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PERSONALISED RETENTION PLANS: TAILORING RETAINERS THROUGH ADVANCED DIAGNOSTIC METHODS

Dr Abhishek Sinha*

*Reader, Department of Orthodontics and Dentofacial Orthopedics, Dr B R Ambedkar Institute of Dental Sciences and Hospital, Patna, Magadh University, Bodh Gaya, drsinhaabhi@gmail.com

ABSTRACT
Orthodontic relapse is a prevalent issue, and it is frequently caused by uniform retention prescriptions that disregard individual risk factors. Despite the advancement of computerized diagnostics, individualization of retainer form and wearing duration is not widely used. This research evaluates a new diagnostic-directed strategy for tailoring retention regimens based on patient-specific anatomic and biomechanical risk factors. To compare the efficacy of individually created retention plans based on sophisticated diagnostics to typical retainer plans in maintaining post-treatment orthodontic stability. 80 patients aged 14-30 years who had completed fixed appliance treatment were randomly assigned to either the tailored or standard retention groups. To stratify the risk of recurrence, the customized group had digital intraoral scanning, Cone-Beam Computed Tomography imaging (CBCT), and 3D cephalometric analysis. Retention plans (type retainer and wear schedule) were also tailored. The control group received a conventional Hawley or Vacuum Formed Retainer (VFR) with the same wear orders. Little's Irregularity Index (LII), cephalometric changes, compliance, and satisfaction were all measured at 6 and 12 months. The personalized group had significantly reduced LII at both time intervals (T1: 1.12 +/- 0.38 mm; T2: 1.36 +/- 0.42 mm) compared to the control group (T1: 1.84 +/- 0.61 mm; T2: 2.24 +/- 0.73 mm; $p < 0.001$). There were also higher compliance and satisfaction ratings. The risk of relapse model demonstrated strong predictive validity (AUC = 0.87). Using diagnostics to customize orthodontic retention improves post-treatment stability, compliance, and recurrence. This procedure is clinically feasible and should be regarded as a future standard for orthodontic retention treatments.

Keywords: *personalized retention, orthodontic relapse, retainer customization, diagnostics, treatment planning.*

1. INTRODUCTION

The retention period of orthodontic therapy is crucial for maintaining the outcomes of active orthodontic therapy. Although the treatment phase focuses on tooth alignment and the elimination of occlusal discrepancies, retention ensures that the achieved outcomes are retained once the active pressures are stopped. Nonetheless, despite the therapeutic significance of this stage, retention methods are still undeveloped, variable, and very broad (Bellini-Pereira et al., 2022). In most therapeutic contexts, they are used based on institutional tradition or physician choice rather than personalized patient characteristics (Ab Rahman et al., 2016). Post-treatment relapse, in which teeth revert to their original mismatched position, is a well-documented and recurring problem. Relapse has a complex etiology, implying the presence of biological, mechanical, and behavioural elements (Steinnes et al., 2017). Alveolar bone remodeling, periodontal ligament memory, soft tissue pressure, growth/development impacts, and patient compliance are all factors that contribute to retention variance. More significantly, individuals are not all equally prone to relapse. The anatomical characteristics of each patient, the orthodontic motions performed, and the duration of therapy might vary substantially. Despite this variability, the one-size-fits-all retention strategy continues to be widely used (Fleming et al., 2024). The most commonly used retainers are Hawley appliances and vacuum-formed retainers (VFRs), which are typically administered without considering a patient's particular risk profile.

This broad strategy has direct effects. Clinical reports and longitudinal studies continue to reveal that 30 to 50 percent of orthodontic patients experience detectable recurrence, particularly in the front mandible, within 12 to 24 months of treatment completion (Alqerban et al., 2014). In the majority of these cases, relapse is caused by a lack of adequate retention planning that does not take into account specific biomechanical tendencies, rather than a lack of compliance. In an era when patients are increasingly seeking long-term outcomes and evidence-based management, such high relapse rates raise the question of whether traditional retention philosophy is sufficient (Samandara et al., 2019).

