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RESEARCH

Digitally measured exposed root surface area for predicting the effectiveness of modified coronally advanced tunnel combined de-epithelialized gingival grafting in the treatment of multiple adjacent gingival recessions

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Abstract

Objectives To assess the predictive value of baseline digitally measured exposure root surface area (ERSA) on the effectiveness of modified coronally advanced tunnel and de-epithelialized gingival grafting (MCAT + DGG) technique for the treatment of multiple adjacent gingival recessions (MAGRs).

Materials and methods A total of 96 gingival recessions (48 RT1 and 48 RT2) from 30 subjects were included. ERSA was measured on the digital model obtained by intraoral scanner. Generalized linear model was used to analyze the possible correlation of ERSA, Cairo recession type (RT), gingival biotype, keratinized gingival width (KTW), tooth type, and cervical step-like morphology on the mean root coverage (MRC) and complete root coverage (CRC) at 1-year after MCAT + DGG. The predictive accuracy of CRC is tested using receiver-operator characteristic curves.

Results At 1-year postoperatively, the MRC for RT1 was 95.14 ± 10.25%, which was significantly higher than 78.42 ± 22.57% for RT2 ($p < 0.001$). ERSA (OR:1.342, $p < 0.001$), KTW (OR:1.902, $p = 0.028$) and lower incisors (OR:15.716, $p = 0.008$) were independent risk factors for predicting MRC. ERSA and MRC showed significant negative correlation in RT2($r = -0.558$, $p < 0.001$), but not in RT1($r = 0.220$, $p = 0.882$). Meanwhile, ERSA (OR:1.232, $p = 0.005$) and Cairo RT (OR:3.740, $p = 0.040$) were independent risk factors for predicting CRC. For RT2, the area under curve was 0.848 and 0.898 for ERSA without or with other correction factors, respectively.

Conclusions Digitally measured ERSA may provide strong predictive values for RT1 and RT2 defects treated with MCAT + DGG.

Clinical relevance This study demonstrates that digitally measured ERSA is a valid outcome predictor for root coverage surgery, especially applicable for predicting RT2 MAGRs.

Keywords Exposed root surface area · Modified coronally advanced tunnel · De-epithelialized gingival graft · Prognostic factors · Multiple gingival recessions · Digital measurement

Introduction

Multiple adjacent gingival recessions (MAGRs) present a high clinical challenge due to a combination of factors including an extensive surgical area, shallow vestibular depth, cervical step-like morphology defects, and narrow keratinized gingiva [1]. By analyzing the anatomical characteristics of gingival recessions at baseline, clinical decision-making can be improved, and postoperative outcomes predicted.

In previous studies, Miller's classification has been mostly used to predict the outcome of root coverage surgery [1, 2]. However, the position of the interdental soft tissue does not truly reflect the position of the interproximal clinical attachment loss (CAL) or alveolar bone. As this classification system was proposed so early, it cannot predict treatment outcomes with the most advanced surgical procedures [3]. Thereafter, the Cairo recession type (RT) classification innovatively proposed the interproximal CAL and its relationship to buccal-lingual recession as criteria for

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classification into RT1, RT2, and RT3 [4]. This system had been accepted by the 2018 World workshop classification as a popular method for identifying gingival recessions. By combining keratinized gingival width and gingival thickness, clinical guidance may be improved [5].

A periodontal probe has often been used in previous studies for unidimensional measurements of gingival recession height (GRH) and width (GRW). However, these measurements are prone to errors as the readings are rounded or the observation angle is changed. Some studies simply multiplied GRH and GRW to calculate avascular exposed root surface area (AERSA) and analyzed its effect on the postoperative outcome of root coverage surgery [6–8]. In recent years, digital technology has developed rapidly, making it possible to accurately and reliably measure the exposed root surface area (ERSA) of the gingival recession based on an intraoral scanner [9].

Among the various root coverage procedures, modified coronally advanced tunnel (MCAT) is a very effective and predictable way to treat MAGRs in RT1 and RT2. Several studies have demonstrated that this technique is less invasive, has a better blood supply, and is more aesthetic since no vertical incisions are required [10]. As a result, the MCAT technique is more widely adapted and has more stable long-term results than the traditional coronally advanced flap (CAF) for teeth with interdental attachment loss or narrower keratinized gingiva.

