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Original Research

Longitudinal study on the impact of orthodontic treatment timing on skeletal and dental development in adolescents

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ABSTRACT:
Objective: This longitudinal study aims to investigate the impact of orthodontic treatment timing on skeletal and dental development in adolescents. The study examines whether early, conventional, or late initiation of orthodontic treatment influences facial skeletal growth, dental alignment, occlusion stability, and treatment duration. **Materials and Methods:** A total of 300 adolescents, aged 10-15 years, were followed for five years. Participants were divided into three groups based on the timing of treatment initiation: early intervention (before peak pubertal growth), conventional intervention (during peak pubertal growth), and late intervention (after peak growth). Skeletal and dental development were measured using cephalometric radiographs, dental models, and clinical evaluations at baseline, during treatment, and after treatment. Key outcome measures included changes in skeletal growth, dental alignment (Peer Assessment Rating [PAR] index), treatment duration, and post-treatment occlusal stability. Data were analyzed using repeated-measures ANOVA to determine differences between the groups. **Results:** Early treatment resulted in significant skeletal improvements, particularly in Class II malocclusion correction (ANB angle reduction: 2.1°), mandibular growth (SNB angle increase: 1.8°), and improved maxillary alignment (SNA stabilization, $p < 0.05$). Conventional treatment achieved the highest reduction in dental malocclusion (PAR index reduced by 85%) with the shortest treatment duration (18.2 months). Late treatment, while effective in dental alignment (PAR reduced by 70%), required the longest treatment duration (24.5 months) and exhibited less skeletal adaptation. Post-treatment occlusion stability was highest in the early and conventional groups, with lower relapse rates compared to the late group (relapse rates: 8%, 10%, and 18%, respectively). **Conclusion:** The timing of orthodontic treatment significantly influences both skeletal and dental outcomes in adolescents. Early treatment maximizes skeletal changes, while conventional treatment offers the best balance between efficiency and dental alignment. Late interventions, although effective in correcting dental issues, require longer treatment times and are associated with a higher risk of relapse. Individualized treatment planning based on skeletal maturity is recommended for optimal outcomes.
Keywords: Orthodontic treatment timing, skeletal development, dental alignment, adolescents, occlusion stability, early intervention, cephalometric analysis.

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INTRODUCTION

Orthodontic treatment timing is a key determinant of clinical outcomes in managing malocclusions and promoting optimal skeletal and dental development in adolescents. Adolescence, particularly the pubertal growth spurt, is a period of rapid skeletal and dental maturation, making it a critical window for orthodontic intervention [1]. While orthodontic treatment can be successful at various stages of development, the timing of intervention is believed to have a significant impact on both skeletal and dental structures. Early treatment, initiated before the peak of the pubertal growth spurt, is often recommended to address skeletal discrepancies, particularly in patients with Class II malocclusions or mandibular retrognathia [2]. On the other hand, conventional treatment, typically initiated during peak growth, focuses on optimizing both skeletal and dental development. Late treatment, initiated after peak growth, primarily targets dental alignment and occlusion but may have limited effects on skeletal development [3].

Despite the clinical importance of treatment timing, there is ongoing debate about the optimal time to begin orthodontic interventions. Some studies advocate for early intervention to take advantage of active growth periods, while others suggest that conventional or late treatments can achieve comparable outcomes with shorter treatment durations [4]. However, few longitudinal studies have comprehensively compared the skeletal and dental outcomes of orthodontic treatments initiated at different stages of adolescent development [5-8].

The purpose of this longitudinal study is to evaluate the impact of orthodontic treatment timing on skeletal and dental development in adolescents. By comparing early, conventional, and late interventions, we aim to provide evidence-based insights into how the timing of treatment influences skeletal growth, dental alignment, and the stability of occlusion. Understanding these differences can guide clinicians in making individualized treatment plans that optimize long-term outcomes for patients.

MATERIALS AND METHODS

Study Design

This is a longitudinal, prospective cohort study conducted over a period of five years. The study was performed in three orthodontic clinics and followed a cohort of 300 adolescents who required orthodontic treatment. Ethical approval was obtained from the institutional review boards of the participating clinics, and informed consent was obtained from all patients and their guardians.

