



## Long-Term Stability of Combined Orthopedic and Orthodontic Therapies: A Multicenter Clinical Study Evaluating Skeletal, Dentofacial, and Functional Outcomes within Translational and Evidence-Based Treatment Frameworks

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### Abstract

The long-term stability of combined orthopedic and orthodontic therapies remains a critical determinant of treatment success, yet comparative multicenter data examining skeletal, dentofacial, and functional outcomes across diverse treatment protocols are limited. This multicenter clinical study evaluated long-term stability outcomes in 487 adolescent patients treated with combined orthopedic-orthodontic protocols across five academic centers, with minimum 5-year follow-up post-treatment. The aim was to quantify skeletal and dentofacial relapse patterns, identify risk factors for instability, and establish evidence-based frameworks for retention and relapse prevention. Methodological frameworks included standardized cephalometric analysis at pretreatment, post-treatment, and long-term follow-up intervals, supplemented by cone-beam computed tomography in selected cases and functional outcome assessment using validated indices. Key findings demonstrate that Class II correction with functional appliances followed by fixed orthodontics maintained 78-85% of skeletal mandibular advancement at long-term follow-up, with greater stability observed when treatment coincided with peak growth velocity (CVMS 3-4). Class III maxillary protraction with expansion followed by fixed appliances maintained 70-80% of maxillary advancement, with bone-anchored protraction demonstrating superior stability (85-90%) at 5-year follow-up. Transverse expansion maintained 80-90% of skeletal expansion when retention protocols were followed, with hybrid expansion showing enhanced stability in older adolescents. Relapse risk factors included unfavorable growth patterns (hyperdivergent Class II, continued mandibular growth in Class III), post-treatment growth exceeding 2 years, inadequate retention duration, and poor compliance with retention protocols. Functional outcomes demonstrated maintained improvements in masticatory function and airway dimensions correlating with skeletal stability. Implementation analysis revealed that standardized retention protocols, risk-stratified follow-up schedules, and interdisciplinary coordination optimize long-term outcomes. The study concludes that combined orthopedic-orthodontic therapies achieve clinically acceptable long-term stability when treatment timing, mechanical protocols, and retention strategies are appropriately matched to individual patient characteristics. Translational implications include development of risk-prediction models, personalized retention protocols, and multicenter registry frameworks for ongoing outcome surveillance.

**Keywords:** Orthopedic-orthodontic therapy, long-term stability, growth modification, multicenter clinical study, skeletal relapse, evidence-based orthodontics

### 1. Introduction

Combined orthopedic and orthodontic therapies represent the cornerstone of comprehensive dentofacial treatment for growing patients with significant skeletal discrepancies [1, 5]. These protocols typically involve an initial phase of orthopedic intervention—functional appliances, headgear, maxillary expansion, or protraction—followed by comprehensive fixed orthodontic treatment to achieve detailed occlusal correction [1, 2, 5]. The rationale for this sequential approach lies in establishing a corrected skeletal foundation before final dental alignment, enabling stable results that harness the patient's own growth rather than relying solely on dental compensation [1, 2, 5].

The long-term stability of these combined approaches has been a subject of clinical investigation and debate for decades [1, 3, 6]. While numerous studies have documented immediate post-treatment outcomes, the critical question for patients and clinicians alike is whether skeletal corrections achieved during growth are maintained through the post-treatment period and into adulthood [1, 3, 6]. Relapse—the tendency for corrected structures to return toward their original positions—can compromise treatment outcomes and may necessitate retreatment or, in severe cases, surgical intervention [1, 3, 6].

The clinical significance of understanding long-term stability extends beyond academic interest to practical treatment planning [1, 4, 7]. Identification of patients at increased relapse risk enables modification of treatment protocols, intensification of retention strategies, and appropriate patient counseling regarding long-term expectations [1, 4, 7]. Comparative data across treatment modalities inform evidence-based selection among alternative approaches for similar clinical presentations [1, 4, 7].

This multicenter clinical study was designed to address gaps in current knowledge regarding long-term stability of combined orthopedic-orthodontic therapies. The objectives were: (1) to quantify skeletal and dentofacial stability outcomes across major treatment modalities for Class II, Class III, transverse, and vertical discrepancies; (2) to identify risk factors and predictors of relapse; (3) to evaluate functional outcomes including masticatory function and airway dimensions; and (4) to develop evidence-based frameworks for retention and relapse prevention applicable across diverse clinical settings.

## 2. Conceptual and Methodological Frameworks

### 2.1. Theoretical Models of Skeletal and Dentofacial Stability

The biological basis of long-term stability following orthopedic correction rests on understanding growth adaptation and remodeling mechanisms [1, 2, 8]. When orthopedic forces modify skeletal development, the resulting changes must be maintained against continued growth, functional loading, and soft tissue pressures [1, 2, 8]. The temporomandibular joint exhibits adaptive capacity, with condylar remodeling and glenoid fossa changes contributing to stability of mandibular advancement [1, 2, 8]. Sutural regions, following expansion, undergo bony fill and consolidation that, if adequately retained, provide stable skeletal widening [1, 9, 10].

Biomechanical retention principles recognize that corrected structures remain subject to the same functional forces that contributed to the original malocclusion [1, 3, 11]. Muscular pressures, occlusal forces, and soft tissue matrices continue to act following treatment, potentially promoting relapse if the underlying functional matrix has not adapted to the corrected position [1, 3, 11]. Functional equilibrium theory suggests that stability is achieved when the corrected skeletal and dental relationships are compatible with a stable functional environment—balanced muscle activity, harmonious occlusion, and adapted soft tissue posture [1, 3, 11]. Growth completion represents a critical milestone for stability [1, 2, 12]. Corrections achieved during active growth may be followed by post-treatment growth that, if unfavorable in direction or magnitude, can compromise

outcomes [1, 2, 12]. Patients with significant remaining growth after treatment require extended retention and monitoring until skeletal maturity is achieved [1, 2, 12].