To our knowledge, no studies have yet used digitally measured ERSA as a primary prognostic criterion for MAGRs. Therefore, the aim of this study was to analyze the predictive significance of the Cairo RT classification, gingival biotype, KTW, tooth type, ERSA, and cervical step-like morphology on the root coverage outcomes at 1-year after MCAT combined with de-epithelialized gingival graft (DGG) for MAGRs.

Material and methods

Study design and participants

The patients with MAGRs were enrolled in the Department of Periodontology, First Clinical Division at Peking University School and Hospital of Stomatology between January 2019 and June 2022. The approval of the Ethics Committee of Peking University Stomatology Hospital was obtained (PKUSSIRB-201947089). And this study was registered in the Chinese Clinical Trial Registry (ChiCTR1900026768). All participants were informed about the study procedures, their associated risks and benefits in accordance with Helsinki Declaration of 1975 as revised in 2000. All patients provided written informed consent.

All participants met the inclusion criteria: (1) aged 18–65; (2) presence ≥ 2 adjacent teeth with ≥ 1.5 mm Cairo RT1 or RT2 recessions in non-molar region [4]; (3) the cervical defect, if any, did not significantly engage the crown border, which was in consistent position with the CEJ of the adjacent tooth; (4) good oral hygiene with calculus index = 0, probing depth (PD) ≤ 3 mm, full mouth plaque score $\leq 15\%$, Full mouth bleeding on probing $\leq 15\%$. The exclusion criteria were: (1) patient with systemic disease or taking medications that may affect the gingival; (2) smoker; (3) pregnant and breastfeeding women; (4) undergoing or intend to undergo orthodontic treatment; (5) teeth with occlusal interference, filling restoration or cervical caries.

Clinical and digital measurement

In order to ensure intra-examiner reproducibility, the examiner performed two measurements one week apart, on five individuals who had RT1 or RT2 recessions prior to the study. An intra-class correlation of > 0.85 was achieved by the examiner. All clinical measurements were performed by one blinded trained examiner (F.X.) using a periodontal probe rounded to the nearest 0.5 mm (PCP-UNC15; Hu-Friedy, Chicago, IL, USA).

At baseline, the following information are recorded for the teeth involved.

Tooth type: maxillary incisors; mandibular incisors; maxillary canines; mandibular canines; maxillary premolars; mandibular premolars;
Cairo RT classification: RT1 is considered if there is no interproximal CAL; RT2 is defined when there is interproximal CAL, but it is less than or equal to that of the buccal-lingual CAL; RT3 is defined as interproximal CAL is greater than that of buccal-lingual side.
Gingival biotype: Thin type had visible periodontal probe profile 1 mm below mid-buccal gingival margin and thick type had invisible probe profile.
Keratinized tissue width (KTW): The distance measured from the most apical point of the gingival margin to the muco-gingival junction (MGJ) at the mid-buccal side. (mm)

An intraoral scanner (3 shape Trios 2 pod color, 3shape, Denmark) was used to obtain digital models at baseline and 1-year after surgery. The digital measurement was assessed by another independent examiner (R.Z.), who was blinded to the clinical measurement. The values were accurate to 0.001.

A baseline digital model was used to measure the following:

Gingival recession height (GRH): The vertical distance between the lowest point of the pre-operative gingival margins and the CEJ. (mm)

Root exposure surface area (RESA): The surface area bounded by the pre-operative marginal gingival and the CEJ. ($mm.^2$)

The baseline and 1-year postoperatively digital models were overlapped, and measured [9]:

Gingival height gain (GHG): The vertical distance between the projection point of the lowest point of the post-operative gingival margin of the involved tooth on the preoperative model and the lowest point of the preoperative gingival margin. (mm)

Mean root coverage (MRC): MRC was calculated as GHG/GRH✖ × 100.(%) Note that if the result is greater than 100%, it is recorded as 100%.

Complete root coverage (CRC): CRC was calculated as the percentage of the number of teeth that achieve 100% MRC over the total number of teeth. (%)

Surgical procedures

All subjects were treated using MCAT technique in combination with DGG by the same surgeon (F.X.) [11]. Prior to the surgical procedure, the exposed root was planed using Gracey curettes (Hu-Friedy, Chicago, IL, USA) and conditioned using 17% ethylenediaminetetraacetic acid (Pulpdent Corp, Watertown, MA, USA) for 3 min. After application of local anesthesia, the split thickness tunnel was extended apically above the MGJ and horizontally beyond one adjacent tooth using tunnel instruments (Hu-Friedy, Chicago, IL, USA) without disrupting the interdental papilla. Thereafter, the tunnel flap could be coronally positioned beyond the CEJ without excessive tension.

