**Original Article**

**Effect of Occlusal Splint Therapy on Condylar Movements Recorded Using an Electronic Pantograph: A Prospective Clinical Study**

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**Aims and Objective:** The effect of occlusal splint therapy on the muscle activity has been addressed in the literature. However, its effect on condylar movements in subjects with normal and abnormal occlusions has not yet been investigated. This prospective clinical study addressed the effect of occlusal splint therapy on condylar movements in subjects with normal and abnormal occlusions using an electronic pantograph. **Materials and Methods:** Two groups of subjects were included in this study. The first group included subjects with normal occlusion, whereas the subjects in the other group were diagnosed with abnormal occlusion. The occlusal splint was fabricated, adjusted clinically, and delivered for each subject. Condylar movements were recorded using a Cadiax Compact II electronic pantograph at baseline, 2-, 4-, and 6-month follow-up periods to assess sagittal condylar inclination (SCI), immediate mandibular lateral translation (IMLT), and progressive mandibular lateral translation (PMLT). The t-test, one-way analysis of variance (ANOVA), and two-way ANOVA were used to compare the parameters between the groups and to assess the time effect on these parameters \((\alpha = 0.05)\). **Results:** Twenty subjects were recruited for this study \((n = 10)\). Among them, 12 were women and eight were men, with a mean age of 34 years. In each group, insignificant differences were reported for each tested parameter at baseline and during the follow-up periods \((P > 0.05)\). However, when comparing the two groups, the only significant difference was found in the SCI during the 6-month follow-up period \((P = 0.014)\). **Conclusions:** Occlusal splints had an insignificant effect on the parameters SCI, IMLT, and PMLT up to 6 months of follow-up for subjects with normal or abnormal occlusion. SCI increased substantially in normal occlusion subjects compared with abnormal occlusion subjects during the 6-month follow-up period.

**Keywords:** Dental occlusion, electronic pantograph, mandibular condylar, occlusal splint

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**Introduction**

Occlusal splint therapy has been fabricated mainly in dentistry for the management of temporomandibular disorders (TMD). The mechanism of action is applied to the reduction of muscle activity, especially temporal and masseter muscles, the management of disk interference disorders, and headache management.¹⁻³ Furthermore, it reduces excessive forces on the teeth and subsequently reduces the possibility of tooth wear and restoration.

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fractures in patients with parafunctional habits, such as clenching and bruxism.\textsuperscript{[1–5]} Okeson reported that after 8 weeks of occlusal splint therapy for patients with TMD, 80\% of these patients were free from joint sounds, pain, and discomfort.\textsuperscript{[6]}

Masticatory muscles are responsible for limiting the border movements of condyles; therefore, occlusal splint therapy may be performed to deprogram masticatory muscle activity and allocate the centric relation (CR) position in patients having excessive tooth structure loss and requiring full-mandible reconstruction.\textsuperscript{[1–7]} In such cases, different condylar movements, which may affect the occlusal morphology of the posterior teeth, can be recorded and transferred in numbers or degrees into a suitable articulator for condylar settings to fabricate the dental prostheses.\textsuperscript{[8,9]}

The purpose of recording and transferring condylar movements to the articulator is to produce the same pattern of mandibular movements on the articulator and the patient occlusion and to minimize the clinical adjustment of dental prostheses. Condylar setting adjustments usually depend on the type of articulator, which includes sagittal condylar inclination (SCI), immediate mandibular lateral translation (IMLT), progressive mandibular lateral translation (PMLT), and intercondylar distance.\textsuperscript{[10–12]} According to Price et al., IMLT caused the main effect on the occlusal morphology of the posterior teeth in an articulator setting, in which an increase in IMLT resulted in an increase in the width of the central fossa and in the movement of the ridges and grooves mesially in the mandibular posterior teeth.\textsuperscript{[13]}