In contrast, the diagnostic toolkit of orthodontists has grown significantly during the previous decade. Digital intraoral scanners now allow for high-resolution, reproducible imprints that are not limited by traditional material limits. Cone-beam computed tomography (CBCT) creates three-dimensional images of skeletal structures, tooth orientations, root placements, and soft tissue contours (Aragón, M. L., 2016). Cephalometric analysis software allows for precise angular and linear measurements of craniofacial connections, while morphometric and photographic analysis provide additional information regarding facial symmetry and growth trends (Lippold et al., 2015).

These technologies have gained widespread recognition in the diagnostic and active treatment stages, particularly in the planning of surgical procedures, complicated malocclusions, and craniofacial abnormalities (Krämer et al., 2020). Nonetheless, they have not been fully utilized in their potential to guide retention strategy. There is a discrepancy between the intricacy of diagnostic methods and the simplicity of retention instructions. The majority of orthodontists continue to provide retention appliances in a fairly typical manner, without re-evaluating the diagnostic information obtained throughout therapy (Edman et al., 2015). This is a missed opportunity to tailor care based on objective assessments of risk of recurrence. While tailored retention makes sense, the current literature is still heavily geared toward comparative evaluations of various types of retainers in unstratified populations (Saleh et al., 2017). The research has been conducted to determine whether a form of Hawley retainer or VFR is more successful, with many yielding equivocal or contradicting results. One of these studies' major flaws is the lack of risk stratification; these patients are treated as a homogenous group, even though they have varying propensities to relapse (Hussain et al., 2024). These comparisons have little therapeutic significance unless they take into account baseline anatomical variability, compliance level, and treatment mechanics (Li et al., 2021).

There has been relatively little research on the potential of digital systems in making post-treatment decisions (Sangalli et al., 2022). The studies tend to focus on treatment progress evaluation or occlusal contact monitoring; however, few of them extend their attention to post-treatment retention (Al Rahma et al., 2018). More specifically, they have not been prospectively clinically verified as part of the retention design. There is limited evidence to suggest how diagnostic tools such as CBCT, digital arch models, and cephalometric assessments may be coupled to assist in tailoring retention mechanisms and reduce relapse (Joda et al., 2024).

Predictive modeling of orthodontic relapse is a new topic of study. Linear regression, support vector machine, and neural network techniques have all been shown to be useful in predicting anterior crowding or arch width changes following therapy (Bichu et al., 2021). However, these models are mostly intellectual and therefore have little therapeutic usage. There is no widely accepted strategy for incorporating such predictive tools into clinical practice to be utilized in retention planning (Khanagar et al., 2021). Overall, the research shows that there is a significant gap between diagnostic skills and their application at the retention stage. The profession lacks an organized, evidence-based retention method that incorporates customized risk assessment using diagnostic data (Raucci et al., 2015). In the absence of such a framework, practitioners will continue to follow outdated practices, and patients will be at risk of recurrence even after active orthodontic care (Qi et al., 2019).

This study assesses the improvement in retention results when the retainer type, design, and wear schedule are changed utilizing advanced diagnostics. To stratify patients and customize retention, a method combining digital scans, CBCT, cephalometric analysis, and relapse risk modeling is used. The study analyzes relapse rates, cephalometric alterations, compliance, and patient satisfaction between personalized and conventional regimens. It also verifies a prediction model based on anatomical and treatment-related parameters. The objective is to provide an evidence-based, clinically practical approach to individualized orthodontic retention that improves long-term stability, decreases relapse, and prioritizes patient-centered care.

2. Materials and Methods

2.1. Study Design and Setting

The study was prospective and controlled, with a focus on comparing the clinical results of customized versus standard therapeutic options. To ensure clinical relevance and homogeneity, participants were selected based on predetermined inclusion and exclusion criteria. All ethical permissions were obtained before recruitment, and all subjects provided informed consent following institutional and international norms. Randomization procedures were used to divide participants into comparative groups and eliminate selection bias. A diagnostic evaluation was used to create an intervention for one group, while the control group received normal treatment practices. The research design incorporated regular follow-up intervals and predetermined evaluation criteria to measure primary and secondary outcomes in a consistent and statistically acceptable way.

