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Longitudinal CBCT evaluation of cervical vertebral adaptation following stabilization splint therapy and subsequent orthodontic treatment in temporomandibular disorders

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Article

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Abstract

This retrospective longitudinal cone-beam computed tomography (CBCT) study evaluated cervical vertebral adaptation following stabilization splint (SS) therapy and subsequent orthodontic treatment in 50 adults with skeletal Class II malocclusion and temporomandibular disorders (TMD). Of these, 25 received SS therapy followed by orthodontic treatment, whereas 25 underwent conservative non-splint management followed by orthodontic treatment. In the SS group, the OPT/CVT angle decreased by 3.24° after SS therapy ($P < 0.001$), with significant changes also observed in SNL–OPT, SNL–CVT, the C2–C5 Cobb angle, and C1–C2 distance. These changes were largely maintained after orthodontic treatment. The comparison group showed no significant longitudinal changes in the 15 cervical measurements. Baseline-adjusted treatment-pathway analysis showed lower final OPT/CVT and C2–C5 Cobb angle values in the SS-plus-orthodontic group. These findings indicate that measurable craniocervical adaptations occurred predominantly during SS therapy and were largely maintained during subsequent orthodontic treatment. Prospective multicenter studies are needed to establish causality and long-term clinical significance.

Introduction

Temporomandibular disorders (TMD) comprise a heterogeneous group of musculoskeletal conditions affecting the temporomandibular joints (TMJs), masticatory muscles, and associated structures. They are among the most common causes of non-dental orofacial pain and typically present with temporomandibular-region pain, masticatory muscle tenderness, joint sounds, and limitations in mandibular movement or function [1–3]. Current evidence supports a multifactorial etiology in which biological, biomechanical, behavioral, and psychosocial factors interact to influence the onset, clinical presentation, and persistence of TMD [1,2]. This multifactorial nature has broadened the understanding of TMD beyond the temporomandibular joint itself and has increased interest in its interaction with adjacent musculoskeletal structures, particularly the cervical spine [4].

The TMJ and cervical spine are anatomically, biomechanically, and neurophysiologically interconnected through shared muscular activity and convergence of trigeminal and upper cervical afferents within the trigeminocervical complex, providing a biological basis for the frequent coexistence of orofacial and cervical symptoms [5,6]. Persistent nociceptive input arising from the TMJ and masticatory muscles may influence cervical muscle activity and motor control, contributing to cervical pain, altered movement patterns, and functional impairment [7]. Consistent with these mechanisms, systematic reviews have reported greater neck disability, reduced cervical mobility, altered pressure-pain sensitivity, and impaired cervical muscle function in patients with TMD [4,8]. However, evidence concerning static head posture and cervical alignment remains inconsistent, and no clear postural pattern has been established across TMD populations [4,9].

Stabilization splint (SS) therapy is widely recommended as a reversible conservative treatment for selected patients with TMD, particularly those with pain-related disorders and intra-articular conditions

[10]. These appliances are designed to establish orthopedic stability between the mandibular condyle and the articular fossa, reduce excessive TMJ loading, facilitate neuromuscular adaptation, and minimize the effects of parafunctional activity [10]. Although systematic reviews have demonstrated that SS can reduce pain and improve mandibular function, treatment outcomes remain heterogeneous owing to differences in TMD subtype, appliance design, wearing protocol, comparator intervention, and duration of follow-up [11]. Beyond their effects on TMJ symptoms, increasing attention has focused on whether SS therapy also influences cervical vertebral position and orientation. A recent systematic review suggested that occlusal splint therapy may improve craniocervical posture and cervical function in patients with TMD; however, the available evidence remains limited by the small number of eligible studies and considerable methodological heterogeneity [12]. Furthermore, several investigations combined splint therapy with physiotherapy or evaluated postural outcomes using indirect assessment methods, making it difficult to determine the independent effect of SSs on cervical vertebral position and orientation [13].

Accurate evaluation of cervical vertebral position and orientation requires imaging modalities capable of overcoming the projection errors, magnification, and anatomical superimposition associated with conventional two-dimensional radiography. Cone-beam computed tomography (CBCT) provides three-dimensional visualization of the craniofacial skeleton and upper cervical spine, enabling accurate assessment of angular and linear craniocervical measurements without image distortion [14]. Furthermore, systematic evidence has demonstrated that three-dimensional cephalometric landmarks obtained from CBCT exhibit high reliability and reproducibility, supporting its application in longitudinal craniofacial assessment [15]. Consequently, CBCT represents a valuable imaging modality for investigating treatment-related changes in cervical vertebral position and orientation following SS therapy [14,15].

Despite increasing interest in the relationship between TMD and the cervical spine, important knowledge gaps remain. Existing studies evaluating the effects of SS therapy on cervical posture are limited by small sample sizes, methodological heterogeneity, and relatively short follow-up periods [12]. Furthermore, most investigations have focused on a single stage of treatment [16], making it difficult to determine whether cervical adaptations achieved during SS therapy are maintained throughout subsequent orthodontic treatment. More importantly, longitudinal CBCT studies distinguishing craniocervical adaptations associated with SS therapy from those occurring during subsequent orthodontic treatment remain limited, particularly in comparison with patients with TMD managed conservatively without splint therapy [13]. These limitations highlight the need for well-designed longitudinal studies using standardized three-dimensional imaging to clarify the temporal pattern of cervical vertebral adaptation during comprehensive TMD and orthodontic management.

