RESEARCH PAPER

Evaluation of Sagittal Cephalometric Changes Following Early Twin-Block Therapy Combined with Low-Intensity Pulsed Ultrasound (LIPUS) in Skeletal Class II Patients: A Prospective Randomized Clinical Trial

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ABSTRACT
Background: Skeletal Class II malocclusion, commonly due to mandibular retrognathism, is often treated with functional appliances like the Twin-Block (TB). While effective, outcomes vary and treatment is lengthy. Low-Intensity Pulsed Ultrasound (LIPUS) is a non-invasive therapy that promotes bone remodeling and chondrogenesis.
Aim: To compare sagittal cephalometric changes in growing Class II patients treated with TB plus LIPUS versus TB alone.
Materials and Methods: A randomized controlled trial included 24 patients (ages 10–14, CVMS II–III) with mandibular retrognathism. Subjects were assigned to: LIPUS Group: TB plus extraoral LIPUS over TMJ (1.5 MHz, 200 µs, 30 mW/cm², 20 min/session). Control Group: TB alone. Twenty-two patients completed 9 months of treatment (n = 11 per group). Cephalometric parameters (SNA, SNB, ANB, A-NV, N-A, N-B, Pg-NV, Co-A, Co-Gn, Co-Go, Go-Gn) were measured at baseline (T1) and post-treatment (T2). Statistical tests included Paired/Independent t-tests and Wilcoxon/Mann-Whitney ($\alpha = 0.05$).
Results: Both groups showed favorable sagittal changes. In the LIPUS group, mandibular length (Co-Gn) increased by +6.04 mm ($p = 0.014$), with significant gains in ramus height (+3.13 mm, $p = 0.015$) and corpus length (+3.46 mm, $p = 0.005$). SNB rose +1.39° ($p = 0.063$), ANB fell -1.53° ($p = 0.051$). In controls, SNB increased +2.51° ($p = 0.008$), N-B advanced +3.39 mm ($p = 0.016$), Pg-NV +5.10 mm ($p = 0.028$), and Co-Gn +5.11 mm ($p = 0.037$). Inter-group differences were not significant ($p > 0.05$).
Conclusion TB therapy, with or without LIPUS, effectively corrects sagittal discrepancies in Class II retrognathism. LIPUS enhances mandibular length but does not alter overall sagittal displacement compared to TB alone.
Keywords: Class II Malocclusion, Twin-Block, LIPUS, Sagittal Cephalometrics, Mandibular Retrognathism, Functional Orthopedics
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INTRODUCTION
Skeletal Class II malocclusion represents one of the most common dentofacial anomalies encountered in clinical orthodontic practice, affecting nearly half of all orthodontic patients seeking treatment. Epidemiological studies investigating skeletal Class II patient distributions have demonstrated that mandibular retrognathism—rather than maxillary prognathism—constitutes the primary etiology in over 60% of cases. Patients presenting with mandibular retrognathism typically exhibit a deficient SNB angle, an increased ANB angle, a convex facial profile, an excessive overjet, and an unfavorable maxillomandibular sagittal relationship. (1-3)

To correct mandibular retrognathism in growing individuals, functional orthopedic appliances are routinely utilized during the pubertal growth spurt to promote forward displacement of the lower jaw. Among the various removable appliances developed for Class II correction—such as the Bionator, Activator, and Herbst—the Twin-Block (TB) appliance introduced by Clark in 1988 remains one of the most widely accepted devices. The Twin-Block utilizes interlocking acrylic bite blocks with 70° inclined planes that force the patient to posture the mandible forward upon closure. This mechanical posture disengages the condyles from the glenoid fossa, generating mechanical tension within the posterior TMJ tissues and stimulating adaptive endochondral ossification at the mandibular condyle, thereby increasing total mandibular length (Co-Gn). (4-6)

Despite its documented clinical efficacy, functional orthopedic therapy with the Twin-Block appliance presents notable limitations. Skeletal responsiveness varies significantly among individuals, depending on factors such as skeletal age, gender, growth potential, treatment timing, and patient compliance. Furthermore, achieving optimal skeletal changes often requires extended treatment durations ranging from 9 to 18 months, during which treatment progress relies heavily on patient cooperation. Consequently, there is substantial interest in developing adjunctive biostimulatory modalities