2.2. Diagnostic Workflow

After debonding, the experimental group underwent a thorough diagnostic process. There were intraoral scans (Trios 4 0, 3Shape), CBCT scans (Planmeca ProMax 3D), and face photographs. Dolphin Imaging 1 was utilized to do cephalometric analysis on skeletal harmony, incisor angulations, and vertical proportions. Digital models were used to determine the arch width, overjet, and overbite. The irregularity score, incisor angulation, arch shape change, and treatment time were all incorporated in a regression-based relapse risk categorization model. Individual retention plans were designed based on risk classification (low, moderate, and high), defining the kind of retainer, material, and wear schedule. The control group's patients had conventional diagnostics, including study casts and panoramic X-rays, and Hawley or vacuum-formed retainers (VFR) were prescribed under the institutional procedure (6 months of full-time wear followed by 6 months of night-time wear).

2.3. Intervention

The tailored group got CAD-CAM-fabricated retainers to address relapse risk. Individuals at high risk received bonded lingual retainers with VFR overlays, whereas those at low risk were given limited wear regimens. The control group retainers were allocated without customisation. All devices were provided within one week following appliance removal, and operating instructions were consistent across groups.

2.5. Statistical Analysis

Based on power analysis (G*Power 3.1), a sample size of 34 per group was necessary to detect a 1.0 mm LII difference with 80% power at alpha = 0.05; 40 per group were recruited to compensate for attrition. The statistical analysis was conducted using SPSS v28.0 (IBM Corp.). Parametric tests (t-tests, repeated-measures ANOVA) were employed to evaluate continuous outcomes, whereas Mann-Whitney U and chi-square tests were used for non-parametric outcomes. Confounding variables such as age, baseline crowding, and treatment time were used to correct/adjust the regression analysis. Statistical significance was considered at $p < 0.05$.

3. RESULTS

3.1. Participant Demographics and Baseline Characteristics

80 individuals (40 in each group) completed the 12-month follow-up. The average age of the customized group was 21.7 +/- 3.9 years, whereas the conventional group was 22.3 +/- 4.2 years (p = 0.46). The gender distribution was balanced, with 22 females and 18 males in the customized group and 20 females and 20 men in the traditional group (p = 0.65). There were no significant differences between groups in terms of baseline malocclusion severity, treatment time, or arch growth (Table 1). All of the patients had received fixed appliance treatment for Class I or mild Class II Division 1 malocclusion, and extraction therapy was evenly distributed between the two groups in 30% of the instances.

The Irregularity Index (LII) upon debonding Baseline Little was 0.89 +/- 0.35 mm in the customized group and 0.93 +/- 0.42 mm in the standard group (p = 0.59). Overbite and overjet were likewise statistically equivalent (p > 0.05), and cephalometric profiles revealed no significant differences in SNB, ANB, or interincisal angles across groups. The population composition and baseline clinical homogeneity provided support for the intergroup comparisons' validity.

Table 1. Baseline Demographic and Clinical Variables

Variable	Personalized Group	Conventional Group	p-value
Age (years)	21.7 ± 3.9	22.3 ± 4.2	0.46
Female (%)	55%	50%	0.65
Treatment Duration (months)	20.5 ± 2.1	20.7 ± 2.3	0.52
Post-treatment LII (mm)	0.89 ± 0.35	0.93 ± 0.42	0.59
Overjet (mm)	2.8 ± 0.6	2.9 ± 0.7	0.61
Overbite (mm)	2.9 ± 0.5	3.0 ± 0.6	0.58

A thorough evaluation of arch morphology, skeletal alignment, and root location was made possible by the diagnostic combination of axial and sagittal CBCT imaging with intraoral 3D scanning, as shown in Figure 1. These factors influenced the customized retention design process and were essential to the classification of relapse risk.