Accordingly, the present retrospective longitudinal **CBCT** study aimed to evaluate changes in cervical vertebral position and orientation following **SS** therapy and to determine whether these changes were maintained after subsequent orthodontic treatment in patients with TMD. Cervical changes were also compared with those observed in a comparison group of patients diagnosed with TMD according to the

Diagnostic Criteria for Temporomandibular Disorders (DC/TMD) [1] who were managed with conservative non-splint therapy before and during orthodontic treatment. We hypothesized that **SS** therapy would induce significant adaptations in cervical vertebral position and orientation and that these changes would be largely maintained following subsequent orthodontic treatment.

An overview of the study design, treatment pathways, and principal findings is presented in Figure 1. The graphical summary illustrates the longitudinal assessment of craniocervical adaptations during SS therapy and subsequent orthodontic treatment.

Materials and Methods

2.1 Study Design and Ethical Approval

This retrospective longitudinal clinical study was conducted at the First Affiliated Hospital of Xi'an Jiaotong University, Xi'an, Shaanxi Province, China. The study utilized existing clinical records and CBCT images acquired as part of the patients' TMD and orthodontic management. The study protocol was reviewed and approved by the Institutional Review Board of the First Affiliated Hospital of Xi'an Jiaotong University (Approval No. XJTU1AF2022LSK-027). All procedures were conducted in accordance with the ethical principles of the Declaration of Helsinki and its subsequent amendments.

Written informed consent for the use of clinical records and radiographic data for research purposes was obtained from all participants before study enrolment.

2.2 Sample Size Calculation

Because of the retrospective design, all eligible patients who met the predefined inclusion and exclusion criteria during the study period were included; therefore, no prospective sample-size calculation was performed. A post hoc sensitivity analysis was conducted using G*Power (version 3.1.9.7; Heinrich Heine University Düsseldorf, Düsseldorf, Germany) [17]. Assuming a two-sided paired t-test, α = 0.05, 80% power, and 25 patients in the SS group, the available sample could detect a minimum within-subject effect size of Cohen’s d_z = 0.58.

2.3 Patient Selection and Eligibility Criteria

Patients were consecutively screened from the Department of Orthodontics and the Temporomandibular Joint Clinic at the First Affiliated Hospital of Xi'an Jiaotong University (Xi'an, Shaanxi Province, China) between **January 2021 and December 2024**. During the study period, **174 TMD patients** were assessed for eligibility. After applying the predefined inclusion and exclusion criteria, **50 patients** were included in the final analysis. Treatment allocation reflected routine clinical practice and was determined by a

multidisciplinary team comprising orthodontists, oral and maxillofacial surgeons, and TMD specialists before commencement of orthodontic treatment.

All participants were adults (≥18 years) with a confirmed diagnosis of pain-related and/or intra-articular TMD according to the DC/TMD, complete clinical records, high-quality pre- and post-treatment CBCT images of the craniofacial region and upper cervical spine, and skeletal Class II malocclusion (ANB > 4°). The SS group comprised 25 patients who received maxillary SS therapy followed by comprehensive orthodontic treatment, whereas the comparison group comprised 25 patients who were managed conservatively without splint therapy, including patient education and self-care instructions, before and during orthodontic treatment because SS therapy was not considered clinically indicated following specialist assessment.

Patients were excluded if they had a history of orthognathic, craniofacial, TMJ, or cervical spine surgery; significant craniofacial or cervical trauma; congenital craniofacial anomalies or syndromes; previous orthodontic treatment; systemic musculoskeletal or connective tissue disorders; concurrent cervical physical therapy or cervical orthoses; medications affecting muscle function or bone metabolism; chronic upper airway disorders influencing head posture; pregnancy during treatment; incomplete clinical records; or **CBCT** images of insufficient quality for reliable landmark identification. The patient selection process, including eligibility assessment and allocation to the study groups, is summarized in Figure 2.

2.4 CBCT Acquisition Protocol

All CBCT examinations were acquired at the Department of Stomatology, First Affiliated Hospital of Xi'an Jiaotong University, using the same CBCT unit (NewTom VGi evo; QR S.r.l., Verona, Italy) and a standardized imaging protocol consistent with our previously published studies [18–20].

During image acquisition, patients were instructed to assume their natural head position by looking at their own eyes in a mirror positioned at eye level. The built-in laser positioning system was used to assist head alignment. Scans were obtained with the teeth in maximum intercuspation, and the head was stabilized using the manufacturer's head-support system. The scan volume included the craniofacial complex and cervical spine to the level of the fifth cervical vertebra (C5). Imaging parameters were standardized at 110 kVp, 5 mA, 18 s exposure time, 0.30-mm isotropic voxel size, and a 360° rotational scan.

For the **SS** group, **CBCT** examinations were obtained before **SS** therapy (T0), after completion of **SS** therapy and before orthodontic treatment (T1), and after completion of orthodontic treatment (T2). For the comparison group, **CBCT** examinations were obtained before orthodontic treatment (T1) and after completion of orthodontic treatment (T2). All post-**SS** scans were acquired **without the splint in situ**. All volumetric datasets were exported in **Digital Imaging and Communications in Medicine (DICOM)** format for subsequent three-dimensional reconstruction and analysis.