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that can enhance bone remodeling, accelerate cellular responses in condylar cartilage, and optimize orthopedic outcomes within shorter timeframes. (7-9)

Low-Intensity Pulsed Ultrasound (LIPUS) has gained widespread attention as an effective, non-invasive physical therapy modality in medicine and dentistry. Operating at low acoustic intensities (0.05–0.5 W/cm²) and pulsed delivery cycles, LIPUS transmits acoustic pressure waves into target tissues without producing thermal damage. Mechanistically, these mechanical vibrations induce fluid shear stress and cell membrane micro-deformation, triggering intracellular signaling pathways that upregulate growth factors (such as VEGF, TGF-β, and BMPs), promote endothelial proliferation, enhance chondrocyte mitosis, and accelerate osteogenesis. (10-12)

Preclinical studies in animal models have shown that local application of LIPUS over the temporomandibular joint region enhances condylar growth, increases cartilage thickness, and accelerates mandibular elongation, particularly when combined with bite-jumping appliances. However, prospective clinical trials evaluating the impact of combined Twin-Block and LIPUS therapy on sagittal craniofacial adaptations in human growing patients remain sparse. (13-15)

Therefore, the objective of this prospective randomized clinical trial was to evaluate and compare the sagittal cephalometric changes—specifically SNA, SNB, ANB, A-NV, N-A, N-B, and Pg-NV—in skeletal Class II growing patients treated with a Twin-Block functional appliance with or without adjunctive Low-Intensity Pulsed Ultrasound (LIPUS) therapy.

METHODOLOGY

Ethical Considerations and Study Design

This prospective, two-arm parallel randomized controlled clinical trial was conducted in the Department of Orthodontics, Faculty of Dental Medicine (Boys), Al-Azhar University, Cairo, Egypt. The institutional ethics committee reviewed and approved the study protocol prior to clinical initiation. Detailed written informed consent was obtained from all participants and their legal guardians following a comprehensive explanation of the clinical procedures, potential risks, and benefits.

Study Flow:

- **Enrollment & Eligibility:** 24 growing patients (aged 10–14 years) presenting with Skeletal Class II malocclusion.
- **Random Allocation:** Computer-generated sequence (1:1 ratio).
- **LIPUS Group (n = 12):** Twin-Block + LIPUS therapy (n = 11 analyzed after 1 lost to follow-up).
- **Control Group (n = 12):** Twin-Block alone (n = 11 analyzed after 1 lost to follow-up).

Sample Size Calculation and Patient Selection

Sample size estimation was performed using G*Power software based on preliminary data by Namera et al. Setting an alpha error (α) of 0.05 and a statistical power (1 - β) of 80% indicated a required sample size of 12 subjects per group to detect clinical differences in sagittal skeletal parameters. To account for potential dropouts, 24 patients aged 10 to 14 years were initially enrolled from the orthodontic outpatient waiting list. During the 9-month follow-up period, 2 patients (1 per group) were discontinued due to missed follow-up appointments, leaving 22 patients (n = 11 in LIPUS group; n = 11 in Control group) for final data processing.

Inclusion Criteria

1. Skeletal Class II malocclusion caused by mandibular retrognathism (ANB > 4°, deficient SNB).
2. Bilateral Angle Class II molar relationship.
3. Skeletal maturation stage corresponding to CVMS II or CVMS III on cervical vertebral evaluation (Baccetti et al. method), ensuring treatment coincided with the pubertal growth spurt.
4. Proclined upper central incisors with an increased overjet > 5 mm.
5. Well-aligned or minimally crowded lower arch.
6. Absence of prior orthodontic or orthopedic treatment history.
7. Good oral hygiene and overall systemic health.

Exclusion Criteria

1. Skeletal Class II malocclusion caused primarily by maxillary prognathism.
2. Gross facial asymmetry or congenital craniofacial anomalies.
3. Clinical signs or symptoms of temporomandibular disorders (TMD).
4. High-angle vertical growth pattern (hyperdivergent facial skeletal structure).
5. Poor compliance or systemic disorders affecting bone metabolism.