Patient Selection

Inclusion Criteria

- Adolescents aged 10 to 15 years requiring orthodontic treatment for malocclusion.
- Patients with Class I or Class II malocclusions, crowding, or mandibular retrognathia.
- No prior orthodontic treatment history.

Exclusion Criteria

- Patients with cleft lip, cleft palate, or other craniofacial anomalies.
- Systemic conditions affecting growth or dental development (e.g., endocrine disorders).
- Patients with poor compliance or unwillingness to participate in follow-up assessments.

Grouping Based on Treatment Timing

Patients were categorized into three groups based on the timing of their orthodontic treatment initiation:

1. Early Treatment Group (n = 100): Treatment initiated before peak pubertal growth (ages 10-12).
2. Conventional Treatment Group (n = 100): Treatment initiated during peak pubertal growth (ages 12-14).
3. Late Treatment Group (n = 100): Treatment initiated after peak pubertal growth (ages 14-15).

The timing of peak pubertal growth was estimated based on skeletal maturity indicators from hand-wrist radiographs and cephalometric analysis.

Data Collection

Data collection occurred at three key time points: baseline (before treatment), mid-treatment (at 12-18 months), and post-treatment (after the completion of orthodontic treatment). The following assessments were conducted at each time point:

Cephalometric Radiographs: Cephalometric analysis was performed to assess skeletal development, including mandibular length, maxillary growth, and the correction of skeletal discrepancies such as Class II malocclusion. Key parameters measured included SNA (maxillary protrusion), SNB (mandibular protrusion), and ANB (skeletal relationship).

Dental Models: Impressions were taken to create dental models for evaluating crowding, spacing, alignment, and occlusion. The Peer Assessment Rating (PAR) index was used to quantify malocclusion severity and the degree of dental alignment over time.

Clinical Evaluations: Periodic clinical evaluations were performed to assess treatment progress, monitor appliance compliance, and identify any potential complications.

Treatment Duration: The total duration of orthodontic treatment, from appliance placement to appliance removal, was recorded for each patient.

Outcome Measures

The primary outcome measures were changes in skeletal development and dental alignment. Secondary outcomes included treatment duration, stability of occlusion post-treatment, and the incidence of relapse.

- Skeletal Development: Measured through changes in cephalometric parameters, focusing on skeletal corrections such as the mandibular and maxillary relationship.

- Dental Alignment: Assessed by reductions in PAR index scores over time, indicating improvements in occlusion and alignment.
- Treatment Duration: Total time required to complete orthodontic treatment.
- Post-Treatment Stability: Evaluated based on relapse rates and the need for post-treatment retention adjustments.

Statistical Analysis

Repeated-measures analysis of variance (ANOVA) was used to assess changes in skeletal and dental outcomes across the three treatment groups. Post-hoc Tukey tests were conducted to identify specific differences between groups. A p-value <0.05 was considered statistically significant.

RESULTS

Patient Demographics and Baseline Characteristics

The baseline characteristics of the patients were well-matched across the three treatment groups: early, conventional, and late intervention. The mean age at baseline was 11.5 years for the early group, 13.2 years for the conventional group, and 14.5 years for the late group. Gender distribution was balanced across all groups. The incidence of Class II malocclusion, crowding, and mandibular retrognathia were similarly distributed among the groups, indicating that the initial conditions of the patients were comparable. These similarities allowed for a more direct comparison of outcomes based on the timing of orthodontic treatment. Table 1

Cephalometric Changes Across Treatment Groups

Significant differences in skeletal development were observed across the three groups. The early treatment group demonstrated the greatest improvement in skeletal measurements, particularly in the correction of Class II malocclusion (measured by the ANB angle), with an average reduction of 2.1°. This was statistically significant compared to the conventional and late groups, where ANB correction was less pronounced. Mandibular growth, as indicated by the SNB angle, was also significantly greater in the early treatment group (1.8° increase) compared to the conventional (1.3°) and late groups (0.3°). Maxillary alignment, measured by SNA, showed marginal improvements across all groups, with the early group showing slightly better outcomes. Table 2

Dental Alignment and Treatment Duration

In terms of dental alignment, the conventional treatment group showed the most efficient reduction in malocclusion severity, with an 85% reduction in PAR index scores from baseline. The early treatment group also demonstrated substantial improvement, but treatment duration was slightly longer. The late treatment group had the slowest progress in dental alignment, with a 70% reduction in PAR scores and the longest treatment duration (24.5 months). The differences in treatment duration were statistically significant, with the late group requiring 4-6 months more on average compared to the early and conventional groups. Table 3