The DICOM datasets were imported into InVivo Dental software (version 6.0.3; Anatomage Inc., San Jose, CA, USA) for three-dimensional reconstruction and cephalometric analysis. Each CBCT volume was individually oriented using the orientation tools incorporated within the software before landmark identification and measurement. This procedure was applied to each patient and at each observation time point to provide a standardized orientation for subsequent analysis. Following orientation, linear and angular measurements were obtained using the software's built-in measurement tools.

2.5 Stabilization Splint (SS) Therapy Protocol

Patients allocated to the SS group were treated using the standardized stabilization splint protocol routinely implemented at our institution and described in detail in our previous publications [18,21]. Briefly, a full-coverage maxillary SS was fabricated and adjusted to provide stable bilateral occlusal contacts in centric relation with appropriate anterior guidance and posterior disclusion. Occlusal adjustments were performed at appliance delivery and during follow-up visits as required to maintain occlusal stability.

Patients were instructed to wear the SS for approximately 20 h/day, removing it only during meals and oral hygiene procedures. Follow-up visits were scheduled one week after appliance delivery, followed by appointments at approximately 15, 30, and 60 days, and monthly thereafter. After completion of SS therapy, patients underwent repeat clinical assessment according to the DC/TMD, followed by CBCT acquisition (T1) before initiation of orthodontic treatment.

2.6 Outcome Measurements and Measurement Reliability

All outcome measurements were performed on standardized **CBCT** reconstructions using **InVivo Dental software** (version 6.0.3; Anatomage Inc., San Jose, CA, USA). Following image standardization, all anatomical landmarks and reference lines were identified by a single calibrated examiner, and the predefined linear and angular measurements were subsequently performed using the measurement tools incorporated within the software.

The primary outcome measures were the OPT/CVT, SNL–OPT, and SNL–CVT angles, which were selected as the principal indicators of cervical vertebral position and orientation. Secondary outcomes included additional craniocervical angular, craniovertebral linear, and cervical curvature measurements. The cervical angular and linear measurements evaluated in the study and their definitions are presented in Table 1, while detailed definitions of the anatomical landmarks and reference lines used to construct these measurements are provided in Supplementary Table S1. The locations of the anatomical landmarks and the construction of the corresponding measurements are illustrated in Fig. 3.

To assess intra-examiner reliability, 10 patients (five from each study group), representing 25 CBCT examinations across all observation time points, were randomly selected and remeasured after a 3-week

interval. The examiner was blinded to the initial measurements during the second assessment. Intra-examiner reliability was evaluated using the intraclass correlation coefficient (ICC) based on a two-way random-effects model with absolute agreement for single measurements[ICC(2,1)] [22]. Random measurement error was assessed using Dahlberg's formula [23]. All measurements demonstrated excellent intra-examiner reliability (ICC > 0.95).

2.7 Statistical Analysis

Statistical analyses were performed using **SPSS version 26.0** (IBM Corp., Armonk, NY, USA). Normality of the paired difference scores was assessed using the Jarque–Bera test. Baseline differences between the SS and comparison groups at T1 were assessed using **Welch's independent-samples *t*-test**. Within-group changes were analyzed using paired *t*-tests when the paired difference scores were normally distributed and Wilcoxon signed-rank tests when the paired difference scores were non-normally distributed. Comparisons included T0–T1, T1–T2, and T0–T2 in the SS group and T1–T2 in the comparison group.

Post-orthodontic outcomes were compared between groups using analysis of covariance (**ANCOVA**), with the corresponding pre-orthodontic measurement included as a covariate. An overall treatment-pathway analysis was performed to compare final T2 outcomes between groups after adjustment for their respective baseline measurements.

For paired *t*-test analyses, results are presented as mean ± SD and mean paired changes with 95% confidence intervals. For Wilcoxon signed-rank analyses, results are presented as medians with interquartile ranges and median paired changes with interquartile ranges. Effect sizes for ANCOVA models were expressed as **partial η^2**. All statistical tests were two-sided, and a *P* value < 0.05 was considered statistically significant.

Results

The study included 25 patients in the SS group and 25 patients in the comparison group. Complete paired measurements were available for all participants, with no missing data. At the pre-orthodontic assessment (T1), FOR/OPT and C1–C2 were significantly higher in the SS group than in the comparison group (both *P* < 0.05), whereas no significant between-group differences were observed for the remaining measurements (Table 2).

3.1 Changes Following Stabilization Splint Therapy (T0–T1)

Following SS therapy, five cervical vertebral measurements changed significantly (Table 3). OPT/CVT demonstrated the greatest reduction after treatment (mean change, −3.24°; *P* < 0.001). Significant

increases were observed in SNL–OPT, SNL–CVT, and C1–C2, whereas the C2–C5 Cobb angle decreased significantly (all $P < 0.05$). No significant changes were observed for the remaining measurements.

3.2 Changes During Orthodontic Treatment in the SS Group (T1–T2)

During the orthodontic phase, relatively limited cervical changes were observed (Supplementary Table S2). Significant changes were detected in OPT/CVT, FOR/OPT, and C0–C3ia (all $P < 0.05$), whereas the remaining measurements showed no statistically significant differences between T1 and T2.