A DGG of 5 mm width and 1 mm thickness was harvested from the palate, then trimmed to fit the dimension of the surgical area. The donor site was recovered with a collagen membrane (Yierkang, Beijing, China) and sutured using 5–0 polypropylene absorbable sutures (Johnson & Johnson, New Brunswick, NJ, USA). Subsequently, the DGG was carefully inserted into the tunnel. Sling sutures along with vertical mattress sutures were used to coronally reposition the tissue (Fig. 1).

All patients were prescribed amoxicillin 500 mg (twice a day for 3 days) and instructed to rinse their mouth using 0.2% chlorhexidine solution (twice a day for 2 weeks). Fenbid (ibuprofen) was given for post-operative pain as needed. The sutures were removed at 2 weeks postoperative. Patients were then instructed to perform the rolling brushing technique with a soft toothbrush. Re-examinations were conducted regularly after surgery.

Statistical analysis

The study used CRC as the primary outcome to calculate the sample size. According to the review and meta-analysis published by Tavelli et al., the CRC of the tunnel technique for the treatment of multiple gingival recessions was considered to be 57.46% [12]. With a defined tolerance error of 0.1 and a confidence level of 0.95, 94 sites were requested for inclusion. Descriptive analyses were performed for all variables stratified by Cairo RT classification. Continuous variables were presented as mean ± standard deviation (SD) and median and interquartile range (IQR) and categorical variables were presented as absolute numbers (n) and percentages (%). Normality of distribution was assessed by the

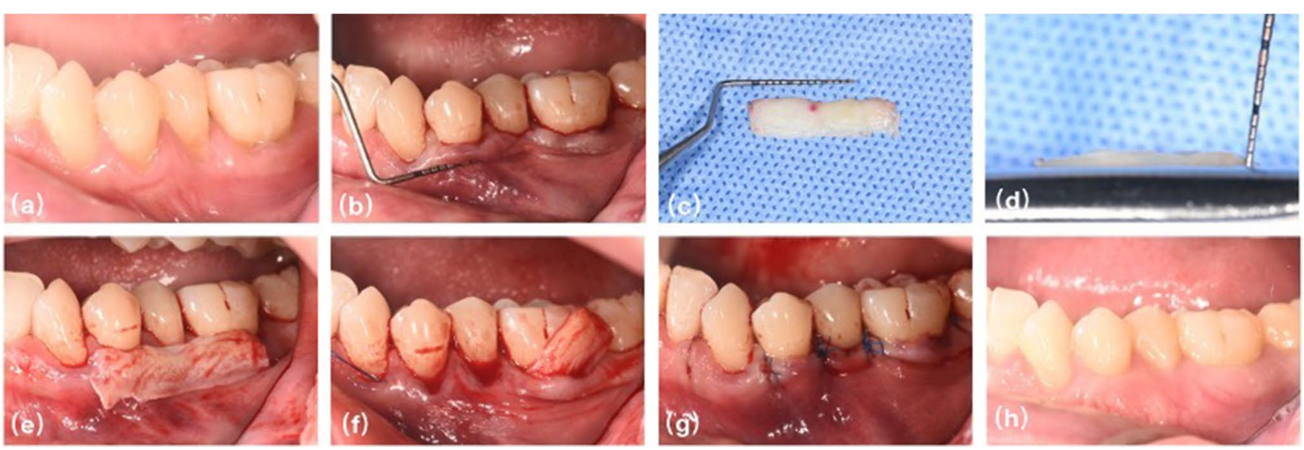

Fig. 1 Treatment of multiple adjacent gingival recessions (MAGRs) using modified coronally advanced tunnel technique (MCAT) combined with de-epithelialized gingival grafting (DGG). (**a**) baseline; (**b**) preparation of a tension-free coronal repositioning tunnel flap; (**c**) obtaining DGG from the maxillary palate; (**d**) the DGG is approximately 1 mm thick; (**e**) trimming the DGG to fit the recipient area; (**f**) placing the DGG into the tunnel; (**g**) sling sutures; and (**h**) 1-year after surgery

Shapiro–Wilk test. Differences between the groups were evaluated using Student-t test or Mann–Whitney-*U* test for continuous variables, and the chi-squared test or Fisher's exact test for categorical variables.