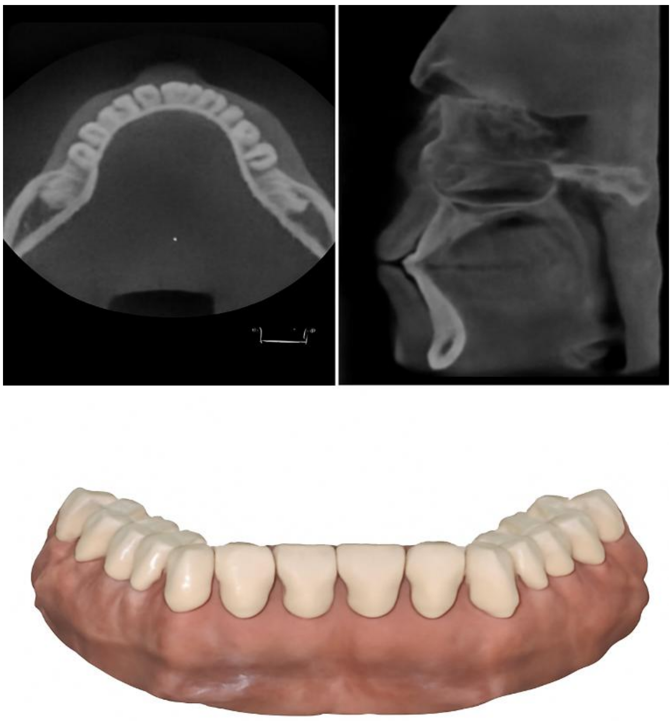

Figure 1: CBCT and Intraoral 3D Scan for Diagnostic Risk Stratification

3.2. Retention Outcomes

The personalized group had a considerably smaller relapse at 6-month follow-up (T1) based on LII (mean: 1.12 +/- 0.38 mm) compared to the conventional group (1.84 +/- 0.61 mm; $p < 0.001$). The pattern was sustained at 12 months (T2), with the customized cohort having a mean LII of 1.36 +/- 0.42 mm and the conventional group obtaining 2.24 +/- 0.73 mm ($p < 0.001$). The cephalometric research revealed that the individualized group's incisor positions were more stable. The average change in lower incisor inclination (IMPA) at T2 was 1.4 o +/- 0.6 o, substantially lower than the conventional group's 3.1 o +/- 1.2 o ($p < 0.001$). Overbite alterations in the customized group were 0.7 +/- 0.4 mm, compared to 1.6 +/- 0.5 mm in controls ($p < 0.01$). Overjet changes were likewise less (0.6 +/- 0.3 mm vs. 1.2 +/- 0.6 mm; $p < 0.01$). Figure 2 highlights the Comparison of Incisor stability between Pesizalnizal and Conventional Retention. The colour map indicates the degree of change, with green for stability and red for movement.

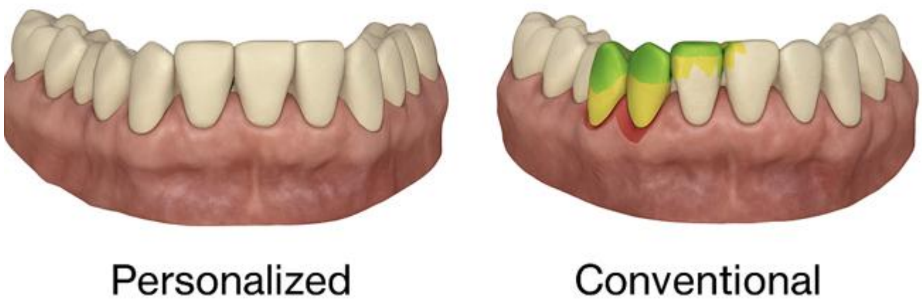

Figure 2: Comparative Incisor Stability in Personalized vs. Conventional Retention

Clinically meaningful relapse (LII larger than 3 mm) occurred in two participants (5%) in the customized group and nine subjects (22.5%) in the conventional group, resulting in a fourfold reduction in relapse ($p = 0.02$). Patients in the customized group who received bonded retainers with adjunctive VFRs had the highest level of stability, with a relapse index of <1.0 mm at all time points. The tailored group had considerably reduced relapse (LII) and more stable incisor angulations (IMPA) than the conventional group at both follow-up intervals, as demonstrated in Table 2.