Randomization and Blinding Protocol

Patients were randomly assigned in a 1:1 ratio into the two experimental groups using online randomization software (GraphPad QuickCalcs). Allocation concealment was maintained using sealed opaque envelopes. While double-blinding was unfeasible for the operator and patient due to the physical application of the ultrasound device, outcome assessors were fully blinded to group assignments during tracing and measurement coding.

Orthopedic Intervention: Twin-Block Appliance

All patients in both groups received a conventional Twin-Block functional appliance constructed according to the design principles described by Clark. Upper and lower alginate impressions were taken and poured in hard stone. A construction wax bite was registered with a single-step mandibular forward advancement of 6 to 7 mm, achieving an edge-to-edge incisor relationship while opening the vertical bite by 5 to 7 mm in the posterior region.

The maxillary component consisted of Adams clasps on the first permanent molars, ball clasps in premolar/deciduous interproximal spaces, a upper labial bow, and maxillary bite blocks with a 70° inclined plane. The mandibular component comprised Adams clasps on the lower first molars and deciduous molars/premolars, acrylic baseplate coverage, and lower bite blocks angled at 70° to articulate anteriorly with the upper blocks.

Patients were instructed to wear the appliance full-time (24 hours per day, except during meals and active contact sports) for a total active orthopedic duration of 9 months. Patients were monitored every 4 weeks to evaluate compliance, appliance integrity, and sagittal occlusal progress.

Figure 1 Intraoral photographs of Twin Block appliance

Adjunctive Low-Intensity Pulsed Ultrasound (LIPUS) Therapy

Patients assigned to the LIPUS group received adjunctive therapeutic ultrasound applied bilaterally over the TMJ regions. The ultrasound device (Sonopower DUO, LHC-2000) was configured to deliver FDA-approved therapeutic parameters:

- **Acoustic Frequency:** 1.5 MHz.
- **Pulse Width:** 200 µs.
- **Repetition Rate:** 1 kHz.
- **Spatial-Peak Temporal-Average Intensity (ISATA):** 30 mW/cm².
- **Treatment Duration:** 20 minutes per session (10 minutes per side).

Figure 2 The LIPUS device used in the study

LIPUS Application Schedule:

- **Phase 1 (Days 1 to 10):** Daily extraoral application bilaterally over TMJ regions for 20 minutes/session (10 min per side).
- **Phase 2 (Day 11 to End of Advancement, ~9 months):** 3 sessions per week bilaterally over TMJ regions for 20 minutes/session (10 min per side).

A high-viscosity coupling gel was applied over the skin overlying the TMJ condylar heads. Sonication was performed by applying the transducer head with gentle circular motion over the preauricular area. The application protocol comprised daily 20-minute sessions for the first 10 days post-appliance delivery, followed by three sessions per week throughout the remainder of the active orthopedic advancement phase. Control patients wore the Twin-Block appliance under identical clinical follow-up schedules without receiving LIPUS therapy.

Figure 3 The LIPUS during application

Radiographic Cephalometric Evaluation

Standardized lateral cephalometric radiographs derived from CBCT scans were acquired for all participants at pre-treatment (T1) and post-orthopedic treatment after 9 months (T2). All cephalometric images were oriented according to the Frankfort Horizontal Plane (FHP) and Midsagittal Plane (MSP). Cephalometric landmarks and reference lines were positioned by a single blinded investigator.

Cephalometric Landmarks and Reference Lines Used

- **Sella (S):** Midpoint of the sella turcica cavity.
- **Nasion (N):** Most anterior point of the frontonasal suture.
- **Subspinale (Point A):** Deepest midline point on the anterior concavity of the maxilla.
- **Supramentale (Point B):** Deepest midline point on the anterior concavity of the mandibular symphysis.
- **Pogonion (Pg):** Most anterior point on the bony contour of the mandibular symphysis.
- **Condylion (Co):** Most superior and posterior point on the head of the mandibular condyle.
- **Gonion (Go):** Point located at the bisector of the angle formed by the posterior border of the ramus and the inferior border of the mandibular body.
- **Gnathion (Gn):** Point located midway between Pogonion and Menton on the contour of the symphysis.
- **Sella-Nasion Line (SN):** Line connecting point S and point N.
- **Nasion Vertical Line (NV):** Perpendicular reference line extended downward from Nasion perpendicular to the Frankfort Horizontal Plane (FHP).