In the study, MRC at 1-year after MCAT + DGG was set at 4 different grades: 1 with a MRC of 100%, 2 with a MRC of 75–100%, 3 with a MRC of 50–75%, and 4 with a MRC of 0–50%. Considering the possible correlation between multiple sites of the same patient included in the analysis, a multilevel analysis was performed [13]. Generalized linear mixed model ordinal logistic regression model were used to determine the association between baseline ERSA (independent variable) and MRC (dependent variable) (model 1, unadjusted) and adjustments for relevant confounders (Cairo RT, gingival biotype, KTW, tooth type, and step-like structure) were applied based on prior research and clinical rationale (model 2, adjusted). Results of the associations are reported as odds ratios (OR) with 95% confidence intervals (95%CI) and p-values. Spearman's analysis was used to test the correlation between ERSA and MRC in different types of gingival recessions. The relationship between baseline ERSA and CRC was also analyzed using generalized linear mixed model binary logistic regression model with CRC as the dependent variable (model 3 and model 4 were unadjusted and adjusted, respectively). Receiver-operating characteristic (ROC) curves were constructed, and the areas under the curve (AUC) and their 95%CI were evaluated for measure the discriminatory ability of baseline ERSA for CRC [14]. Statistical analyses were performed by SPSS v 24.0 (IBM, Armonk, NY, USA). The significance level of 0.05 was adopted.

Results

Study participant information

The study sample consisted of 30 patients (15 males and 15 females) with a mean age of 35.67 ± 7.70 years old. From the total of 96 recessions, 48 (50.00%) were in the RT1 and 48 (50.00%) were in the RT2 group. The details of the descriptive statistics of the involved sites at baseline stratified by Cairo RT are shown in Table 1.

At 1-year postoperatively, 51 of 96 sites achieved 100% MRC, 24 sites had MRC between 75 and 100%, 13 sites had MRC between 50 and 75%, and 8 sites had MRC between 0 and 50%. Figure 2 shows the distribution of various indicators over the four ordinal grades of MRC for the involved teeth at baseline. Baseline ERSA showed a tendency for higher values of ERSA to be correlated with higher MRCs relative to lower MRCs (Fig. 2e). In contrast, KTW at baseline had a similar distribution regardless of MRC grade (Fig. 2f).

At 1-year postoperatively, the MRC for RT1 was 95.14 ± 10.25%, which was significantly higher than 78.42 ± 22.57% for RT2 ($p < 0.001$). Among 75.00% of RT1 and 31.25% of RT2, CRC was achieved, which was statistically significant ($p < 0.001$).

Association between ERSA and MRC

Generalized linear mixed model ordinal logistic regression analyses revealed significant association between baseline ERSA and MRC at 1-year after MCAT combined with DGG in the unadjusted (OR: 1.313, 95%CI: 1.171–1.473, $p < 0.001$) and adjusted model (OR: 1.342, 95%CI: 1.169–1.541, $p < 0.001$) (Table 2). The likelihood of having a grade lower MRC at 1-year postoperatively increased 1.902-fold with each unit increase in KTW (e.g., 1 mm) (OR: 1.902, 95%CI: 1.072–3.374, $p = 0.028$) in model 2. Additionally, tooth type was statistically significant ($p = 0.004$). Mandibular incisors were 15.716 times more likely to have at least one grade lower MRC than maxillary incisors (OR: 15.716, 95%CI: 2.087–118.327, $p = 0.008$).

According to a correlation analysis, baseline ERSA and MRC showed a significant negative correlation in RT2 ($r = -0.558$, $p < 0.001$). However, there was no significant correlation in RT1 ($r = 0.220$, $p = 0.882$).

Association between ERSA and CRC

Generalized linear mixed model binary logistic regression analysis showed that for achieving CRC, baseline ERSA in both unadjusted (OR: 1.340, 95%CI: 1.146–1.567, $p < 0.001$) and adjusted models with forward conditional (OR: 1.232, 95%CI: 1.066–1.424, $p = 0.005$) was significantly correlated variable. Model 4 showed that for achieving CRC, Cairo RT ($p = 0.040$) and baseline ERSA ($p = 0.005$) were significantly associated variables, while gingival biotype ($p = 0.232$), tooth type ($p = 0.609$), KTW ($p = 0.357$) and step-like morphology ($p = 0.609$) were not. RT2 was 3.740 times more likely to fail to achieve CRC than RT1 (OR = 3.740, 95%CI = 1.061–13.187). The likelihood of failing to obtain CRC 1-year postoperatively increased by 1.232-fold with 1mm^2 increase in baseline ERSA. There was 86.3% prediction accuracy for success achieving CRC, 68.9% for failure to meet CRC, and 78.1% for overall prediction accuracy. It was higher than the corresponding prediction accuracies of 55.6%, 78.4%, and 67.7% for model 3 (Table 3).