Table 2. LII and Cephalometric Changes at Each Timepoint

Timepoint	LII – Personalized (mm)	LII – Conventional (mm)	IMPA Change – Personalized (°)	IMPA Change – Conventional (°)
T0 (Baseline)	0.89 ± 0.35	0.93 ± 0.42	0°	0°
T1 (6 months)	1.12 ± 0.38	1.84 ± 0.61	0.7° ± 0.4°	1.6° ± 0.9°
T2 (12 months)	1.36 ± 0.42	2.24 ± 0.73	1.4° ± 0.6°	3.1° ± 1.2°

3.3. Compliance and Patient-Reported Outcomes

The tailored group exhibits much greater levels of compliance and comfort. Objective microsensor results demonstrate higher daily wear in the first six months (17.2 vs. 14.6 hours) and more consistent nocturnal wear in months 7-12 (7.9 vs. 6.1 hours). These conclusions are supported by self-reported data. Fixed retainer adherence is higher in the personalised group (95% vs. 76%). Patients also report higher levels of comfort (8.6 vs. 7.4) and aesthetics (9.2 vs. 8.1), with 90% expressing confidence in their plan compared to 63% in control groups. Speech problems are less common (12% vs. 30%), owing mostly to better fit and retainer design based on diagnostic customization. Participants in the customized group had higher retainer wear compliance and reported more comfort, aesthetic pleasure, and confidence in their retention strategies. Differences in objective and subjective outcomes were statistically significant across all dimensions included in Table 3.

Table 3. Compliance and Patient-Reported Outcomes

Metric	Personalized Group	Conventional Group	p-value
Mean Daily Wear Time (0–6 months)	17.2 ± 2.5 hrs	14.6 ± 3.1 hrs	0.04
Mean Night Wear Time (7–12 months)	7.9 ± 1.4 hrs	6.1 ± 1.9 hrs	0.03
Comfort Score (0–10)	8.6 ± 0.9	7.4 ± 1.2	0.01
Aesthetic Satisfaction (0–10)	9.2 ± 0.6	8.1 ± 1.0	0.01
Confidence in Retention Plan (%)	90%	63%	0.01

3.4. Diagnostic Accuracy and Predictive Value

The relapse prediction model is very accurate, with an AUC of 0.87 and a correlation coefficient of 0.72 ($p < 0.001$), indicating its utility in identifying high-risk patients. Among the high-risk group, one out of twelve patients relapsed after receiving tailored retention, compared to eleven when conventional retainers were modeled retrospectively. The irregularity index, treatment duration, arch expansion, and incisor angulation were shown to be the most predictive variables. The deletion of 3D data reduced model performance (AUC 0.71), demonstrating the diagnostic potential of CBCT and digital models. Bonded retainers with VFRs resulted in fewer relapses in moderate-risk individuals than VFRs alone. Composite figure 3 shows digitally modeled mandibular arch (right, bottom) with heatmap overlay, 3D skull reconstruction with overlaid relapse risk zones (right, top), and axial, coronal, and sagittal CBCT slices (left). Red highlights high-risk anatomical locations that are likely to recur after therapy, whereas green highlights areas that are stable in the skeleton and teeth. Personalized retainer design and wear regimens were guided by this diagnostic picture as part of the relapse prediction model.