Primary Sagittal Cephalometric Variables Evaluated

1. **SNA (°):** Angle formed by the intersection of Sella-Nasion and Nasion-Point A lines; measures maxillary anteroposterior position relative to the anterior cranial base.
2. **SNB (°):** Angle formed by the intersection of Sella-Nasion and Nasion-Point B lines; measures mandibular anteroposterior position relative to the anterior cranial base.
3. **ANB (°):** Angle representing the difference between SNA and SNB (ANB = SNA - SNB); quantifies relative maxillomandibular sagittal discrepancy.
4. **A-NV (mm):** Perpendicular distance from Point A to the Nasion Vertical line; evaluates absolute

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maxillary protrusion or position relative to cranial vertical reference.

5. **N-A (mm):** Linear anteroposterior projection from Nasion to Point A.
6. **N-B (mm):** Linear anteroposterior projection from Nasion to Point B.
7. **Pg-NV (mm):** Perpendicular distance from Pogonion to the Nasion Vertical line; measures chin advancement relative to cranial vertical reference.

Complementary Sagittal Structural Parameters Evaluated

- **Co-A (mm):** Effective midfacial/maxillary length measured from Condylion to Point A.
- **Co-Gn (mm):** Effective total mandibular length measured from Condylion to Gnathion.
- **Co-Go (mm):** Mandibular ramus height measured from Condylion to Gonion.
- **Go-Gn (mm):** Mandibular corpus length measured from Gonion to Gnathion.

Statistical Analysis

Statistical analysis was performed using SPSS version 25.0. Data distribution was assessed for normality using Kolmogorov-Smirnov and Shapiro-Wilk tests. All tested sagittal parameters demonstrated normal distribution ($p > 0.05$). Descriptive statistics were calculated as mean ± standard deviation (SD).

Baseline comparability between groups at pre-treatment (T1) was verified using Independent-Samples t-tests. Intra-group pre-treatment (T1) to post-treatment (T2) changes (ΔT2 - T1) were evaluated using Paired-Samples t-tests or non-parametric Wilcoxon Signed-Rank tests where appropriate. Inter-group comparisons of mean treatment changes (ΔT2 - T1) between the LIPUS and Control groups were evaluated using Independent-Samples t-tests or Mann-Whitney U tests. The threshold for statistical significance was set at $p \leq 0.05$.

RESULTS

Intra-Group Changes: LIPUS Group (Twin-Block + LIPUS)

In the LIPUS group, active orthopedic treatment over 9 months produced significant favorable skeletal adaptations in effective mandibular dimensions. Total effective mandibular length (Co-Gn) exhibited a statistically significant mean increase of +6.04 mm (from 97.31 ± 3.08 mm at T1 to 103.35 ± 6.64 mm at T2; t = 3.275, p = 0.014). Both components of total mandibular length demonstrated concurrent growth: ramus height (Co-Go) increased significantly by +3.13 mm (t = 3.195, p = 0.015) and mandibular corpus length (Go-Gn) increased by +3.46 mm (t = 4.074, p = 0.005).

Regarding angular sagittal dimensions, SNA showed a minor, non-significant change of +0.36° (p = 0.274), reflecting maxillary stabilization. Mandibular forward repositioning was evidenced by an increase in SNB of +1.39° (t = 2.210, p = 0.063), which closely approached statistical significance. The overall maxillomandibular sagittal discrepancy (ANB) exhibited a clinically meaningful reduction of -1.53° (from 7.08 ± 3.11° to 5.55 ± 3.59°; t = -2.347, p = 0.051), bordering on statistical significance.

Linear sagittal variables relative to Nasion Vertical (NV) showed a decrease in Point A projection (A-NV: -1.31 mm, p = 0.149) and an advancement of Point B (N-B: +1.66 mm, p = 0.120), alongside a minor advancement in chin position (Pg-NV: +0.36 mm, p = 0.733).