The ROC analysis Based on all teeth is shown in Fig. 3. When considering only ERSA, the AUC was 0.731 (95%CI: 0.630–0.833), which corresponds to a sensitivity of 51.11% and specificity of 90.20%. With the addition of the correction factors Cairo RT, the AUC increased to 0.789 (95%CI: 0.693–0.884), which corresponds to a sensitivity of 64.44% and a specificity of 88.24%. In the case of RT2, the AUC was

Table 1 The clinical characteristics of the treated sites at baseline

Variables	Total ($n=96$)	RT1 ($n=48$)	RT2 ($n=48$)	p value
Gingival biotype				
Thick	51(53.13)	33(66.6)	18 (37.50)	0.004*
Thin	45(46.87)	15(29.2)	30 (62.50)	
Tooth type				
Upper incisor	7(7.30)	1(2.08)	6(12.50)	< 0.001*
Lower incisor	20(20.83)	1(2.08)	19(39.58)	
Upper canine	13(13.54)	11(22.92)	2(4.17)	
Lower canine	9(9.37)	4(8.33)	5(10.42)	
Upper premolar	23(23.96)	17(35.42)	6(12.50)	
Lower premolar	24(25.00)	14(29.17)	10(20.83)	
Step				
+	63(65.63)	36 (54.2)	27 (56.25)	0.085
-	33(34.37)	12 (45.8)	21 (43.75)	
PD (mm)				
Mean ± SD	1.19 ± 0.39	1.27 ± 0.45	1.10 ± 0.31	0.065
Mean(IQR)	1(0)	1(1)	1(0)	
KTW (mm)				
Mean ± SD	2.08 ± 1.02	2.07 ± 0.97	2.08 ± 1.09	0.820
Mean(IQR)	2(1.5)	2(1.5)	2(1.63)	
GRH (mm)				
Mean ± SD	2.07 ± 0.95	1.95 ± 0.66	2.18 ± 1.17	0.358
Mean(IQR)	2.03(0.99)	1.86(0.91)	2.08(1.43)	
GRW (mm)				
Mean ± SD	3.33 ± 1.03	3.22 ± 0.69	3.44 ± 1.29	0.719
Mean(IQR)	3.17(1.03)	3.17(0.97)	3.19(1.11)	
ERSA (mm^2)				
Mean ± SD	8.11 ± 3.86	6.81 ± 2.25	9.41 ± 4.65	0.006*
Mean(IQR)	7.24(4.57)	6.60(3.33)	8.41(6.52)	

RT, recession type; *PD*, probing depth; *KTW*, keratinized tissue width; *GRH*, gingival recession height; *GRW*, gingival recession width; *ERSA*, exposed root surface area; *SD*, standard deviation; *IQR*, interquartile range

0.848 (95%CI: 0.732–0.963) when considered ERSA only, corresponding to a sensitivity and specificity of 78.79% and 80.00%, respectively. When other factors were added for correction, the AUC further increased to 0.898 (95%CI: 0.812–0.984), with a sensitivity of 81.82% and specificity of 93.33%.

Discussion

Recent advances in microsurgery have increased interest in periodontal plastic surgery [15]. Considering that the success of root coverage surgery depends on a variety of factors, scholars have attempted to discuss the predictive power of baseline clinical parameters on postoperative outcomes [7, 16, 17]. Given that the morphological changes of gingival soft tissues are irregular in three-dimensional, the data of traditional methods are mostly collected based on periodontal probes or clinical photographs, which are prone to errors due to subjective factors [16, 18]. As a non-invasive and high-precision evaluation tool, computer-aided image analysis technology has advantages in realistic, effective and objective quantitative assessment of two- or three-dimensional morphological changes of soft tissues [19]. To the best of our knowledge, this study is the first to assess the predictive significance of digitally measured ERSA on postoperative outcomes of root coverage surgery with the aim of providing theoretical guidance for clinical treatment. In order to provide higher comparability and reference with other studies using periodontal probes, ordinal logistic regression analyses were used to differentiate the MRC results.