3.3 Overall Longitudinal Changes in the SS Group (T0–T2)

Comparison of the pre-treatment and final post-orthodontic assessments demonstrated that the changes observed after SS therapy were largely maintained (Table 4). OPT/CVT, SNL–OPT, SNL–CVT, C1–C2, and the C2–C5 Cobb angle remained significantly different from their corresponding pre-treatment values (all $P < 0.05$).

3.4 Changes in the Comparison Group (T1–T2)

No statistically significant changes were observed in any of the 15 cervical measurements between the pre- and post-orthodontic assessments in the comparison group. The smallest *P* values were observed for SNL–OPT ($P = 0.095$), C1–C2 ($P = 0.100$), and C0–C3ia ($P = 0.101$).

3.5 Between-Group Comparison After Orthodontic Treatment

After adjustment for the corresponding pre-orthodontic measurements using ANCOVA, LM/OPT was the only variable demonstrating a significant difference between groups at the completion of orthodontic treatment (adjusted mean difference, 6.02°; 95% CI, 0.29–11.75°; $P = 0.040$) (Table 5). No significant adjusted group differences were identified for the remaining variables.

3.6 Overall Treatment-Pathway Comparison

Comparison of the final treatment outcomes after adjustment for baseline values demonstrated significantly lower OPT/CVT and C2–C5 Cobb angle values in the SS plus orthodontic group than in the comparison group ($P < 0.001$ and $P = 0.034$, respectively) (Supplementary Table S3). No statistically significant differences were observed for the remaining measurements.

Discussion

The present study evaluated longitudinal changes in cervical vertebral position and orientation following SS therapy and subsequent orthodontic treatment in adult skeletal Class II patients with TMD. The most pronounced change following SS therapy was observed in OPT/CVT, accompanied by significant changes in SNL–OPT, SNL–CVT, the C2–C5 Cobb angle, and C1–C2 distance. Most changes occurred during the SS phase, with relatively limited additional changes during subsequent orthodontic treatment, and the principal SS-associated changes were largely maintained at the final assessment. In contrast, no significant longitudinal changes were observed in the comparison group, whose TMD was managed conservatively without SS therapy.

Compared with previous CBCT investigations that primarily evaluated cervical posture before and after SS therapy, the present study followed patients across three consecutive treatment stages, allowing assessment of both the timing and persistence of cervical adaptations. Recent CBCT studies have demonstrated favorable changes in craniocervical posture following SS therapy in patients with TMD, including changes in craniocervical relationships, hyoid position, and upper airway morphology [16,19]. However, whether these adaptations are maintained throughout subsequent orthodontic treatment has remained largely unexplored. The present findings therefore extend previous evidence by providing longitudinal assessment beyond the splint-treatment phase. They are also consistent with the systematic review by Ferrillo et al., which suggested that occlusal splint therapy may improve craniocervical posture and cervical function in patients with TMD, although the available evidence remains heterogeneous [12]. This heterogeneity is consistent with broader evidence indicating that the relationship between TMD and cervical posture is multifactorial and influenced by patient characteristics and study design [4].

The concurrent changes in OPT/CVT, SNL–OPT, SNL–CVT, the C2–C5 Cobb angle, and C1–C2 distance suggest that the observed response involved multiple components of the craniocervical complex rather than isolated cervical measurements. One plausible explanation is the close neurophysiological relationship between the temporomandibular joint and the upper cervical spine. Sensory afferents from the TMJ, masticatory muscles, and upper cervical structures converge within the trigeminocervical complex, providing an anatomical and physiological basis for interactions between orofacial pain and cervical motor control [5–7,24]. Persistent nociceptive input may alter cervical muscle function and contribute to compensatory changes in cervical posture and alignment [24]. Clinical evidence that forward head posture is more strongly associated with painful than painless TMD further suggests that pain may influence cervical postural adaptation [25]. Accordingly, the observed changes may reflect coordinated neuromuscular adaptation within the craniomandibular–cervical system rather than a direct mechanical effect of the splint on the cervical spine. This interpretation is consistent with systematic and CBCT evidence supporting functional relationships between TMD and the cervical region [4,12,16,26].

Although significant cervical adaptations occurred during SS therapy, relatively few additional changes were observed during the subsequent orthodontic phase. This pattern suggests that much of the craniocervical adaptation had already occurred before orthodontic treatment commenced. Stabilization splint therapy aims to reduce excessive TMJ loading, establish a reproducible mandibular position, and improve neuromuscular coordination of the masticatory system, whereas comprehensive orthodontic treatment primarily focuses on achieving dental alignment and stable functional occlusion [10,27]. Once a stable mandibular position had been established, subsequent orthodontic treatment appeared to preserve rather than substantially modify the established craniocervical relationship. This interpretation is consistent with recent CBCT studies reporting craniocervical changes following SS therapy [16,19] and is further supported by CBCT evidence indicating relatively limited additional changes in the craniocervical complex during orthodontic treatment in skeletal Class II patients following functional correction [28]. Consequently, the present findings suggest that cervical adaptations established during SS therapy were largely maintained throughout subsequent orthodontic treatment.

After adjustment for the corresponding pre-orthodontic value, LM/OPT was the only parameter that differed significantly between groups after orthodontic treatment. Because LM/OPT represents the angular relationship between the mandibular plane and the upper cervical column, this finding may reflect differences in integrated mandibular–craniocervical orientation rather than an isolated change in cervical posture. Previous evidence in skeletal Class II patients has demonstrated associations between mandibular morphology and craniocervical posture, supporting a relationship between mandibular orientation and upper cervical alignment [28]. Nevertheless, as LM/OPT was the only parameter demonstrating a significant adjusted between-group difference at T2, this isolated finding should be interpreted cautiously and requires confirmation in future studies.