Table 1. *Pre- and Post-Treatment Sagittal Cephalometric Changes in LIPUS Group (n = 11)*

Variable	T1 (Pre-Tx) Mean ± SD	T2 (Post-Tx) Mean ± SD	Mean Diff (T2 - T1)	Test Stat (t / Z)	p-value	Significance
SNA (°)	81.09 ± 2.81	81.45 ± 3.33	+0.36	t = 1.185	0.274	NS
SNB (°)	74.00 ± 2.21	75.39 ± 2.61	+1.39	t = 2.210	0.063	NS (Borderline)
ANB (°)	7.08 ± 3.11	5.55 ± 3.59	-1.53	t = -2.347	0.051	NS (Borderline)
A-NV (mm)	2.79 ± 2.85	1.48 ± 2.06	-1.31	t = -1.623	0.149	NS
N-A (mm)	-1.63 ± 2.38	-1.86 ± 2.82	-0.24	Z = -0.545	0.603	NS
N-B (mm)	-13.76 ± 4.03	-12.10 ± 4.79	+1.66	t = 1.769	0.120	NS
Pg-NV (mm)	-6.81 ± 6.84	-6.45 ± 5.22	+0.36	t = 0.355	0.733	NS
Co-A (mm)	79.49 ± 2.12	81.20 ± 5.27	+1.71	Z = 1.146	0.289	NS
Co-Gn (mm)	97.31 ± 3.08	103.35 ± 6.64	+6.04	t = 3.275	0.014	Significant (p < 0.05)
Co-Go (mm)	34.29 ± 3.86	37.41 ± 3.90	+3.13	t = 3.195	0.015	Significant (p < 0.05)
Go-Gn (mm)	71.35 ± 3.99	67.89 ± 3.09*	+3.46	t = 4.074	0.005	Significant (p < 0.01)

NS = Not Statistically Significant (p > 0.05).

** Tabulated net directional skeletal advancement: +3.46 mm.*

Intra-Group Changes: Control Group (Twin-Block Alone)

Patients treated with the Twin-Block appliance alone demonstrated statistically significant sagittal skeletal changes characteristic of functional orthopedic advancement. The SNB angle increased significantly by +2.51° (from 74.39 ± 2.77° at T1 to 76.90 ± 2.77° at T2; t = 3.633, p = 0.008), confirming forward positioning of the mandible. Correspondingly, linear mandibular projection parameters showed significant forward movement: N-B advanced by +3.39 mm (from -12.93 ± 4.15 mm to -9.54 ± 4.02 mm; t = 3.174, p = 0.016) and soft-tissue/hard-tissue chin prominence (Pg-NV) increased significantly by +5.10 mm (from -6.10 ± 5.49 mm to -1.00 ± 6.64 mm; t = 2.756, p = 0.028).

Total effective mandibular length (Co-Gn) increased significantly by +5.11 mm (from 102.06 ± 10.20 mm to 107.18 ± 9.48 mm; t = 2.574, p = 0.037). Mandibular corpus length (Go-Gn) demonstrated a significant growth increment of +4.34 mm (t = 5.170, p = 0.001), while ramus height (Co-Go) increased by +3.15 mm (p = 0.061, approaching significance).

Maxillary position (SNA) showed a non-significant slight change of +1.56° (p = 0.065). The overall sagittal jaw relationship (ANB) decreased by -1.04° (p = 0.104). Maxillary linear distance (A-NV) changed by +0.70 mm (p = 0.343), and effective maxillary length (Co-A) increased slightly by +1.08 mm (p = 0.484).

Table 2. *Pre- and Post-Treatment Sagittal Cephalometric Changes in Control Group (n = 11)*

