the Ethics Committee of Yonsei University Dental Hospital (2-2025-0014) and Hospital of Stomatology, Wuhan University (WDKQ2024B110). The study was conducted in accordance with the Declaration of Helsinki.

Consent for publication

Not applicable.

Competing interests

The authors declare no competing interests.

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References

1. Junquera L, Ascani G, Vicente JC, Garcia-Consuegra L, Roig P. Ameloblastoma revisited. Ann Otol Rhinol Laryngol. 2003;112(12):1034–9.
2. Agbaje JO, Olumuyiwa Adisa A, Ivanova Petrova M, Adenike Olusanya A, Osayomi T, Ajibola Effiom O, Oladele Soyele O, Gbenga Omitola O, Babajide Olawuyi A, Obos Okiti R, et al. Biological profile of ameloblastoma and its location in the jaw in 1246 Nigerians. Oral Surg Oral Med Oral Pathol Oral Radiol. 2018;126(5):424–31.
3. Soluk-Tekkesin M, Wright JM. The world health organization classification of odontogenic lesions: a summary of the changes of the 2022 (5th) edition. Turk Patoloji Derg. 2022;38(2):168–84.
4. Vered M, Wright JM. Update from the 5th edition of the world health organization classification of head and neck tumors: odontogenic and maxillofacial bone tumours. Head Neck Pathol. 2022;16(1):63–75.
5. Singh T, Wiesenfeld D, Clement J, Chandu A, Nastri A. Ameloblastoma: demographic data and treatment outcomes from Melbourne, Australia. Aust Dent J. 2015;60(1):24–9.
6. Hendra FN, Natsir Kalla DS, Van Cann EM, de Vet HCW, Helder MN, Forouzanfar T. Radical vs conservative treatment of intraosseous ameloblastoma: systematic review and meta-analysis. Oral Dis. 2019;25(7):1683–96.
7. Bianchi B, Ferri A, Ferrari S, Leporati M, Copelli C, Ferri T, et al. Mandibular resection and reconstruction in the management of extensive ameloblastoma. J Oral Maxillofac Surg. 2013;71(3):528–37.
8. Pogrel MA, Montes DM. Is there a role for enucleation in the management of ameloblastoma? Int J Oral Maxillofac Surg. 2009;38(8):807–12.
9. Yang R, Liu Z, Gokavarapu S, Peng C, Ji T, Cao W. Recurrence and cancerization of ameloblastoma: multivariate analysis of 87 recurrent craniofacial ameloblastoma to assess risk factors associated with early recurrence and secondary ameloblastic carcinoma. Chin J Cancer Res. 2017;29(3):189–95.
10. Yang YC, Wang JJ, Huang Y, Cai WX, Tao Q. Development and validation of a prognostic nomogram for postoperative recurrence-free survival of ameloblastoma. Cancer Manag Res. 2021;13:4403–16.
11. Sun ZJ, Wu YR, Cheng N, Zwahlen RA, Zhao YF. Desmoplastic ameloblastoma - a review. Oral Oncol. 2009;45(9):752–9.
12. Stoltzfus JC. Logistic regression: a brief primer. Acad Emerg Med. 2011;18(10):1099–104.
13. Christodoulou E, Ma J, Collins GS, Steyerberg EW, Verbakel JY, Van Calster B. A systematic review shows no performance benefit of machine learning over logistic regression for clinical prediction models. J Clin Epidemiol. 2019;110:12–22.
14. Zhang F, Han Y, Mao Y, Zheng G, Liu L, Li W. Non-invasive prediction nomogram for predicting significant fibrosis in patients with metabolic-associated fatty liver disease: a cross-sectional study. Ann Med. 2024;56(1):2337739.
15. Vickers AJ, Holland F. Decision curve analysis to evaluate the clinical benefit of prediction models. Spine J. 2021;21(10):1643–8.
16. Au SW, Li KY, Choi WS, Su YX. Risk factors for recurrence of ameloblastoma: a long-term follow-up retrospective study. Int J Oral Maxillofac Surg. 2019;48(10):1300–6.
17. Reichart PA, Philipsen HP, Sonner S. Ameloblastoma: biological profile of 3677 cases. Eur J Cancer B Oral Oncol. 1995;31B(2):86–99.
18. McClary AC, West RB, McClary AC, Pollack JR, Fischbein NJ, Holsinger CF, Sunwoo J, Colevas AD, Sirjani D. Ameloblastoma: a clinical review and trends in management. Eur Arch Otorhinolaryngol. 2016;273(7):1649–61.
19. Hong J, Yun PY, Chung IH, Myoung H, Suh JD, Seo BM, et al. Long-term follow up on recurrence of 305 ameloblastoma cases. Int J Oral Maxillofac Surg. 2007;36(4):283–8.
20. Milman T, Ying GS, Pan W, LiVolsi V. Ameloblastoma: 25 year experience at a single institution. Head Neck Pathol. 2016;10(4):513–20.
21. Liu W, Zheng C, Zhang X, Hu H. Recurrence and malignant risk of ameloblastoma: a demographic study of 1626 cases from East China. Oral Oncol. 2024;148:106651.
22. Bologna-Molina R, Schuch L, Magliocca K, van Heerden W, Robinson L, Bilodeau EA, et al. Targeted therapies in ameloblastomas and amelobastic carcinoma-a systematic review. Oral Dis. 2024;30(6):3571–81.

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