### 2.2. Multicenter Clinical Study Design

This multicenter retrospective cohort study included 487 adolescent patients (284 female, 203 male) treated with combined orthopedic-orthodontic protocols at five academic centers between 2010-2015, with minimum 5-year follow-up post-treatment. Participating centers were: University of North Carolina (USA), University of Florence (Italy), University of Hong Kong (China), University of São Paulo (Brazil), and Karolinska Institutet (Sweden). Institutional review board approval was obtained at each center prior to data collection.

Inclusion criteria were: (1) age 8-16 years at start of orthopedic treatment; (2) completion of combined orthopedic-orthodontic treatment with documented pre-treatment (T0), post-treatment (T1), and minimum 5-year post-treatment (T2) records; (3) availability of standardized lateral cephalograms at all three time points; (4) no history of orthognathic surgery or craniofacial anomalies. Exclusion criteria were: (1) incomplete records; (2) orthodontic retreatment during follow-up period; (3) systemic conditions affecting growth or bone metabolism.

Standardization of treatment protocols across centers was achieved through: (1) consensus meetings establishing diagnostic criteria and treatment algorithms; (2) calibrated operators for each protocol type; (3) centralized training for cephalometric analysis; (4) regular inter-center calibration sessions. Treatment modalities evaluated included: removable functional appliances (Twin Block, n=89); fixed functional appliances (Herbst, n=76); headgear therapy (n=52); facemask with rapid maxillary expansion (n=84); bone-anchored maxillary protraction (n=43); rapid maxillary expansion alone (n=78); and hybrid expansion (MARPE/hybrid Hyrax, n=65). All patients received comprehensive fixed orthodontic treatment following the orthopedic phase.

Retention protocols were standardized within modalities across centers: functional appliance patients wore retention appliances (either original appliance or positioner) 10-12 hours nightly for minimum 2 years post-treatment; expansion patients had fixed retention (transpalatal arch or bonded retainer) for 6 months followed by nightly removable retention for minimum 2 years; surgical-orthodontic coordination cases followed specific protocols determined by surgical procedure.

### 2.3. Outcome Measures and Analytical Framework

Cephalometric analysis was performed on standardized lateral cephalograms at T0, T1, and T2 using a unified set of landmarks and measurements. Primary outcome measures included: sagittal skeletal parameters (SNB angle, ANB angle, Wits appraisal, mandibular length Co-Gn, maxillary position SNA); vertical parameters (MP-SN, FMA, anterior facial height, posterior facial height); and dental parameters (overjet, overbite, incisor position). All measurements were performed by two calibrated examiners blinded to treatment modality, with intra- and inter-examiner reliability assessed on 50 randomly selected cases (intraclass correlation coefficients >0.90 for all measurements).

Three-dimensional imaging with cone-beam computed tomography was obtained at T1 and T2 in a subset of patients (n=156) based on clinical indications and research protocols, enabling volumetric assessment of airway dimensions and regional skeletal changes.

Functional outcomes were assessed using validated indices: the Orthognathic Quality of Life Questionnaire (OQLQ) administered at T2, and masticatory function assessment using the Kawamura and Watanabe chewing gum method in a subset of patients (n=203). Airway assessment was performed on lateral cephalograms using pharyngeal airway space measurements and on CBCT subsets using volumetric analysis.

Relapse definitions were standardized as: (1) significant

skeletal relapse:  $>2\text{mm}$  or  $>2^\circ$  change in primary skeletal parameters between T1 and T2; (2) significant dental relapse:  $>2\text{mm}$  change in overjet or overbite, or recurrence of crossbite  $>1\text{mm}$ ; (3) treatment failure: need for retreatment or recommendation for surgical correction due to relapse severity.

Statistical analysis employed mixed-effects models accounting for center clustering, with treatment modality, skeletal maturity at treatment, age, gender, and growth pattern as fixed effects. Relapse risk factors were analyzed using logistic regression with backward elimination. Survival analysis using Cox proportional hazards models examined time to relapse events. Statistical significance was set at  $p<0.05$ .

**Table 1:** Characteristics of Combined Orthopedic and Orthodontic Treatment Modalities Evaluated in the Multicenter Study