Different mechanical and electronic tracing devices are available to record mandibular movements and to determine the condylar reference point. Electronic pantograph devices have been manufactured for the three-dimensional registration of mandibular movements to program the articulator’s condylar settings.\textsuperscript{[11–18]} Chan et al. confirmed the reliability and validity of an electronic pantograph device for recording and transferring condylar movements to the articulator’s settings using a 10-mm condylotrack distance.\textsuperscript{[11]} Franklin et al. found that programmed articulators with pantographic recordings produced a significantly greater matching of tooth contacts than unprogrammed articulators when compared with intraoral excursive tooth contacts.\textsuperscript{[19]}

As occlusal splint therapy has been shown to have a positive effect on reducing the muscular activity, its effect on the condylar articulator’s settings has not yet been identified, especially for patients who are required to wear a splint appliance to verify the CR position and assess the possibility of increasing the vertical dimension of occlusion before full-mouth reconstruction with definitive dental prostheses. Therefore, this clinical study aimed to evaluate the effect of occlusal splint therapy on SCI, IMLT, and PMLT in patients with normal and abnormal occlusion after follow-up periods of 2, 4, and 6 months compared with the baseline. The null hypothesis is that occlusal splint therapy does not affect the SCI, IMLT, and PMLT in subjects with normal and abnormal occlusion.

**Materials and Methods**

The ethical approval for this study was obtained from the Institutional Review Board (IRB) Committee of Imam Abdulrahman Bin Faisal University (IRB-2019-02-127). The sample size calculation was determined using G* software (G*Power software V3.1.9.6, Heinrich Heine University Düsseldorf, Düsseldorf, Germany), and the input data included a power of 95\%, an effect size \( f = 0.86 \), and \( \alpha = 0.05 \). The software analysis revealed the critical F value (4.4), the noncentrality parameter (14.8), and the number of samples for each group (10).

The subjects were recruited for this clinical study and divided into two main groups based on their occlusal analysis. The first group was categorized as the normal occlusion group (G1), in which all the subjects fulfilled the following inclusion criteria of normal occlusion: even contact between the maxillary and the mandibular teeth either in the centric occlusion or maximum intercuspation position, canine guidance or group function in the working side during lateral mandibular movements, no tooth contact in the nonworking side, and anterior guidance with no contact between the posterior teeth during the protrusive mandibular movements. The second group (GII) was categorized as the abnormal occlusion group, in which all the subjects fulfilled the following inclusion criteria: with TMD, occlusal interferences in either centric or eccentric mandibular movements, class II or III dental malocclusion, loss of posterior support, signs of reduced vertical dimension of occlusion, and/or a loss of anterior guidance. Consent forms were distributed to and signed by all subjects. All subjects were investigated and treated at prosthodontic clinics at the Dental Hospital of Imam Abdulrahman Bin Faisal University in Dammam, Saudi Arabia. One well-trained operator was assigned to perform all the clinical procedures for standardization purposes.

The tracing of the different mandibular movements was performed for each subject using a Cadiax Compact...
II electronic pantograph (Cadiax, Gamma Co., Klosterneuburg, Austria) to record the SCI, IMLT, and PMLT of the right and left condyles, following the manufacturer’s instructions. The recording process was carried out by stabilizing an occlusal clutch on the mandibular teeth using bite registration material (Virtual CADbite, Ivoclar Vivadent, Schaan, Liechtenstein). Afterward, the maxillary bow was installed; the knobs were placed into the ear canals on both sides; and the glabella support was stabilized against the nose bridge. The mandibular bow was installed with the middle clamp pushed onto the occlusal clutch and screwed. The electronic flags were then fixed to the maxillary bow, and the styli were attached to the mandibular bow, following the manufacturer’s instructions.

One operator was assigned to perform all recording procedures for all subjects. Each subject was guided to the CR position and trained to conduct protrusion, lateral, and open and close movements to ensure smooth and continuous movements without any interference. These movements were recorded starting from the CR position. Each movement was recorded three times, and all data were saved and translated by the software to the average measurements of the SCI, IMLT, and PMLT for the right and left condyles of each subject using a 10-mm condylotrack distance [Figure 1].

Maxillary and mandibular preliminary impressions were made for each subject using alginate impression material (Major Prodotti Dentari SPA, Moncalieri, Italy). Facebow records were made using a Denar slidematic bow (Denar, Whip Mix, Fort Collins, USA), and CR records were obtained using bite registration material (Virtual CADbite, Ivoclar Vivadent, Schaan, Liechtenstein). Impressions were poured into a model stone (Fujirock, GC Europe, Leuven, Belgium), and the diagnostic casts were mounted on a semi-adjustable articulator (Hanau H2, Whip Mix, Fort Collins, USA).