Although the present findings do not support the use of SSs solely to modify cervical posture, they highlight the importance of considering the functional relationship among the temporomandibular joint, cervical spine, and craniofacial complex during comprehensive patient management. From a clinical perspective, assessment of craniocervical posture may provide complementary information during the evaluation and treatment planning of patients with TMD, particularly those with skeletal Class II malocclusion undergoing interdisciplinary management involving SS therapy followed by orthodontic treatment.

Strengths and limitations

The present study has several methodological strengths that should be considered when interpreting the findings. The longitudinal design enabled evaluation of cervical vertebral adaptations across three consecutive treatment stages, allowing differentiation between changes occurring during SS therapy and those maintained throughout subsequent orthodontic treatment. Furthermore, the use of validated DC/TMD diagnostic criteria, standardized three-dimensional CBCT orientation, and a clinically relevant comparison group supported consistency of the longitudinal assessment. Importantly, only adult

patients with skeletal Class II malocclusion (ANB > 4°) were included to minimize variability related to craniofacial morphology. This approach was particularly relevant because craniovertebral relationships and cervical posture have been reported to vary according to skeletal pattern and facial morphology, while systematic evidence also suggests associations among skeletal Class II malocclusion, TMD, and cervical spine alterations [29,30]. By restricting the study to a single skeletal phenotype, the study design was intended to reduce variability in cervical measurements attributable to craniofacial morphology and facilitate interpretation of treatment-related changes.

Nevertheless, several limitations should be acknowledged. The retrospective design precludes causal inference, and the single-center setting and relatively modest sample size may limit the generalizability of the findings. In addition, because all participants presented with skeletal Class II malocclusion, the results should be interpreted within this specific craniofacial phenotype and may not be directly applicable to patients with other sagittal skeletal relationships. The study also evaluated radiographic adaptations without assessing cervical disability or muscle activity, which could provide additional insight into the clinical significance of the observed structural changes. Finally, although significant cervical adaptations were identified during treatment, the long-term stability of these changes after completion of orthodontic therapy remains to be determined through prospective multicenter studies involving larger and more diverse populations.

Conclusion

This study showed that SS therapy was associated with significant adaptations in cervical vertebral position and orientation in adult skeletal Class II patients with TMD. Most cervical changes occurred during the SS phase and were largely maintained throughout subsequent orthodontic treatment, whereas no significant longitudinal cervical adaptations were observed in the comparison group during orthodontic treatment. Using standardized longitudinal CBCT assessment, the present study provides additional evidence supporting a functional relationship between the temporomandibular joint and the craniocervical complex. Further prospective multicenter studies with larger and more diverse populations are warranted to validate these findings and determine their long-term clinical significance.

Declarations

Data availability

The datasets generated and/or analyzed during the current study are available from the corresponding author on reasonable request. The data are not publicly available because they contain clinical and radiographic information that could compromise participant privacy.

Competing interests

The authors declare no competing interests.

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Author Contributions

S.I. and L.Q. contributed equally to the conception and design of the study, methodology development, data analysis and interpretation, and drafting of the manuscript. Z.Y. contributed to the interpretation of the results and critically reviewed and revised the manuscript. Z.X. contributed to the study design and performed the statistical analysis. X.Z. contributed to data collection, interpretation of the results, and critical revision of the manuscript. M.M. contributed to data acquisition, participant recruitment, and data collection. S.A.A. contributed to data curation and writing—review and editing. X.C. supervised the study and acquired funding. L.C. contributed to the conception of the study, interpretation of the findings, development of the discussion, and critical revision of the manuscript. All authors reviewed and approved the final version of the manuscript.

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Tables

Table 1. Definitions of outcome measurements used for evaluating cervical vertebral position and orientation.

Measurement	Definition
OPT/CVT (°)	Angle formed between the odontoid process tangent (OPT) and the cervical vertebral tangent (CVT).
SNL–OPT (°)	Angle formed between the Sella–Nasion line (SNL) and the odontoid process tangent (OPT).
SNL–CVT (°)	Angle formed between the Sella–Nasion line (SNL) and the cervical vertebral tangent (CVT).
FOR/OPT (°)	Angle formed between the foramen magnum line (FOR) and the odontoid process tangent (OPT).
CVT/Hor (°)	Angle formed between the cervical vertebral tangent (CVT) and the true horizontal reference line (Hor).
SN/LM (°)	Angle formed between the Sella–Nasion line (SN) and the lower mandibular plane (LM).
LM–CVT (°)	Angle formed between the lower mandibular plane (LM) and the cervical vertebral tangent (CVT).
LM–OPT (°)	Angle formed between the lower mandibular plane (LM) and the odontoid process tangent (OPT).
C0–OD Distance (mm)	Linear distance between the occipital landmark (C0) and the OD point.
Linear S–OD (mm)	Linear distance between Sella (S) and the odontoid process (OD).
Linear C0–C1 (mm)	Linear distance between the occipital landmark (C0) and the atlas (C1).
Linear C1–C2 (mm)	Linear distance between the atlas (C1) and the axis (C2).
Linear C0–C3ia (mm)	Linear distance between the occipital landmark (C0) and the anteroinferior point of C3 (C3ia).
Modified Ishihara Method (C2–C4)	Cervical curvature index calculated from landmarks on C2, C3 and C4 according to the modified Ishihara method.
C2–C5 Cobb Angle (°)	Angle formed between the inferior endplates of C2 and C5, representing cervical sagittal curvature.