Post-Treatment Stability

Post-treatment stability was assessed through occlusal relapse and retention requirements. Both the early and conventional groups exhibited greater long-term stability in occlusion, with only 8% and 10% of patients, respectively, experiencing relapse. The late treatment group had a higher relapse rate of 18%, and a greater percentage of these patients required adjustments in retention protocols post-treatment. These findings suggest that earlier treatment initiation results in more stable outcomes in the long term. Table 4

Table 1: Patient Demographics and Baseline Characteristics

Characteristic	Early Group (n = 100)	Conventional Group (n = 100)	Late Group (n = 100)
Mean Age (years)	11.5 ± 0.8	13.2 ± 0.9	14.5 ± 0.7
Gender (Male/Female) (%)	48% / 52%	50% / 50%	46% / 54%
Class II Malocclusion (%)	65%	62%	68%
Crowding (%)	55%	52%	60%
Mandibular Retrognathia (%)	48%	45%	50%

Table 2: Cephalometric Changes Across Treatment Groups

Cephalometric Parameter	Early Group	Conventional Group	Late Group	p-value
ANB (Class II Correction)	-2.1° ± 0.5	-1.5° ± 0.4	-0.5° ± 0.3	<0.05
SNB (Mandibular Growth)	+1.8° ± 0.6	+1.3° ± 0.5	+0.3° ± 0.2	<0.05
SNA (Maxillary Protrusion)	+0.5° ± 0.2	+0.3° ± 0.2	+0.1° ± 0.1	<0.05

Table 3: PAR Index Reduction and Treatment Duration Across Groups

Group	PAR Score Reduction (%)	Treatment Duration (Months)	p-value
Early Group	75%	20.3 ± 3.2	<0.05
Conventional Group	85%	18.2 ± 2.5	<0.05
Late Group	70%	24.5 ± 4.1	<0.05

Table 4: Post-Treatment Stability and Relapse Rates

Group	Relapse Rate (%)	Retention Adjustments Required (%)	p-value
Early Group	8%	12%	<0.05
Conventional Group	10%	15%	<0.05
Late Group	18%	22%	<0.05

DISCUSSION

Impact of Treatment Timing on Skeletal Development

This longitudinal study provides significant insights into the impact of orthodontic treatment timing on both skeletal and dental development in adolescents. The findings confirm that early orthodontic intervention, initiated before peak pubertal growth, has the greatest influence on skeletal development, particularly in addressing skeletal discrepancies like Class II malocclusions. As shown in **Table 2**, early treatment resulted in a significant reduction in the ANB angle, indicating improved mandibular advancement and better correction of skeletal Class II patterns. The increase in SNB values in the early group (+1.8°) suggests that initiating treatment during active growth periods allows for enhanced mandibular growth. These findings support the notion that early intervention takes advantage of the remaining pubertal growth, which facilitates skeletal remodeling and better overall structural outcomes [1,2].

In contrast, conventional treatment also yielded positive skeletal changes but to a lesser extent, while late treatment was associated with minimal skeletal improvement. Patients in the late group showed only a slight improvement in SNB and ANB angles, reflecting limited mandibular adaptation. This is likely due to the fact that by the time treatment was initiated, the pubertal growth spurt had already concluded, and skeletal structures had largely matured. As a result, the skeletal modifications in the late group were more constrained to dental changes, aligning with previous studies that indicate the skeletal response diminishes once the major growth phases are complete [3].

Dental Alignment and Treatment Efficiency

The conventional treatment group demonstrated the most efficient dental alignment, as indicated by the highest reduction in PAR index scores (85% reduction) and the shortest treatment duration (18.2 months), as shown in **Table 3**. This group benefited from being treated during the peak of pubertal growth, a period marked by high responsiveness of both skeletal and dental tissues. As the results suggest, this timing allows for optimal use of the body's natural growth processes, leading to faster tooth movement and alignment. The shorter treatment duration in the conventional group compared to the early and late groups further emphasizes that treating patients at the right developmental stage can minimize the total time required for orthodontic intervention while achieving desirable outcomes [4].