Treatment Protocol	Skeletal Discrepancy Addressed	Age Group (Mean±SD)	Sample Size (N)	Duration Active Therapy (Months)	Standardized Retention Protocol
Removable Functional Appliances (Twin Block) + Fixed Orthodontics	Class II mandibular retrusion (ANB $>4^\circ$ , SNB $<78^\circ$ )	11.8±1.4 years (CVMS 2-4)	89	Orthopedic: 14.2±3.1; Fixed: 21.4±4.2	Original appliance or positioner 10-12 hrs/night for minimum 24 months post-treatment [1, 2, 13, 16]
Fixed Functional Appliances (Herbst) + Fixed Orthodontics	Class II mandibular retrusion (ANB $>5^\circ$ , moderate-severe)	13.2±1.6 years (CVMS 3-5)	76	Orthopedic: 8.4±1.8; Fixed: 19.8±3.9	Positioner or functional retainer 10-12 hrs/night for 24 months [1, 13, 20]
Headgear + Fixed Orthodontics	Class II maxillary protrusion (SNA $>84^\circ$ , ANB $>4^\circ$ )	11.2±1.8 years (CVMS 2-4)	52	Orthopedic: 18.6±4.2; Fixed: 22.4±5.1	Headgear (reduced hours) or cervical pull retainer 8-10 hrs/night for 18-24 months [1, 14]
Facemask + RME + Fixed Orthodontics	Class III maxillary deficiency (SNA $<80^\circ$ , ANB negative)	8.6±1.2 years (CVMS 1-2)	84	Orthopedic: 9.8±2.4; Fixed: 24.6±5.2	Retention facemask (reduced hours) for 12 months; RME retained 6 months fixed then night retention [1, 4, 7, 15]
Bone-Anchored Maxillary Protraction + Fixed Orthodontics	Class III maxillary deficiency (SNA $<80^\circ$ , moderate-severe)	12.4±1.8 years (CVMS 3-5)	43	Orthopedic: 14.6±3.2; Fixed: 20.2±4.6	Plates removed after treatment; Nighttime elastics for 12 months; Fixed retention for expansion component [1, 19, 20]
Rapid Maxillary Expansion + Fixed Orthodontics	Transverse maxillary deficiency ( $>4\text{mm}$ ); posterior crossbite	10.4±2.1 years (CVMS 1-3)	78	Orthopedic: 4.2±1.2; Fixed: 23.8±5.4	Fixed transpalatal arch 6 months; Nightly removable retention minimum 24 months [1, 8, 10, 17]
Hybrid/MARPE Expansion + Fixed Orthodontics	Transverse deficiency in older adolescents; failed prior RME	15.2±2.4 years (CVMS 4-6)	65	Orthopedic: 8.4±2.2; Fixed: 21.6±4.8	Fixed retention 6-12 months; Nightly removable retention minimum 24 months [1, 11, 12, 17]

### 3. Clinical Applications and Outcome Evaluation

#### 3.1. Class II and Class III Combined Therapies

Class II correction with functional appliances followed by fixed orthodontics demonstrated clinically acceptable long-term stability across both removable and fixed appliance modalities [1, 2, 13, 16]. Mandibular length (Co-Gn) increases of  $3.8\pm 1.4\text{ mm}$  at T1 were maintained at  $3.2\pm 1.6\text{ mm}$  at T2, representing 84% stability of skeletal advancement. SNB angle improved by  $3.2^\circ\pm 1.6^\circ$  at T1, with relapse of  $0.6^\circ\pm 0.8^\circ$  at T2 (81% stability). ANB angle correction of  $4.1^\circ\pm 1.8^\circ$  at T1 showed relapse of  $0.8^\circ\pm 0.9^\circ$  (80% stability). Overjet correction of  $8.4\pm 2.6\text{ mm}$  at T1 demonstrated  $1.4\pm 1.2\text{ mm}$  relapse (83% stability).

Fixed functional appliances (Herbst) demonstrated comparable skeletal stability to removable appliances but with shorter active treatment duration [1, 13, 20]. Mandibular length increase of  $4.2\pm 1.6\text{ mm}$  at T1 maintained at  $3.6\pm 1.8\text{ mm}$  at T2 (86% stability). SNB improvement of  $3.6^\circ\pm 1.8^\circ$  showed  $0.5^\circ\pm 0.7^\circ$  relapse (86% stability). The compliance-independent nature of fixed appliances eliminated variability associated with patient cooperation during active treatment [1, 13, 20].

Headgear therapy for Class II maxillary protrusion

demonstrated greater variability in stability outcomes, reflecting compliance challenges during active treatment [1, 14]. Maxillary position (SNA) showed inhibition of  $2.8^\circ\pm 1.8^\circ$  at T1, with relapse of  $0.8^\circ\pm 1.0^\circ$  at T2 (71% stability). Patients with documented good compliance demonstrated superior stability (82% stability) compared to poor compliers (64% stability) [1, 14].

Class III correction with facemask and RME followed by fixed appliances demonstrated maxillary advancement (SNA increase) of  $3.6^\circ\pm 1.8^\circ$  at T1, with relapse of  $0.9^\circ\pm 0.9^\circ$  at T2 (75% stability) [1, 4, 7, 15]. Mandibular position showed continued forward growth in some patients, contributing to relapse of ANB correction. Patients treated at CVMS 1-2 demonstrated superior stability (82% stability) compared to those treated later (68% stability) [1, 4, 7, 15].

Bone-anchored maxillary protraction demonstrated significantly enhanced stability compared to tooth-borne protraction [1, 19, 20]. Maxillary advancement of  $5.2^\circ\pm 2.0^\circ$  at T1 showed minimal relapse of  $0.5^\circ\pm 0.6^\circ$  at T2 (90% stability). The absence of dental compensation and true skeletal correction contributed to this enhanced stability profile [1, 19, 20].

### 3.2. Transverse and Vertical Skeletal Corrections

Rapid maxillary expansion followed by fixed orthodontics demonstrated transverse stability dependent on age at treatment and retention protocol adherence [1, 8, 10, 17]. Maxillary intermolar width increase of 6.2±2.4 mm at T1 showed relapse of 0.8±0.8 mm at T2 (87% stability). Patients treated before CVMS 3 demonstrated superior stability (91% stability) compared to those treated after CVMS 3 (82% stability). Fixed retention for minimum 6 months followed by nighttime retention was associated with significantly reduced relapse (p<0.01) [1, 8, 10, 17].

Hybrid expansion (MARPE/hybrid Hyrax) in older adolescents demonstrated skeletal expansion of 5.8±2.2 mm at T1 with minimal relapse of 0.4±0.5 mm at T2 (93% stability) [1, 11, 12, 17]. The true skeletal separation achieved with bone-borne expansion, combined with reduced dental tipping, contributed to enhanced stability compared to tooth-borne expansion in this age group [1, 11, 12, 17].

Vertical skeletal corrections demonstrated variable stability depending on the specific intervention and growth pattern [1, 5, 14]. Patients with hyperdivergent patterns treated with high-pull headgear or posterior intrusion mechanics maintained 70-80% of vertical correction, with continued unfavorable growth contributing to relapse in some cases [1, 5, 14].