Table 2. Baseline between-group differences at the pre-orthodontic assessment (T1)

Variable	SS Group (n = 25) Mean ± SD	Comparison Group (n = 25) Mean ± SD	Mean Difference (95% CI)	*P* value
FOR/OPT (°)	93.11 ± 7.90	88.14 ± 9.41	4.98 (0.03 to 9.92)	**0.049**
C1–C2 (mm)	28.91 ± 8.44	22.70 ± 9.92	6.21 (0.97 to 11.45)	**0.021**

Note: Only variables showing statistically significant between-group differences are presented. No significant baseline differences were observed for the remaining measurements.

Table 3. Changes following stabilization splint therapy (T0–T1)

Variable	T0	T1	Change	Test	*P* value
OPT/CVT (°)	8.62 ± 3.87	5.38 ± 3.55	−3.24 (−3.90 to −2.58)	Paired *t*	**<0.001**
SNL–OPT (°)	101.0 (89.7–105.8)	103.0 (93.4–105.8)	0.4 (0.0–3.0)	Wilcoxon	**0.003**
SNL–CVT (°)	105.5 (97.9–113.0)	109.0 (100.0–115.0)	1.9 (0.5–4.0)	Wilcoxon	**0.007**
C1–C2 (mm)	20.91 ± 7.87	28.91 ± 8.44	8.00 (4.12 to 11.88)	Paired *t*	**<0.001**
C2–C5 Cobb angle (°)	11.30 ± 7.71	7.97 ± 5.99	−3.33 (−4.73 to −1.93)	Paired *t*	**<0.001**

Note: No significant changes were observed for the remaining variables. Data are presented as mean ± SD with mean paired change (95% CI) for variables analyzed using paired *t*-tests and as median (Q1–Q3) with median paired change (Q1–Q3) for variables analyzed using Wilcoxon signed-rank tests. Changes were calculated as the later measurement minus the earlier measurement.

Table 4. Overall longitudinal changes in the splint group (T0–T2)

Variable	T0	T2	Change	Test	*P* value
OPT/CVT (°)	8.8 (6.0–10.0)	6.1 (4.1–7.7)	−2.3 (−3.0 to −1.5)	Wilcoxon	**<0.001**
SNL–OPT (°)	98.06 ± 10.40	99.98 ± 10.38	1.92 (0.13 to 3.71)	Paired *t*	**0.037**
SNL–CVT (°)	105.5 (97.9–113.0)	111.0 (99.0–115.6)	0.9 (−0.4 to 3.0)	Wilcoxon	**0.030**
C1–C2 (mm)	20.91 ± 7.87	27.92 ± 11.28	7.01 (3.40 to 10.62)	Paired *t*	**<0.001**
C2–C5 Cobb angle (°)	11.30 ± 7.71	8.40 ± 6.87	−2.90 (−3.84 to −1.95)	Paired *t*	**<0.001**

Note: No significant changes were observed for the remaining variables. Data are presented as mean ± SD with mean paired change (95% CI) for variables analyzed using paired t-tests and as median (Q1–Q3) with median paired change (Q1–Q3) for variables analyzed

using Wilcoxon signed-rank tests. Changes were calculated as the later measurement minus the earlier measurement.

Table 5. Baseline-adjusted comparison of post-orthodontic outcomes (ANCOVA)

Variable	Adjusted SS Mean	Adjusted Comparison Mean	Adjusted Difference (95% CI)	Partial η^2	*P* value
LM/OPT (°)	68.31	62.29	6.02 (0.29 to 11.75)	0.087	**0.040**

Note: No significant adjusted group differences were observed for the remaining variables.