As early as 20 years ago, Bouchard et al. pointed out that vertical linear measurements in mm at the mid-buccal of the recession cannot accurately capture the pattern of this area [20]. Nevertheless, conventional studies are limited by measurement tools available and can only use unidimensional GRH [21] or the rough results (AERSA) [7, 8] obtained by multiplying the GRH and GRW, both of which are obtained from

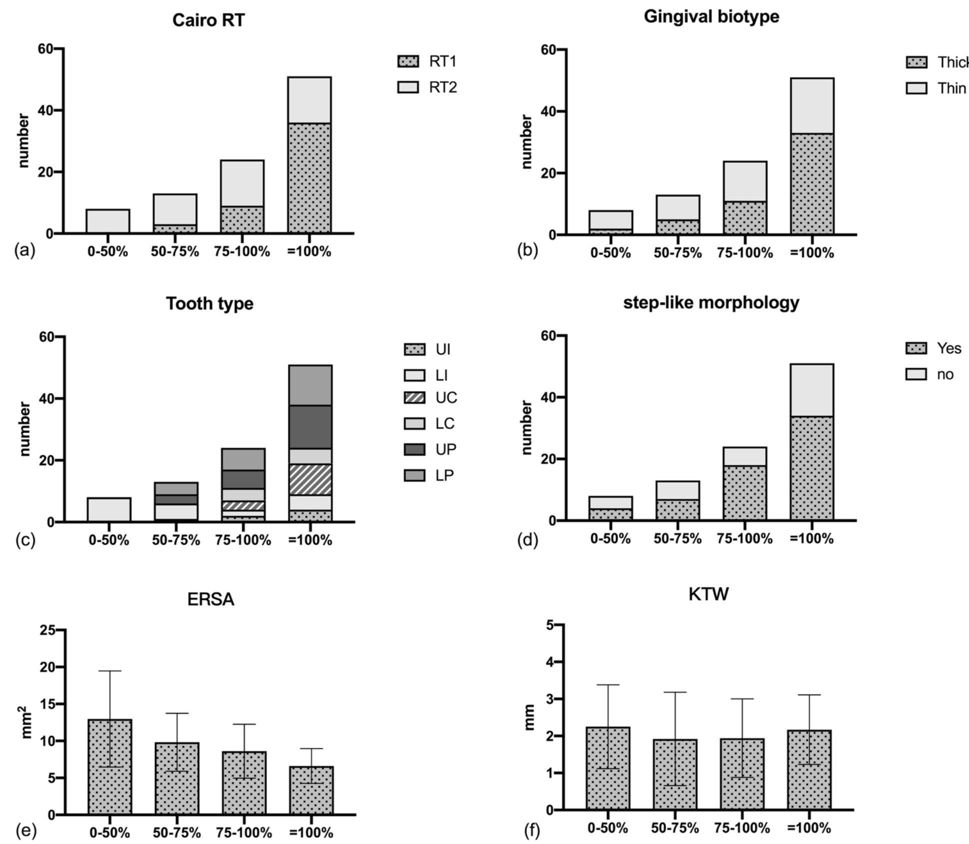

Fig. 2 Distribution of Cairo RT (**a**), gingival biotype (**b**), tooth type (**c**), presence of cervical step-like morphology (**d**), ERSA (**e**), and KTW (**f**) at baseline with respect to the four ordinal grades of MRC at 1-year postoperatively

Table 2 Generalized linear mixed model ordinal logistic regression analyses of mean root coverage at 1-year postoperatively

Models	Variables		OR	95%CI	*p* value
Model 1	ERSA		1.313	1.171–1.473	< 0.001*
Model 2	ERSA		1.342	1.169–1.541	< 0.001*
	Cairo RT	RT1	Ref		
		RT2	2.221	0.769–6.415	0.140
	Gingival biotype	Thick	Ref		
		Thin	1.750	0.556–5.508	0.337
	KTW		1.902	1.072–3.374	0.028*
	Step-like morphology	No	Ref		
		Yes	1.687	0.508–5.600	0.392
	Tooth type	Maxillary incisors	Ref		
		Mandibular incisors	15.716	2.087 -118.327	0.008*
		Maxillary canines	0.307	0.036–2.616	0.279
		Mandibular canines	0.684	0.085–5.486	0.720
		Maxillary premolars	1.913	0.303–12.092	0.489
		Mandibular premolars	2.209	0.271–18.020	0.458