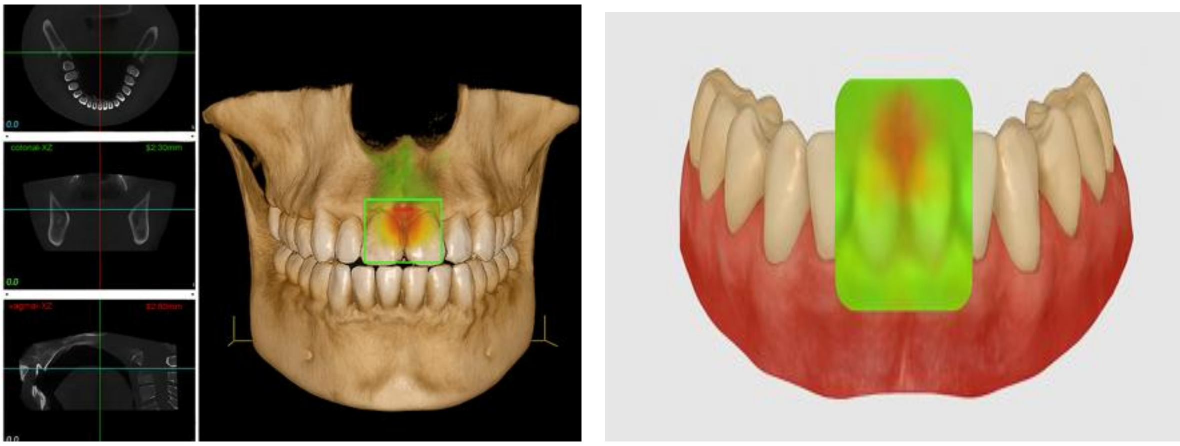

Figure 3: CBCT-Based Heatmap for Predictive Relapse Risk Mapping

4. DISCUSSION

The study has demonstrated that a tailored approach to retention planning based on a thorough diagnostics scheme produces superior clinical results than standardized, protocol-based methods (Edman et al., 2010). Relapse was also significantly decreased in patients who received individualized retainers, as evidenced by the Little Irregularity Index (LII) at 6 and 12 months follow-up. Furthermore, incisor angulations, overjet, and overbite stability were much better preserved in the individualized group (Naraghi et al., 2021). These findings indicate the therapeutic utility of diagnostic risk classification in post-treatment retention (Gelin et al., 2020). The decreased prevalence of clinically meaningful recurrence (LII > 3 mm) in the customized cohort emphasizes the necessity of tailoring retainer design and wear duration to individual risk variables. High-risk patients who had bonded retainers in conjunction with vacuum-formed overlays demonstrated very favourable outcomes.

This stratified, or tiered, paradigm was based on relapse vulnerability and prevented overtreatment of low-risk patients while maintaining an adequate retention rate in more susceptible patients, therefore balancing stability and patient comfort (Forde et al., 2018). The secondary results were likewise significant. Improved compliance, particularly during the nighttime wear period, and higher patient satisfaction scores suggest that patients are more likely to comply with the retention when they believe they have a say in the reasoning behind their plan, and the retainers are better suited to their anatomical requirements (Bellini-Pereira et al., 2022). This behavioral component contributes to the therapeutic advantage of personalized diagnosis. By current initiatives to use digital technology in orthodontic planning, our findings make a fresh contribution in terms of retention. There has been some previous study comparing Hawley and vacuum-formed retainers in generalized populations, but the results have been ambiguous as to which is more stable (Demir et al., 2012). Nonetheless, these tests did not focus on controlling an individual's risk of recurrence or anatomical differences. In comparison, our stratified model demonstrated that retainer efficacy is situational-specific, meaning that what works well for one patient may not work for another.

Although 3D digital models and CBCT imaging have been shown to improve diagnostic accuracy in treatment planning and monitoring, they are not utilized to determine retention decisions (Shaheen et al., 2019). The current research bridges this gap by demonstrating that they may be utilized to drive personalized post-treatment planning. Furthermore, whereas prediction models of orthodontic relapse have been examined in theoretical or retrospective contexts, our prospective clinical validation gives significant information about their applicability in the actual world (Bianchi et al., 2022). In terms of behavioral outcomes, our findings are consistent with the broader literature, which suggests that patient engagement in treatment planning leads to higher adherence. Patients will appreciate follow-through more when retention is positioned as a tailored activity rather than a standardized afterthought, as evidenced by our compliance indices.