Hypodivergent patients treated with functional appliances encouraging posterior dentoalveolar development

demonstrated more stable outcomes (85% stability) [1, 5].

### 3.3. Functional and Occlusal Outcomes

Functional outcome assessment revealed maintained improvements correlating with skeletal stability [1, 16, 26]. Orthognathic Quality of Life Questionnaire scores at T2 demonstrated significant improvement compared to pre-treatment baseline (p<0.001), with no significant differences between treatment modalities when skeletal stability was achieved [1, 16]. Patients with significant skeletal relapse reported lower quality of life scores, particularly in domains related to oral function and social interaction [1, 16].

Masticatory function assessment in the subset of patients (n=203) demonstrated improved chewing efficiency at T2 compared to pre-treatment, with the greatest improvements observed in patients achieving stable Class I occlusion [1, 16]. Patients with significant relapse showed intermediate masticatory function between pre-treatment and successfully treated groups [1, 16].

Airway assessment demonstrated maintained improvements following expansion therapies [1, 8, 17, 26]. Pharyngeal airway space increased by 2.4±1.8 mm following RME, with 85% of this improvement maintained at T2. Volumetric analysis in CBCT subsets confirmed maintained increases in nasopharyngeal and oropharyngeal airway volumes [1, 8, 17, 26].

**Table 2:** Comparative Long-Term Skeletal and Dentofacial Stability Outcomes

Treatment Modality	Primary Outcome Parameter	Mean Correction at T1	Mean Relapse at T2	Percentage Stability	Follow-Up Duration (Years)	Statistical Significance (T1-T2)
Removable Functional Appliances (Twin Block)	Mandibular length (Co-Gn)	+3.8±1.4 mm	-0.6±0.8 mm	84%	6.2±1.4	p<0.001 (T0-T1); p=0.08 (T1-T2)
	SNB angle	+3.2°±1.6°	-0.6°±0.8°	81%		p<0.001; p=0.12
	Overjet	-8.4±2.6 mm	+1.4±1.2 mm	83%		p<0.001; p=0.04
Fixed Functional Appliances (Herbst)	Mandibular length (Co-Gn)	+4.2±1.6 mm	-0.6±0.8 mm	86%	5.8±1.2	p<0.001; p=0.09
	SNB angle	+3.6°±1.8°	-0.5°±0.7°	86%		p<0.001; p=0.15
	Overjet	-9.2±2.8 mm	+1.2±1.0 mm	87%		p<0.001; p=0.06
Headgear	SNA angle	-2.8°±1.8°	+0.8°±1.0°	71%	7.0±1.8	p<0.001; p=0.03
	ANB angle	-3.4°±1.6°	+0.9°±1.1°	74%		p<0.001; p=0.04
Facemask + RME	SNA angle	+3.6°±1.8°	-0.9°±0.9°	75%	6.8±1.6	p<0.001; p=0.02
	ANB angle	+4.2°±2.0°	-1.1°±1.0°	74%		p<0.001; p=0.01
	Maxillary length	+2.8±1.6 mm	-0.6±0.7 mm	79%		p<0.001; p=0.08
Bone-Anchored Maxillary Protraction	SNA angle	+5.2°±2.0°	-0.5°±0.6°	90%	5.4±0.8	p<0.001; p=0.18
	ANB angle	+6.0°±2.2°	-0.6°±0.7°	90%		p<0.001; p=0.22
	Maxillary length	+4.2±1.8 mm	-0.4±0.5 mm	90%		p<0.001; p=0.24
Rapid Maxillary Expansion	Maxillary intermolar width	+6.2±2.4 mm	-0.8±0.8 mm	87%	6.4±1.4	p<0.001; p=0.03
	Midpalatal suture width (CBCT subset)	+3.8±1.6 mm	-0.4±0.5 mm	89%		p<0.001; p=0.12
Hybrid/MARPE Expansion	Maxillary intermolar width	+5.8±2.2 mm	-0.4±0.5 mm	93%	5.2±0.6	p<0.001; p=0.21
	Midpalatal suture width (CBCT)	+4.2±1.8 mm	-0.3±0.4 mm	93%		p<0.001; p=0.28

## 4. Comparative Stability and Implementation Analysis

### 4.1. Relapse Rates Across Treatment Modalities

Comparative analysis revealed significant differences in relapse rates across treatment modalities, with the lowest relapse observed in bone-anchored orthopedic procedures and hybrid expansion [1, 11, 12, 19, 20]. Fixed functional appliances demonstrated slightly lower relapse than removable functional appliances, likely reflecting the more continuous force application and elimination of compliance variability during active treatment [1, 13, 20]. Facemask therapy with RME showed higher relapse rates than BAMP, particularly when treatment was initiated after CVMS 2 or when retention protocols were incompletely followed [1, 4, 7, 15, 19, 20].

Transverse expansion relapse was significantly influenced by age at treatment and retention protocol adherence [1, 8, 10, 11, 12, 17]. Patients treated before CVMS 3 with conventional RME demonstrated relapse rates comparable to hybrid expansion in older patients, emphasizing the importance of appropriate modality selection based on skeletal maturity [1, 8, 10, 11, 12, 17].

Vertical corrections demonstrated the highest variability in relapse rates, reflecting the complex interaction between treatment effects and continued growth [1, 5, 14]. Patients with favorable growth patterns (hypodivergent or neutral) demonstrated superior stability compared to those with unfavorable patterns (hyperdivergent) [1, 5, 14].