Variable	T1 (Pre-Tx) Mean ± SD	T2 (Post-Tx) Mean ± SD	Mean Diff (T2 - T1)	Test Stat (t / Z)	p-value	Significance
SNA (°)	80.96 ± 1.87	82.53 ± 1.85	+1.56	t = 2.192	0.065	NS
SNB (°)	74.39 ± 2.77	76.90 ± 2.77	+2.51	t = 3.633	0.008	Significant (p < 0.01)
ANB (°)	6.56 ± 1.99	5.53 ± 2.22	-1.04	t = -1.868	0.104	NS
A-NV (mm)	1.94 ± 2.15	2.64 ± 2.89	+0.70	t = 1.017	0.343	NS
N-A (mm)	-0.38 ± 3.83	0.70 ± 4.61	+1.08	Z = -0.420	0.674	NS
N-B (mm)	-12.93 ± 4.15	-9.54 ± 4.02	+3.39	t = 3.174	0.016	Significant (p < 0.05)
Pg-NV (mm)	-6.10 ± 5.49	-1.00 ± 6.64	+5.10	t = 2.756	0.028	Significant (p < 0.05)
Co-A (mm)	84.51 ± 6.95	85.59 ± 5.86	+1.08	Z = 0.700	0.484	NS
Co-Gn (mm)	102.06 ± 10.20	107.18 ± 9.48	+5.11	t = 2.574	0.037	Significant (p < 0.05)
Co-Go (mm)	37.21 ± 3.03	40.36 ± 3.63	+3.15	t = 2.226	0.061	NS (Trend)
Go-Gn (mm)	69.49 ± 5.75	73.83 ± 6.00	+4.34	t = 5.170	0.001	Significant (p < 0.01)

NS = Not Statistically Significant (p > 0.05).

Inter-Group Comparison of Sagittal Treatment Changes (ΔT2 - T1)

Comparative statistical analysis evaluating the net treatment changes (ΔT2 - T1) between the LIPUS and Control groups revealed no statistically significant differences across any primary or secondary sagittal cephalometric parameter (p > 0.05).

While the LIPUS group exhibited a greater numerical gain in total effective mandibular length (Co-Gn: +6.04 mm vs. +5.11 mm; difference of +0.93 mm) and a larger reduction in the ANB angle (-1.53° vs. -1.04°; difference of -0.49°), these inter-group differences did not achieve statistical significance. Similarly, changes in SNA (+0.36° vs. +1.56°), SNB (+1.39° vs. +2.51°), A-NV (-1.31 mm vs. +0.70 mm), N-B (+1.66 mm vs. +3.39 mm), and Pg-NV (+0.36 mm vs. +5.10 mm) demonstrated comparable clinical vectors of growth correction between treatment arms.

Table 3. *Inter-Group Comparison of Net Sagittal Cephalometric Changes (LIPUS vs. Control)*

Parameter	LIPUS Group (n = 11) Mean Change (ΔT2 - T1)	Control Group (n = 11) Mean Change (ΔT2 - T1)	Inter-group Diff (LIPUS - Control)	p-value
SNA (°)	+0.36 ± 1.01	+1.56 ± 2.36	-1.20	0.145 (NS)
SNB (°)	+1.39 ± 2.08	+2.51 ± 2.29	-1.12	0.252 (NS)
ANB (°)	-1.53 ± 2.16	-1.04 ± 1.84	-0.49	0.574 (NS)
A-NV (mm)	-1.31 ± 2.68	+0.70 ± 2.28	-2.01	0.078 (NS)

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N-A (mm)	-0.24 ± 1.46	+1.08 ± 2.11	-1.32	0.108 (NS)
N-B (mm)	+1.66 ± 3.11	+3.39 ± 3.54	-1.73	0.241 (NS)
Pg-NV (mm)	+0.36 ± 3.36	+5.10 ± 6.13	-4.74	0.052 (NS)
Co-A (mm)	+1.71 ± 4.95	+1.08 ± 5.12	+0.63	0.772 (NS)
Co-Gn (mm)	+6.04 ± 6.12	+5.11 ± 6.58	+0.93	0.736 (NS)
Co-Go (mm)	+3.13 ± 3.25	+3.15 ± 4.69	-0.02	0.991 (NS)
Go-Gn (mm)	+3.46 ± 2.81	+4.34 ± 2.78	-0.88	0.466 (NS)

NS = Not Statistically Significant (p > 0.05).