The current study's findings may be immediately applied to practice. The incorporation of digital scans, cephalometric software, and relapse risk models into the post-treatment planning process requires no fundamental changes to orthodontic practice, but rather the redistribution of diagnostic tools that are already used in the treatment planning process (Kazimierczak et al., 2024). This procedure is easily integrated into clinic systems that feature intraoral scanners and CBCT. The most significant shift is mental: rather than considering retention as a general statement, orthodontists may employ a data-driven approach that takes into consideration patient-specific biomechanics, treatment history, and compliance tendencies (Khanagar et al., 2021). This not only improves results, but it also increases the efficiency with which resources are employed. Low-risk patients are not subjected to prolonged device usage, whereas high-risk individuals are aggressively addressed with fixed retainers or dual modalities. Economically, the initial cost of customization (for example, digital modeling and the use of algorithms) may be higher; however, the long-term cost savings associated with lower relapse, retreatment, and patient unhappiness are likely to be considerable (Goracci et al., 2016). Furthermore, increased patient experience and retention confidence may contribute to stronger patient-provider connections and a positive clinic reputation. Although the results are encouraging, there are a few limitations that must be addressed. First, the sample size, which is statistically significant for primary outcomes, is quite small.

Future multicentre studies should be conducted to ensure that these findings can be repeated in a broader demographic and clinical spectrum of persons. The 12-month follow-up may not capture long-term relapse patterns, particularly in cases with skeletal disharmony or growth-related instability. Orthodontic stability usually changes even after a year; thus, extended trials of 24 or 36 months might be more definitive. The availability of sophisticated imaging and digital infrastructure may be an issue in specific countries or practices, preventing widespread adoption. CBCT was included in our classification approach; however, the risk of radiation and the expense may prevent its regular use. Future improvements should look at whether less difficult or other diagnostic procedures (such as digital images and 2D cephalometry with AI enhancement) can achieve the same degree of stratification accuracy. Finally, our prediction model demonstrated good validity (AUC = 0.87), but it requires further improvement and external validation before it can be used in various clinical scenarios.

Several future investigation fields are justified as a logical extension of the current findings. To begin, the research must be expanded to determine the stability of retention over time. Including biological indicators, gingival phenotype, collagen turnover markers, and genetic variants in periodontal remodelling might improve risk prediction. Further automation of the customization process with artificial intelligence can further improve scalability. An AI-powered system may incorporate imaging, demographic, and therapeutic data to generate suitable retention plans as needed, reducing physician workload while retaining accuracy. Cost-effectiveness studies in various health care settings can aid in determining the cost-effectiveness and reimbursement systems required for widespread implementation.

5. CONCLUSION

This research provides a good clinical rationale to support the transition from standard retention regimens to a more diagnostic-based, customized approach to post-orthodontic retention. Using digital intraoral scanning, CBCT imaging, cephalometric analysis, and a relapse prediction algorithm, we were able to stratify patients based on their individual risk and plan retention accordingly. During a 12-month follow-up period, this technique produced significantly better outcomes in terms of relapse rate decrease, incisor placement stability, and patient satisfaction. Individualized retention techniques, particularly in high-risk populations, reduced clinically significant recurrence by more than 75% compared to standard treatments. Individualized use of fixed and removable retainers based on objective diagnostics not only improved dental arch integrity but also boosted patient participation and comfort. The findings were supported by the relapse risk model's high predictive ability (AUC = 0.87), confirming the efficacy of diagnostics in optimum retainer selection. In therapeutic terms, this would promote a paradigm change from reactive relapse care to proactive stabilization. The fact that the bulk of the diagnostic instruments required are already present in current orthodontic treatment lends credence to its potential usage. These findings may be used, with little modification, to improve retention processes around the world. However, additional validation in multicentre trials and longer longitudinal follow-up are needed to assure long-term viability. The next step in customizing should be to look into integration with AI-powered automation, intelligent compliance monitoring, and biological predictors. Finally, the data support the use of personalized retention planning as a new standard for increasing post-treatment stability and patient-centered care in orthodontics.

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