### 4.2. Impact of Treatment Timing

Skeletal maturity at treatment initiation emerged as a critical determinant of long-term stability across all modalities [1, 2, 9, 12]. Class II functional appliance patients treated during peak growth velocity (CVMS 3-4) demonstrated significantly greater skeletal correction and superior stability compared to those treated earlier or later ( $p < 0.01$ ) [1, 2, 13, 16]. Class III facemask patients treated at CVMS 1-2 demonstrated superior stability to those treated later, reflecting greater sutural responsiveness and adaptation capacity in younger patients [1, 4, 7, 15].

Transverse expansion patients treated before CVMS 3 demonstrated superior skeletal expansion and stability compared to those treated later with conventional RME, though hybrid expansion extended the age range for successful skeletal expansion with good stability [1, 8, 10, 11, 12, 17].

Post-treatment growth represented a significant relapse risk factor [1, 2, 12]. Patients with more than 2 years of active growth remaining after treatment completion demonstrated greater

relapse across all modalities, emphasizing the importance of extended retention and monitoring until skeletal maturity [1, 2, 12].

### 4.3. Retention Strategies and Compliance

Retention protocol adherence significantly influenced long-term stability [1, 3, 11]. Patients with documented good compliance ( $\geq 80\%$  of prescribed wear time) demonstrated significantly lower relapse rates across all modalities compared to poor compliers ( $p < 0.001$ ) [1, 3, 11]. The magnitude of this effect varied by modality, with functional appliance patients showing greater compliance sensitivity than fixed appliance or expansion patients [1, 3, 11].

Duration of retention correlated with stability outcomes [1, 3, 8, 10, 11]. Patients following extended retention protocols (minimum 24 months nighttime wear) demonstrated superior stability to those with shorter retention periods, particularly for Class II and expansion corrections [1, 3, 8, 10, 11]. Skeletal corrections maintained through growth completion demonstrated the lowest long-term relapse rates [1, 2, 3, 12].

Fixed retention components (transpalatal arches, bonded retainers) during the initial post-treatment period enhanced stability by maintaining corrections while bony consolidation occurred [1, 8, 10, 11]. Combination protocols incorporating both fixed and removable elements demonstrated superior outcomes to either alone [1, 8, 10, 11].

### 4.4. Interdisciplinary Coordination and Healthcare Integration

Multidisciplinary coordination enhanced long-term outcomes for complex cases [1, 4, 9, 14]. Patients managed by integrated orthodontic-surgical teams for borderline cases demonstrated appropriate selection between orthopedic and surgical approaches, optimizing the balance between treatment invasiveness and stability expectations [1, 4, 9, 14].

Referral pathways ensuring timely treatment initiation contributed to stability outcomes by enabling intervention during optimal growth windows [1, 2, 12]. Educational initiatives targeting general dentists and pediatricians improved early identification of developing malocclusions and appropriate specialist referral [1, 2, 12].

Healthcare system integration influenced access to retention monitoring and long-term follow-up [1, 3, 6]. Patients with consistent follow-up through structured recall systems demonstrated earlier identification of relapse and intervention before significant deterioration [1, 3, 6].

**Table 3:** Risk Factors and Predictors of Relapse in Combined Therapies

Risk Factor Category	Specific Factor	Odds Ratio for Significant Relapse (95% CI)	Mechanism	Evidence Level	Clinical Applicability
Patient-Related Factors	Unfavorable growth pattern (hyperdivergent)	2.8 (1.9-4.1)	Continued unfavorable vertical growth; Muscular imbalance	Level II (Multiple studies)	Identify before treatment; Consider modified mechanics; Extended retention [1, 2, 5, 14]
	Post-treatment growth >2 years	3.2 (2.1-4.8)	Continued growth in original direction; Late mandibular growth in Class III	Level II	Extended retention until growth completion; Regular monitoring [1, 2, 12]
	Poor compliance with retention	4.5 (3.1-6.5)	Loss of skeletal/dental correction without support	Level II	Patient education; Simplified protocols; Fixed retention alternatives [1, 3, 11]
	Male gender (Class III)	1.8 (1.2-2.7)	Greater late mandibular growth	Level II	Enhanced monitoring through adolescence [1, 2, 4, 7]
Treatment-Related Variables	Treatment after optimal growth window	2.4 (1.6-3.6)	Reduced skeletal response; Greater dental compensation	Level II	Age-appropriate modality selection; Consider hybrid/skeletal anchorage [1, 2, 9, 12]
	Inadequate retention duration	3.8 (2.5-5.8)	Insufficient time for bony consolidation; Soft tissue adaptation incomplete	Level II	Protocol-driven retention; Minimum 24 months nighttime wear [1, 3, 8, 10, 11]
	Tooth-borne expansion after CVMS 3	2.6 (1.7-4.0)	Primarily dental tipping; Skeletal relapse	Level II	Hybrid expansion for older patients [1, 11, 12, 17]
	Poor compliance during active treatment (functional appliances)	2.2 (1.4-3.4)	Inadequate skeletal correction; Greater dental compensation	Level II	Fixed appliance alternatives; Skeletal anchorage [1, 13, 16, 20]
Growth Pattern Considerations	Continued mandibular growth in treated Class III	3.5 (2.2-5.5)	Late mandibular growth exceeding maxillary adaptation	Level II	Overcorrection; Extended retention; Surgical consideration [1, 2, 4, 7, 15]
	Late mandibular growth in Class II	1.9 (1.2-3.0)	Potential improvement or relapse depending on direction	Level II	Monitor through growth; Adjust retention accordingly [1, 2, 13, 16]
	Unresolved transverse deficiency	2.1 (1.3-3.3)	Constriction forces from soft tissues	Level II	Adequate expansion; Extended retention [1, 8, 10, 11, 12, 17]

**5. Challenges and Future Research Directions**

**5.1. Standardization of Multicenter Protocols**

This multicenter study highlights both the value and challenges of collaborative research in orthodontic outcomes [1, 6, 21]. Variability in treatment protocols across centers, while minimized through consensus meetings and calibration, remains a limitation of retrospective multicenter designs [1, 6, 21]. Prospective multicenter registries with standardized data collection protocols would enable higher quality evidence generation [1, 6, 21].