Figures

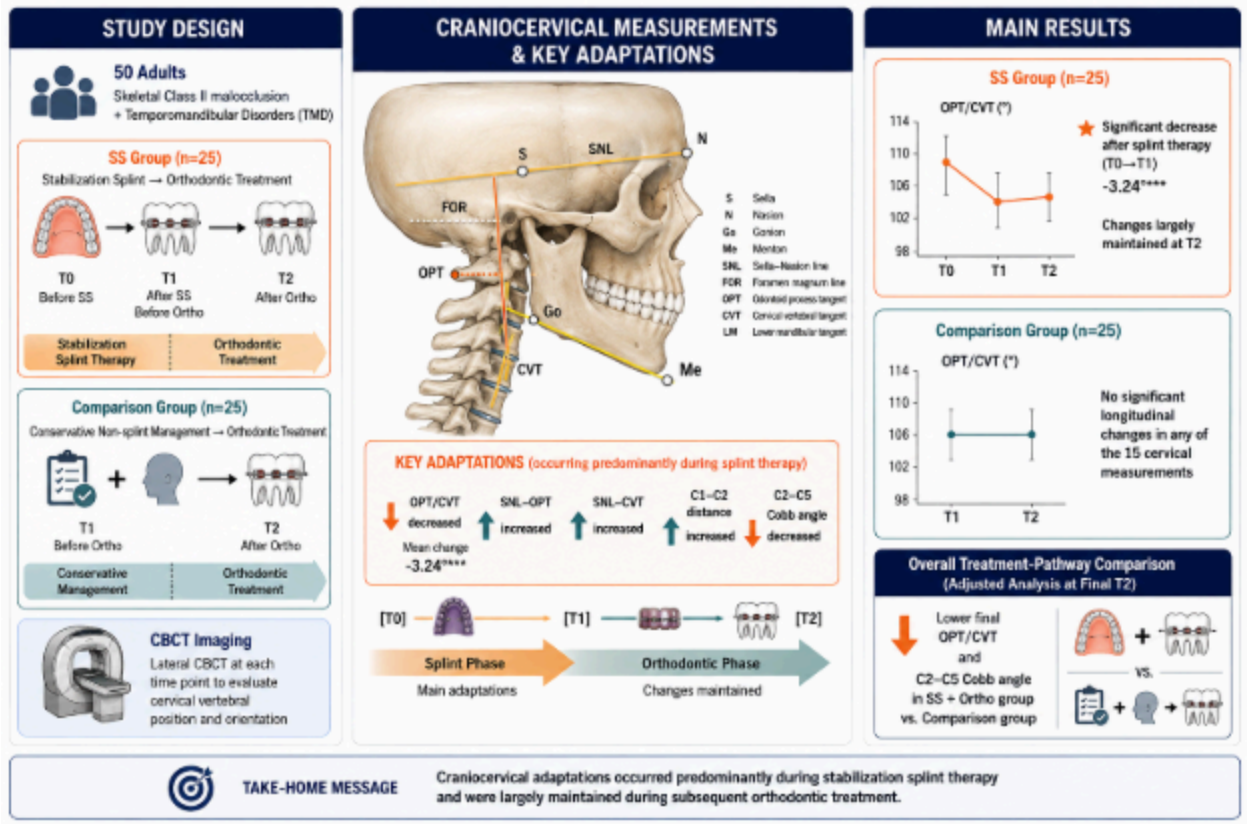


Figure 1

Graphical overview of the study design, treatment pathways, and principal findings. SS, stabilization splint; TMD, temporomandibular disorders; CBCT, cone-beam computed tomography.