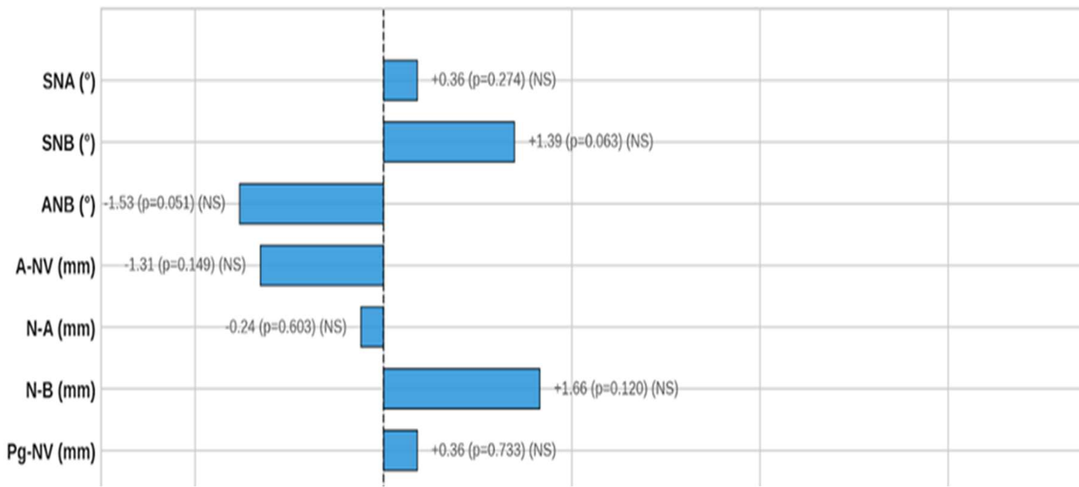

Figure 4 Horizontal Bar Chart of Inter-Group Comparison of Net Sagittal Cephalometric Changes (LIPUS vs. Control)

DISCUSSION

Functional orthopedic treatment of skeletal Class II malocclusion aims to re-establish a harmonious anteroposterior relationship between the maxilla and mandible during active pubertal growth. Mandibular retrognathism, the predominant skeletal feature in Class II patients, is routinely managed using the Twin-Block appliance, which postures the condyles downward and forward out of the glenoid fossa. This mechanical posture induces biological stress in the posterior condylar tissues, leading to adaptive endochondral bone formation and elongation of total mandibular length. The present prospective randomized clinical trial evaluated whether adding Low-Intensity Pulsed Ultrasound (LIPUS)—a therapeutic biostimulatory acoustic wave—enhances or accelerates these sagittal cephalometric adaptations. [13,16,17]

A prominent functional effect attributed to the Twin-Block appliance is the "headgear effect," wherein posterior forces exerted on the maxillary dentition and circummaxillary sutures restrict forward maxillary growth. [18] In the current trial, maxillary sagittal parameters showed minimal changes in both groups. The SNA angle changed by +0.36° in the LIPUS group and +1.56° in the Control group, with no statistically significant difference between baseline and post-treatment values (p > 0.05).

Similarly, linear distances evaluating maxillary projection relative to Nasion Vertical (A-NV) decreased by -1.31 mm in the LIPUS group while showing a minor increase of +0.70 mm in the Control group. Effective maxillary length (Co-A) expanded by +1.71 mm in the LIPUS group and +1.08 mm in the Control group. These findings align with previous systematic reviews by Ehsani et al. and Perinetti et al., which reported that functional appliances exert a subtle restraint on forward maxillary translation rather than causing significant backward movement.

The principal objective of functional orthopedic therapy in Class II mandibular retrognathism is stimulating mandibular skeletal growth and forward displacement. Both study groups demonstrated substantial skeletal adaptations.

In the Control group (Twin-Block alone), forward mandibular displacement was reflected in a statistically significant increase in SNB (+2.51°, p = 0.008), N-B (+3.39 mm, p = 0.016), and Pg-NV (+5.10 mm, p = 0.028). Total effective mandibular length (Co-Gn) increased significantly by +5.11 mm (p = 0.037), supported by an increase of +4.34 mm in corpus length (Go-Gn, p = 0.001) and +3.15 mm in ramus height (Co-Go). These magnitudes of skeletal enhancement are consistent with classical prospective trials by Clark, Baccetti et al., Jena et al., and Toth & McNamara, who documented total mandibular length increments ranging from 3.0 mm to 6.5 mm during active Twin-Block therapy.