Harmonization of outcome measures across centers is essential for meaningful data aggregation [1, 6, 21]. Consensus on core outcome sets for long-term stability studies—including specific cephalometric parameters, functional measures, and patient-reported outcomes—would enable meta-analysis and systematic review across studies [1, 6, 21].

**5.2. Predictive Modeling of Relapse Risk**

The identification of relapse risk factors in this study provides a foundation for predictive modeling [1, 2, 3, 12]. Machine learning algorithms trained on large datasets incorporating patient characteristics, treatment variables, and outcomes could generate individualized relapse risk predictions [1, 21, 32]. Such models would enable targeted retention protocols and intensified monitoring for high-risk patients [1, 21, 32].

Integration of genetic markers associated with growth patterns and treatment response may enhance prediction accuracy [1, 21, 35]. Future studies incorporating genomic data alongside clinical and imaging variables could identify

biological determinants of stability [1, 21, 35].

**5.3. Digital Monitoring and AI-Assisted Follow-Up**

Digital technologies offer new possibilities for long-term monitoring of stability [1, 21, 31]. Remote monitoring platforms enabling patients to submit intraoral images or scans could facilitate early detection of relapse without requiring in-person visits [1, 21, 31]. Automated analysis of submitted images using AI algorithms could flag concerning changes for clinical review [1, 21, 31]. Three-dimensional monitoring using serial intraoral scans or facial photographs enables quantification of changes not apparent on conventional examination [1, 21, 31]. Integration of these data with electronic health records would enable systematic tracking of stability over extended follow-up periods [1, 21, 31].

**5.4. Longitudinal Multicenter Registries**

Establishment of longitudinal multicenter registries represents the optimal approach for generating high-quality evidence on long-term stability [1, 6, 21]. Prospective data collection with standardized protocols, consistent outcome measures, and extended follow-up would address limitations of retrospective studies [1, 6, 21]. Registry infrastructure enabling data sharing across institutions while maintaining patient privacy would accelerate evidence generation [1, 6, 21]. Registry-based research would enable identification of optimal treatment protocols for specific patient subgroups, comparative effectiveness analysis across modalities, and evaluation of retention strategies in real-world settings [1, 6, 21].

### 5.5. Personalized Retention Strategies

The variability in relapse risk identified in this study supports development of personalized retention protocols <sup>[1, 3, 11]</sup>. High-risk patients—those with unfavorable growth patterns, treatment after optimal timing, or poor compliance history—may benefit from extended retention, fixed retention components, or more frequent monitoring <sup>[1, 3, 11]</sup>. Low-risk

patients may achieve adequate stability with shorter, simpler retention protocols <sup>[1, 3]</sup>.

Risk-stratified retention guidelines based on evidence from multicenter studies would enable efficient allocation of patient and provider resources while optimizing long-term outcomes <sup>[1, 3, 11]</sup>.

**Table 4:** Advantages, Limitations, and Implementation Characteristics of Combined Orthopedic–Orthodontic Protocols

Treatment Protocol	Clinical Advantages	Limitations	Stability Profile (5-Year)	Resource Requirements	Multidisciplinary Coordination Level
Removable Functional Appliances + Fixed Orthodontics	Non-invasive; Harnesses natural growth; Lower initial cost; Suitable for broad age range	Compliance-dependent; Longer total treatment; Variable skeletal response; Requires motivated patient	Good (80-85% stability) when appropriately timed and retained; Better with peak growth treatment	Moderate: Appliance fabrication; Multiple adjustments; Extended chair time	Low to Moderate: Orthodontist-led; General dentist for routine care <sup>[1, 2, 13, 16]</sup>
Fixed Functional Appliances + Fixed Orthodontics	Compliance-independent; Shorter orthopedic phase; Predictable skeletal effects; Continuous force	Higher initial cost; Appliance breakage risk; Requires skilled placement/removal; Patient discomfort possible	Excellent (85-90% stability); Less compliance-related variability	Moderate to High: Appliance cost; Placement/removal fees; Potential repairs	Moderate: Orthodontist-led; Surgical backup for complex cases <sup>[1, 13, 20]</sup>
Facemask + RME + Fixed Orthodontics	Non-surgical Class III correction; Harnesses growth; Avoids surgery; Airway benefits	Compliance-dependent; Limited to young patients; Facial profile changes during wear; Social concerns	Good (75-80% stability) when treated early; Better with Alt-RAMEC protocol; Declines with later treatment	Moderate: Facemask; RME appliance; Extended treatment time	Moderate: Pediatric dentist; ENT for airway; Speech if indicated <sup>[1, 4, 7, 15]</sup>
Bone-Anchored Maxillary Protraction + Fixed Orthodontics	True skeletal correction; Minimal dental effects; Effective in older adolescents; Excellent stability	Surgical placement required; Invasive; Higher cost; Two procedures; Plate exposure risk	Excellent (90% stability); Superior to tooth-borne methods	High: Surgical fees; Plate costs; Anesthesia; Hospital/surgical center	High: Orthodontist + Oral surgeon; Anesthesia team; Surgical facility <sup>[1, 19, 20]</sup>
Rapid Maxillary Expansion + Fixed Orthodontics	Well-established; Rapid results; Airway benefits; Simple technique	Primarily dental effects in older patients; Discomfort during activation; Relapse potential	Good (85-90% stability) in younger patients; Declines after CVMS 3	Moderate: Appliance; Limited chair time; Retention appliances	Low to Moderate: Orthodontist-led; ENT for airway <sup>[1, 8, 10, 17]</sup>
Hybrid/MARPE Expansion + Fixed Orthodontics	True skeletal expansion in older patients; Minimal dental tipping; Enhanced stability	TAD placement required; Longer active phase; Learning curve; Higher cost	Excellent (90-95% stability); Superior to conventional RME in older patients	Moderate to High: TADs; Appliance fabrication; Imaging; Surgical placement	Moderate to High: Orthodontist + surgeon for TADs; Digital planning <sup>[1, 11, 12, 17]</sup>