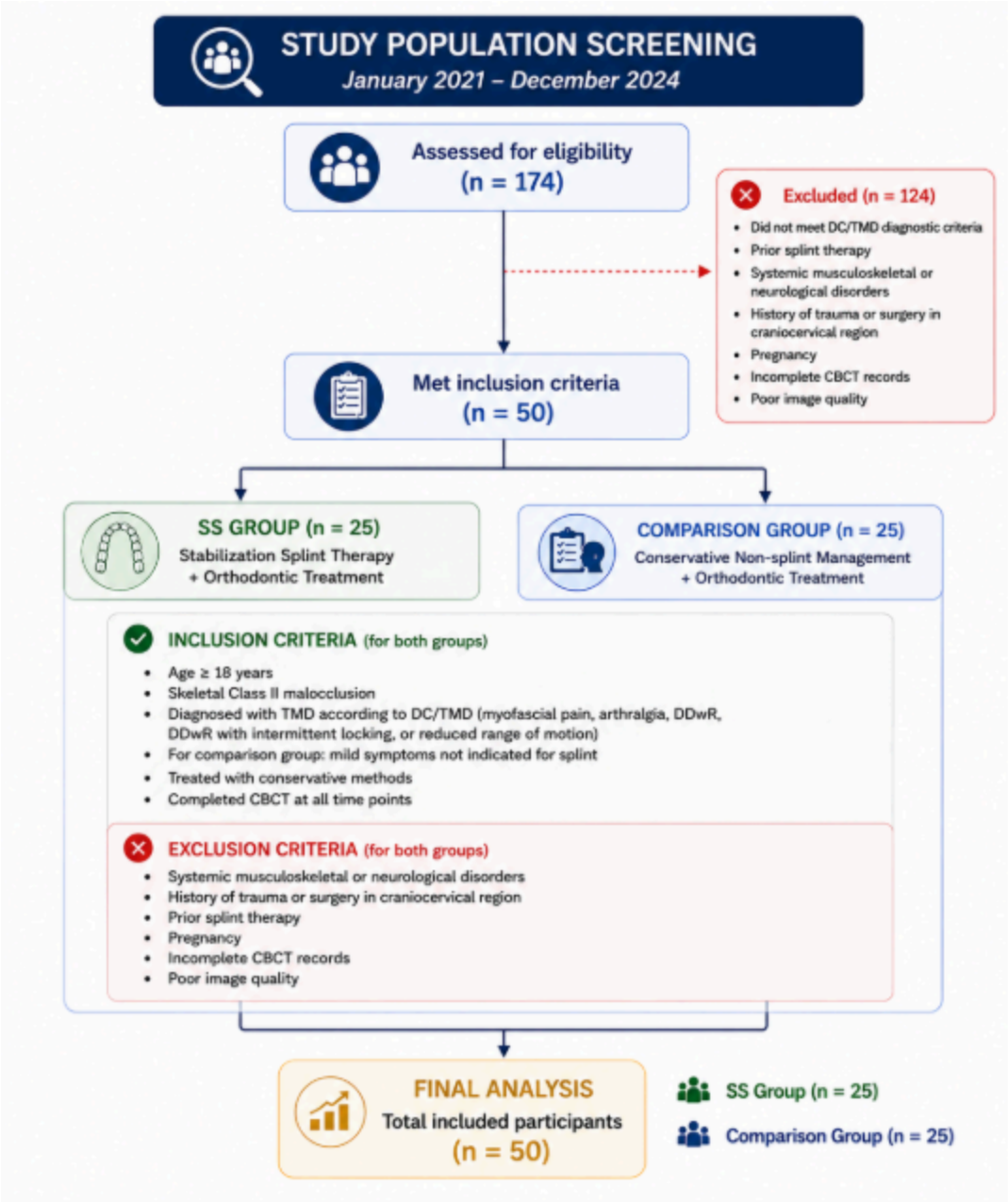


Figure 2

Flowchart of patient screening, eligibility assessment, and study-group allocation. SS, stabilization splint; TMD, temporomandibular disorders.

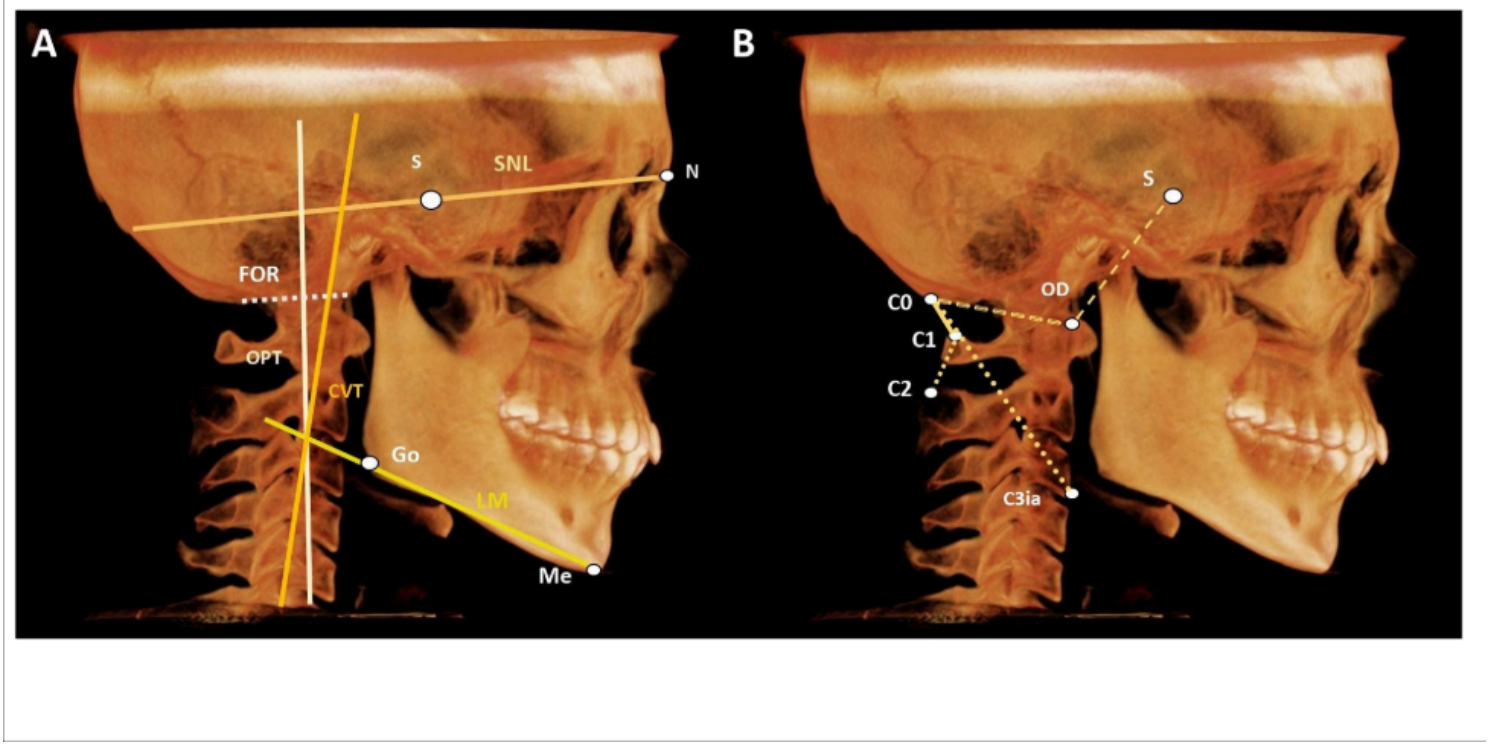


Figure 3

Anatomical landmarks and reference lines used for craniocervical and mandibular measurements.

Representative three-dimensional CBCT reconstruction showing the anatomical landmarks and reference lines used for measurements. **(A)** Reference lines and planes used for angular measurements: S, sella; N, nasion; Go, gonion; Me, menton; SNL, Sella–Nasion line; FOR, foramen magnum line; OPT, odontoid process tangent; CVT, cervical vertebral tangent; and LM, lower mandibular plane. **(B)** Anatomical landmarks used for linear measurements: S, sella; OD, odontoid point; C0, occipital reference point; C1 and C2, posterior reference points of the first and second cervical vertebrae, respectively; and C3ia, anteroinferior point of the third cervical vertebral body. Dashed lines illustrate the corresponding linear reference measurements.

Supplementary Files

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- SupplementaryTables.docx