Interestingly, although the early group demonstrated significant skeletal improvements, the treatment duration was slightly longer (20.3 months) compared to the conventional group. This may be due to the need to maintain treatment through the pubertal growth spurt to fully capitalize on skeletal changes. While early intervention offers significant benefits in terms of skeletal adaptation, the extended treatment time reflects the challenge of managing patients who are still undergoing active growth. By contrast, the late treatment group required the longest treatment duration (24.5 months) and had slower progress in dental alignment. This supports the understanding that once growth has ceased, orthodontic treatment becomes primarily dental in nature, requiring more time and effort to achieve alignment due to reduced biological responsiveness in the absence of active growth [5].

Post-Treatment Stability and Relapse

One of the critical concerns in orthodontic treatment is post-treatment stability, particularly the risk of occlusal relapse. As shown in **Table 4**, patients in the early and conventional treatment groups exhibited greater stability in dental alignment post-treatment, with relapse rates of 8% and 10%, respectively. These groups had more stable occlusions, likely due to the better skeletal support and more favorable jaw relationships achieved during the treatment period. In addition, these patients required fewer retention adjustments, indicating that the structural changes were more stable in the long term. This aligns with the understanding that treatments initiated during periods of skeletal growth not only improve dental alignment but also provide a more stable foundation for the occlusion [6].

In contrast, the late treatment group had a higher relapse rate (18%), and a greater percentage of these patients required adjustments in their retention protocol post-treatment. This suggests that the lack of significant skeletal changes in the late group may have contributed to less stable occlusions, leading to a higher likelihood of relapse. Since treatment in the late group was primarily focused on dental alignment without significant skeletal correction, the teeth were more prone to shifting post-treatment due to the lack of skeletal adaptation. These findings highlight the importance of timing in orthodontic interventions, not just for achieving initial alignment but also for maintaining long-term stability [7-10].

Clinical Implications

The results of this study have important implications for orthodontic practice, particularly in determining the optimal timing for initiating treatment. Early treatment offers significant advantages in terms of skeletal development, making it particularly beneficial for patients with skeletal discrepancies such as Class II malocclusions or mandibular retrognathia. However, early treatment requires a longer treatment duration, which may be a consideration for both clinicians and patients. Conventional treatment appears to strike the best balance between efficiency and outcomes, offering optimal dental alignment and shorter treatment durations while still taking advantage of pubertal growth. For patients who seek treatment later, while dental alignment can be effectively achieved, the longer treatment times and higher relapse rates suggest that it may be less efficient and more prone to instability [8-10].

Ultimately, the decision on when to initiate orthodontic treatment should be individualized, taking into account the patient's skeletal maturity, dental needs, and the specific malocclusion being addressed. Clinicians should consider using skeletal maturity indicators, such as hand-wrist radiographs or cephalometric analysis, to guide treatment timing and optimize outcomes for each patient.

Limitations

While this study provides valuable insights, there are several limitations to consider. First, the study focused on adolescents aged 10-15 years, and the findings may not be directly applicable to younger children or adults. Additionally, while the study followed patients for five years, longer-term follow-up is necessary to assess whether these findings hold over decades. Another limitation is that compliance with retention protocols was self-reported, which may introduce bias in assessing relapse rates.

Future Directions

Further research is needed to evaluate the impact of orthodontic treatment timing on other outcomes, such as facial aesthetics, speech development, and overall quality of life. Future studies could also explore the cost-effectiveness of early, conventional, and late treatments, providing a comprehensive evaluation of the benefits and challenges of each approach. Additionally, investigations into emerging treatment modalities, such as accelerated orthodontics or new biomaterials, could offer new strategies for optimizing treatment efficiency and stability across different age groups.

CONCLUSION

This longitudinal study demonstrates that the timing of orthodontic treatment significantly influences both skeletal and dental outcomes in adolescents. Early intervention leads to the greatest skeletal changes, particularly in the correction of Class II malocclusions, while conventional treatment is the most efficient in terms of dental alignment and treatment duration. Late treatment, although effective in aligning teeth, requires longer treatment times and is associated with higher relapse rates. These findings emphasize the importance of individualized treatment planning based on skeletal maturity and highlight the critical role of timing in achieving stable, long-term orthodontic outcomes.

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