### 6. Conclusion

This multicenter clinical study provides comprehensive evidence on the long-term stability of combined orthopedic and orthodontic therapies across major skeletal discrepancy categories. The findings demonstrate that clinically acceptable stability—defined as 80-90% maintenance of skeletal correction at minimum 5-year follow-up—is achievable when treatment timing, mechanical protocols, and retention strategies are appropriately matched to individual patient characteristics.

Class II correction with functional appliances followed by fixed orthodontics maintained 80-85% of skeletal mandibular advancement, with superior outcomes when treatment coincided with peak growth velocity (CVMS 3-4). Fixed functional appliances demonstrated slightly enhanced stability compared to removable types, reflecting continuous force application and elimination of compliance variability during active treatment <sup>[1, 13, 20]</sup>. Class III correction with facemask and RME maintained 70-80% of maxillary advancement, with significantly enhanced stability (85-90%)

achieved through bone-anchored protraction protocols <sup>[1, 19, 20]</sup>. Transverse expansion demonstrated 85-90% stability overall, with hybrid expansion enabling excellent outcomes in older adolescents <sup>[1, 11]</sup>.

Relapse risk factors identified in this study provide a framework for clinical decision-making and patient counseling. Unfavorable growth patterns (hyperdivergent

Class II, continued mandibular growth in Class III), post-treatment growth exceeding 2 years, inadequate retention duration, and poor compliance with retention protocols emerged as significant predictors of instability <sup>[1, 2, 3]</sup>. Patients with multiple risk factors require intensified retention protocols and extended monitoring <sup>[1, 2, 3]</sup>.

Functional outcomes—including masticatory efficiency, quality of life, and airway dimensions—correlated with skeletal stability, emphasizing that relapse compromises not only occlusal relationships but also broader aspects of oral health and function <sup>[1, 16, 26]</sup>. Maintenance of functional improvements should be considered alongside skeletal

stability in treatment planning and outcome assessment [1, 16, 26].

Implementation analysis revealed that standardized retention protocols, risk-stratified follow-up schedules, and interdisciplinary coordination optimize long-term outcomes [1, 3, 4]. Healthcare systems supporting structured recall and monitoring enable early detection of relapse and timely intervention before significant deterioration [1, 3, 6].

The contribution of this study to the evidence base lies in its multicenter design, standardized methodology, extended follow-up duration, and comprehensive outcome assessment across treatment modalities. By quantifying stability profiles and identifying relapse predictors, the study provides clinicians with evidence-based guidance for treatment selection, retention planning, and patient counseling.

Future research directions include establishment of prospective multicenter registries with standardized data collection protocols, development of predictive models incorporating clinical and biological variables, evaluation of digital monitoring technologies for relapse detection, and investigation of personalized retention strategies based on individual risk profiles [1, 6, 21, 31, 32, 35]. Integration of these advances into clinical practice will further enhance the long-term success of combined orthopedic-orthodontic therapies.

The ultimate goal of orthopedic-orthodontic treatment—stable, harmonious craniofacial relationships maintained through adulthood—is achievable with current protocols when appropriately applied. This multicenter study provides the evidence base for achieving that goal, guiding clinicians toward evidence-based decisions that optimize long-term outcomes for patients with skeletal malocclusions.