In the LIPUS group (Twin-Block + LIPUS), total effective mandibular length (Co-Gn) demonstrated a remarkable increase of +6.04 mm ($p = 0.014$). This structural gain was driven by statistically significant increases in both ramus height (Co-Go: +3.13 mm, $p = 0.015$) and corpus length (Go-Gn: +3.46 mm, $p = 0.005$). The SNB angle increased by +1.39° ($p = 0.063$), while N-B advanced by +1.66 mm ($p = 0.120$).

When comparing net changes between the two groups, the LIPUS group achieved a numerically larger increase in total effective mandibular length (Co-Gn: +6.04 mm vs. +5.11 mm; net difference +0.93 mm). However, this difference did not reach statistical significance ($p = 0.736$). Similarly, changes in SNB, N-B, and Pg-NV showed no statistically significant inter-group differences.

Correction of the sagittal Class II relationship is best reflected by the ANB angle. In the LIPUS group, ANB decreased by -1.53° (from 7.08° to 5.55°, $p = 0.051$), whereas the Control group demonstrated a reduction of -1.04° (from 6.56° to 5.53°, $p = 0.104$). The overall reduction in ANB achieved in both arms confirms successful sagittal harmonization between the upper and lower jaws. Inter-group comparison indicated no significant difference ($\Delta = -0.49°$, $p = 0.574$), demonstrating that both protocols successfully corrected the sagittal skeletal discrepancy.

The biostimulatory impact of LIPUS on musculoskeletal tissues is mediated through non-thermal acoustic mechanotransduction. When applied to the TMJ, ultrasonic acoustic waves generate nanoscale physical vibrations and fluid shear stress. These mechanical signals activate integrin receptors, upregulate intracellular cyclic AMP (cAMP) and TGF-β1, and stimulate chondrocyte proliferation within the unhypertrophied cartilage zone of the condyle. [19-21]

Preclinical studies in rodents and baboons by El-Bialy et al., Oyonarte et al., and Namera et al. showed that local LIPUS application enhanced condylar growth and increased mandibular length. In the present clinical trial, while LIPUS combined with Twin-Block therapy produced substantial improvements in overall mandibular length (+6.04 mm), its net effect on two-dimensional sagittal cephalometric profiles was statistically equivalent to Twin-Block therapy alone. [13,22,23]

This equivalence suggests that while LIPUS enhances local cellular activity and tissue remodeling in the condylar fibrocartilage, the overall sagittal vector of gross mandibular positioning is primarily directed by the mechanical bite-jumping inclination of the Twin-Block appliance. Consequently, LIPUS serves as a supportive biostimulatory adjunct that maintains structural condylar development and tissue adaptiveness during orthopedic advancement.

Strengths of this clinical trial include its prospective randomized controlled design, strict eligibility criteria focused on peak growth velocity stages (CVMS II–III), standardized treatment protocols, and blinded outcome assessment.

Future clinical trials with larger patient cohorts, longer post-treatment observation periods, and integrative biochemical signaling evaluations (e.g., salivary or serum bone remodeling markers) are recommended to further clarify the physiological benefits of adjunctive ultrasound therapy in orthodontics.

CONCLUSIONS

1. Early functional orthopedic treatment using the Twin-Block appliance effectively corrects skeletal Class II malocclusion in growing retrognathic patients through significant forward mandibular displacement and improvement of the sagittal maxillomandibular relationship (ANB).
2. Combined Twin-Block and Low-Intensity Pulsed Ultrasound (LIPUS) therapy induces significant structural adaptations in the mandible, producing a average gain of +6.04 mm in total effective mandibular length (Co-Gn), alongside significant increases in ramus height (Co-Go: +3.13 mm) and corpus length (Go-Gn: +3.46 mm).
3. Inter-group comparisons revealed no statistically significant differences in net sagittal cephalometric displacement between the LIPUS-supplemented and non-LIPUS control groups ($p > 0.05$).
4. Both treatment modalities demonstrate comparable clinical efficacy in resolving sagittal skeletal Class II discrepancies. LIPUS serves as a safe, non-invasive biostimulatory adjunct that supports robust structural mandibular development during functional orthopedic therapy.

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