OR, odds ratio; *CI*, confidence interval; *ERSA*, exposed root surface area; *RT*, recession type; *Ref*, reference; *KTW*, keratinized tissue width

periodontal probes. This study utilizes the digitally measured ERSA which is a three-dimensional indicator that is more accurate in describing the irregular shape of the gingival recession area. In general, the larger the ERSA, the less likely it is that the root surface will be covered. In 2015, Ozcelik et al. had found an excellent correlation between AERSA and MRC at 6-month postoperatively ($r = 0.90$) in a sample of Miller I and II single gingival recession treated with laterally positioned

Table 3 Generalized linear mixed model binary logistic regression analysis of complete root coverage at 1-year postoperatively

Models	Variables		OR	95%CI	*p* value
Model 3	Intercept				< 0.001*
	ERSA		1.340	1.146–1.567	< 0.001*
Model 4	Intercept				0.009*
	ERSA		1.232	1.066–1.424	0.005*
	Cairo RT	RT1	Ref		
		RT2	3.740	1.061–13.187	0.040*
	Gingival biotype	Thick	Ref		
		Thin	2.263	0.588–8.717	0.232
	KTW		1.355	0.706–2.603	0.357
	Step-like morphology	No	Ref		
		Yes	1.382	0.395–4.834	0.609
	Tooth type	Maxillary incisors	Ref		
		Mandibular incisors	1.959	0.191 -20.067	0.567
		Maxillary canines	0.761	0.070–8.257	0.820
		Mandibular canines	0.988	0.087–11.268	0.992
		Maxillary premolars	1.667	0.148–18.796	0.676
		Mandibular premolars	1.355	0.706–2.603	0.357

OR, odds ratio; *CI*, confidence interval; *ERSA*, exposed root surface area; *RT*, recession type; *Ref*, reference; *KTW*, keratinized tissue width

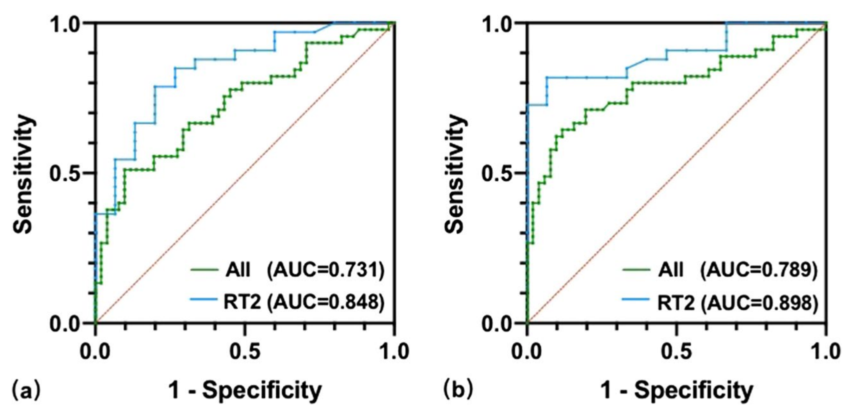

Fig. 3 Receiver-operating characteristic curve and AUC for the unadjusted model (**a**) and adjusted model (**b**) predicting CRC

flap combined with sCTG [7]. In addition, the ROC curve showed that AERSA could be a better predictor of CRC at 6-month postoperatively when using CAF [8]. Due to differences in inclusion criteria and surgical procedure, ERSA values in this study were slightly lower than those 2 studies. A recent research assessing the role of EMD in MCAT combined with DGG for MAGRs demonstrated that baseline AERSA was strongly associated with either > 85% MRC or CRC [6]. As a result of our regression analysis, both univariate and multivariate analyses indicated that digitally measured ERSA was a valid predictor of both MRC and CRC at 1-year postoperatively. For every 1 mm^2 increase in baseline ERSA, the probability of a one-grade decline in MRC or failure to obtain CRC at 1-year postoperatively increases by approximately 30%. However, it should be noted that ERSA cannot demonstrate the height of interdental tissues, so other indicators may be necessary to obtain a more accurate prediction than that resulting from ERSA alone.