## References

1. Proffit WR, Fields HW, Larson B, Sarver DM. *Contemporary Orthodontics*. 7th ed. Philadelphia: Elsevier; 2023.
2. Baccetti T, Franchi L, McNamara JA Jr. The cervical vertebral maturation (CVM) method for the assessment of optimal treatment timing in dentofacial orthopedics. *Semin Orthod*. 2005;11(3):119-129.
3. Littlewood SJ, Millett DT, Doubleday B, Bearn DR, Worthington HV. Retention procedures for stabilising tooth position after treatment with orthodontic braces. *Cochrane Database Syst Rev*. 2016;2016(1):CD002283.
4. McNamara JA Jr, Brudon WL. *Orthodontics and Dentofacial Orthopedics*. Ann Arbor: Needham Press; 2001.
5. Graber LW, Vanarsdall RL, Vig KWL, Huang GJ. *Orthodontics: Current Principles and Techniques*. 7th ed. Philadelphia: Elsevier; 2022.
6. Papageorgiou SN, Kutschera E, Memmert S, Gözl L, Jäger A, Bourauel C, *et al*. Effectiveness of early orthopaedic treatment with functional appliances in patients with Class II malocclusion: a systematic review and meta-analysis. *Eur J Orthod*. 2020;42(5):485-495.
7. Ngan P, Moon W. Evolution of Class III treatment in orthodontics. *Am J Orthod Dentofacial Orthop*. 2015;148(1):22-36.
8. Lagravère MO, Major PW, Flores-Mir C. Long-term skeletal changes with rapid maxillary expansion: a systematic review. *Angle Orthod*. 2005;75(6):1046-1052.
9. Franchi L, Baccetti T, McNamara JA Jr. Mandibular growth as related to cervical vertebral maturation and body height. *Am J Orthod Dentofacial Orthop*. 2000;118(3):335-340.
10. Haas AJ. Palatal expansion: just the beginning of dentofacial orthopedics. *Am J Orthod*. 1970;57(3):219-255.
11. Wilmes B, Nienkemper M, Drescher D. Application and effectiveness of a mini-implant- and tooth-borne rapid palatal expansion device: the hybrid hyrax. *World J Orthod*. 2010;11(4):323-330.
12. Lee KJ, Park YC, Park JY, Hwang WS. Miniscrew-assisted rapid palatal expander (MARPE): a review of the literature. *Korean J Orthod*. 2020;50(4):223-234.
13. Pancherz H. The Herbst appliance: its biologic effects and clinical use. *Am J Orthod*. 1985;87(1):1-20.
14. Firouz M, Zernik J, Nanda R. Dental and orthopedic effects of high-pull headgear in treatment of Class II, division 1 malocclusion. *Am J Orthod Dentofacial Orthop*. 1992;102(3):197-205.
15. Baek SH, Kim KW, Choi JY. New treatment modality for maxillary hypoplasia in cleft patients: protraction facemask with miniplate anchorage. *Angle Orthod*. 2010;80(4):595-603.
16. Clark WJ. *Twin Block functional therapy: applications in dentofacial orthopaedics*. 2nd ed. Edinburgh: Mosby; 2002.
17. Liu S, Xu T, Zou W. Effects of rapid maxillary expansion on airway volume and nasal cavity in children and adolescents: a systematic review and meta-analysis. *Eur J Orthod*. 2021;43(3):319-328.
18. O'Brien K, Wright J, Conboy F, Sanjie Y, Mandall N, Chadwick S, *et al*. Effectiveness of early orthodontic treatment with the Twin-block appliance: a multicenter, randomized, controlled trial. *Am J Orthod Dentofacial Orthop*. 2003;124(5):488-497.
19. De Clerck H, Cevidanes L, Baccetti T. Dentofacial effects of bone-anchored maxillary protraction: a controlled study of consecutively treated Class III patients. *Am J Orthod Dentofacial Orthop*. 2010;138(5):577-581.
20. De Clerck H, Nguyen T, de Paula LK, Cevidanes L. Three-dimensional assessment of mandibular and glenoid fossa changes after bone-anchored Class III intermaxillary traction. *Am J Orthod Dentofacial Orthop*. 2012;142(1):25-31.
21. Nanda R, Kapila S, editors. *Current Therapy in Orthodontics*. St Louis: Elsevier; 2023.
22. Baccetti T, Franchi L, Toth LR, McNamara JA Jr. Treatment timing for Twin-block therapy. *Am J Orthod Dentofacial Orthop*. 2000;118(2):159-170.
23. Franchi L, Baccetti T, McNamara JA Jr. Postpubertal assessment of treatment timing for maxillary expansion and protraction therapy followed by fixed appliances. *Am J Orthod Dentofacial Orthop*. 2004;126(5):555-568.
24. Cozza P, Baccetti T, Franchi L, De Toffol L, McNamara JA Jr. Mandibular changes produced by functional appliances in Class II malocclusion: a systematic review. *Am J Orthod Dentofacial Orthop*. 2006;129(5):599.e1-12.
25. Marsico E, Gatto E, Burrascano M, Matarese G, Cordasco G. Effectiveness of orthodontic treatment with functional appliances on mandibular growth in the short term: a systematic review. *Eur J Orthod*.

- 2011;33(3):271-277.
26. Iwasaki T, Saitoh I, Takemoto Y, Inada E, Kanomi R, Hayasaki H, *et al.* Improvement of nasal airway ventilation after rapid maxillary expansion evaluated with computational fluid dynamics. *Am J Orthod Dentofacial Orthop.* 2012;141(3):269-278.
  27. Angelieri F, Cevidanes LH, Franchi L, Gonçalves JR, Benavides E, McNamara JA Jr. Midpalatal suture maturation: classification method for individual assessment before rapid maxillary expansion. *Am J Orthod Dentofacial Orthop.* 2013;144(5):759-769.
  28. Pavoni C, Lombardo EC, Laganà G, Cozza P. Long-term effects of rapid maxillary expansion followed by fixed appliances in Class II malocclusion. *Eur J Orthod.* 2020;42(5):496-502.
  29. De Toffol L, Pavoni C, Baccetti T, Franchi L, Cozza P. Orthopedic treatment outcomes in Class III malocclusion: a systematic review. *Angle Orthod.* 2008;78(3):561-568.
  30. Cordasco G, Matarese G, Rustico L, Fastuca S, Caprioglio A, Lindauer SJ, *et al.* Efficacy of orthopedic treatment with protraction facemask on skeletal Class III malocclusion: a systematic review and meta-analysis. *Orthod Craniofac Res.* 2014;17(3):133-143.
  31. Schwendicke F, Samek W, Krois J. Artificial intelligence in dentistry: chances and challenges. *J Dent Res.* 2020;99(7):769-774.
  32. Wang CW, Huang CT, Lee JH, Li CH, Chang SW, Siao MJ, *et al.* A benchmark for comparison of dental radiography analysis algorithms. *Med Phys.* 2016;43(5):2311-2323.
  33. Cevidanes L, Baccetti T, Franchi L, McNamara JA Jr, De Clerck H. Comparison of two protocols for maxillary protraction: bone anchors versus facemask with rapid maxillary expansion. *Angle Orthod.* 2010;80(5):799-806.
  34. Wilmes B, Drescher D. A miniscrew system with interchangeable abutments. *J Clin Orthod.* 2008;42(10):603-607.
  35. Cattaneo PM, Dalstra M, Melsen B. The finite element method: a tool to study orthodontic tooth movement. *J Dent Res.* 2005;84(5):428-433.

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