The results of this study showed MRCs of 95.14 ± 10.25% and 78.42 ± 22.57% for RT1 and RT2, respectively, with statistical differences between groups. These results are similar to those reported in studies using MCAT in combination with sCTG using the single-incision technique for RT1 and RT2 gingival recession, respectively [22, 23]. A cross-sectional study found that 88.11% of subjects with GR ≥ 1 mm had at least one RT1 and RT2 tooth, and 31.35% had them both [24]. Previous research has limited information regarding MAGRs in RT2 [25]. At 1-year postoperatively, 35% of the sites in this study reached CRC, higher than the 24% in the previous study, which used a single-incision sCTG as a graft[4]. MCAT technique, which elevates interdental gingival papillae, as well as DGG technique, which provides denser connective tissue, may explain these results. The spatial support provided by DGG enabled some RT2 recessions with insignificant interproximal CAL to achieve reasonable root coverage. ROC analysis showed Cairo RT and ERSA were significant in predicting CRC, with an AUC of 0.898, sensitivity and specificity of 81.82% and 93.33%, respectively. There may be a correlation between RT2 recession and the height of the interproximal CAL, as well as a potential blood supply provided by the interdental papillae.

A significant correlation was found between baseline KTW and postoperative MRC, but no difference was found between thick and thin gingival biotypes. Rasperini et al. performed a tunnel technique without additional grafts in subjects with thick and extra-thick gingiva and concluded that the key factor in obtaining root coverage was the amount of KTW rather than sCTG itself [26]. A prospective multicenter study showed that thin gingiva biotype was strongly associated with low MRC and CRC in 21 patients with RT1 defects treated with CAF alone [27]. Gingival biotype may not have made any significant difference in the prediction of efficacy since this study used DGG that compensated for thin gingiva instability and shrinkage tendency of the gingiva.

According to the present study, mandibular incisors were a statistically significant indicator of MRC in the ordinal regression analysis compared to maxillary incisors, but not for CRC. Gorski et al. suggested that tooth type had a significant influence on whether 85% MRC was achieved, but failed to consider the jaw position of the teeth at the same time. The above study also included molars that were not included in this study [6]. It should be noted that RT2 recessions were more prevalent in the mandibular incisors in this study, which is consistent with the finding in the cross-sectional study that RT2 recessions did not occur at the same rate in different positions and types of teeth. RT1 recessions were mostly observed on maxillary and mandibular premolars as well as on maxillary canines, while RT2 and RT3 recessions were mostly observed on mandibular incisors and maxillary premolars [24].

Gingival recession is commonly associated with noncarious cervical lesions (NCCL), which may involve both the crown and root of the tooth [28, 29]. In this study, the presence of a step-like morphology with a depth of more than 0.5 mm in the cervical area was determined with reference to the 2018 world workshop classification system [30]. The results did not reveal a statistically significant correlation between step-like morphology and MRC or CRC 1-year postoperatively. On the one hand, this may indicate that the procedure used in this study could be useful in compensating for the deficiency of the cervical profile. On the other hand, it may also indicate that the 0.5 mm cut-off is a rather conservative criterion, and that a larger threshold may have a significant impact on the postoperative outcome. Further, given the clinical observations of decreased root coverage at follow-up at deep NCCL sites, the long-term results need to be evaluated.

This exploratory study has limitations, such as the limited sample size and the absence of an analysis of the impact of tooth cervical convexity on the outcome of root coverage. Moreover, it is noteworthy that most of the RT2 recessions that were included in this study had relatively small CAL values. No analysis was done on the effects of interproximal attachment loss and the size of the gingival papilla. However, despite the fact that these anatomic criteria are independent diagnostic variables, they seem to have an interactional effect on root coverage. In the future, we plan to expand the sample size as well as refine the parameters to further improve the accuracy of the prediction model.

Within the limitations of this study, the digitally measured exposed root surface area, ERSA, can be a reliable predictor of the outcome of root coverage surgery. ERSA, KTW, and tooth type appear to provide strong predictive value for MRC 1-year after MCAT combined with DGG, while ERSA and Cairo RT classification may be accepted as risk factors related with not achieving CRC. Clinical clinicians may be able to make more informed decisions and assess the prognosis of patients based on these findings.

Author contribution F.X., Y.Z. and Y.C. conceived the study strategy. F.X. operated the procedure, R.Z. performed the digital measurements. F.X. and R.Z. equally contributed to the implementation of the study and to the writing of the manuscript. J.L. entered the data. F.X., J.L. and JY.D. designed and performed the statistical analyses, including figures. Y.Z. and Y.C. provided supervision and revised the manuscript. All authors have read and agreed to the published version of the manuscript.

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Data Availability The complete documentation of all patients enrolled in this study belongs to the authors and is available from Dr. Fei Xue upon reasonable request.

Declarations

Ethics approval and consent to participate The Ethics Committee of the Peking University School and Hospital of Stomatology approved the study protocol. All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki Declaration and its later amendments or comparable ethical standards.

Conflict of interest The authors declare no competing interests.

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