An occlusal splint with a flat surface was fabricated for all subjects on the maxillary casts by a single lab technician. A wax-up of the splint was made with a 2-mm occlusal thickness, and a mold of the wax-up was fabricated using putty material (3M ESPE, Neuss, Germany). A wax elimination procedure was performed. A clear auto-polymerized acrylic resin (Major Prodotti Dentari SPA, Moncalieri, Italy) was mixed and poured into the putty mold. The mold was placed in a pressure chamber with water at 30 Psi for 15 min. Finishing and polishing procedures were applied to each occlusal splint following conventional methods.

One week following the recording visit, the occlusal splint was seated intraorally for each subject, and any occlusal discrepancy was adjusted to ensure contact between the mandibular teeth and the maxillary occlusal splint in the CR position. Adequate anterior guidance on the splint was confirmed to create disocclusion of the posterior teeth in the protrusive and lateral mandibular movements. Postoperative instructions, such as wearing

![Figure 1: Curves represent the electronic recording of condylar movements](image-url)
the splint during daytime hours except while eating, were given to the subjects. Each subject underwent 2-, 4-, and 6-month follow-up periods to perform tracing of the mandibular movements to assess the SCI, IMLT, and PMLT.

The Statistical Package for Social Sciences (SPSS v. 23) was used for the data analysis. The averages and standard deviations (SDs) were computed for the descriptive presentation of the data. For inferential statistics, two independent samples t-test was used to compare the average difference between the two groups of the tested parameters. A one-way analysis of variance (ANOVA) was used to test the effect of time on the parameters (SCI, IMLT, and PMLT). Similarly, a two-way ANOVA was used to test the combined effects of time and type of group on the measured parameters. A P value of less than 0.05 was considered statistically significant.

RESULTS

Twenty subjects (eight men, 12 women) were recruited in the current study (n = 10/group), with an age range of 24–63 years (mean = 34). Table 1 shows the minimum, maximum, and mean values with SD of the tested parameters within each group and between groups at baseline without the occlusal splint and during the 2-, 4-, and 6-month follow-up periods after the insertion of the occlusal splint.

For GI, based on a one-way ANOVA, the comparison of averages for each tested property between the baseline and the 2-, 4-, and 6-month follow-up periods showed insignificant differences (SCI: P = 0.457 and F = 0.893; PMLT: P = 0.739 and F = 0.422; IMLT: P = 0.849 and F = 0.267). The SCI mean values showed an increasing trend from the baseline (41.4° ± 10.6) to the 6-month follow-up period (48.5° ± 6.1). The minimum PMLT mean value was observed during the 2-month follow-up (5.37° ± 0.69), whereas the maximum PMLT mean value was recorded during the 6-month follow-up (5.83° ± 0.75). The lowest mean value of IMLT was observed at baseline (0.16 mm ± 0.32) and the highest during the 2-month follow-up (0.35 mm ± 0.51).

For GII, insignificant differences were found between the different follow-up periods for the mean values of SCI (P = 0.275, F = 1.356), PMLT (P = 0.878, F = 0.225), and IMLT (P = 0.293, F = 1.299). The maximum SCI mean value was 46.75° ± 6.8 at baseline, whereas the minimum value was 40.67° ± 2.3 during the 6-month follow-up. The highest mean value of PMLT was 6.85° ± 2.2 at baseline and during the 2-month follow-up, whereas the lowest mean value was 6.2° ± 1.47 during the 6-month follow-up. The maximum (0.12 mm ± 0.13) and minimum (0.05 ± 0.06) mean IMLT values were recorded during the 6-month follow-up and at baseline, respectively.

| Table 1: Comparison of averages of the tested variables at baseline and follow-up periods |
|-----------------------------------------------|-------------------|-------------------|-------------------|-------------------|
| Variables                                    | Time (months)     | Normal occlusion  | Abnormal occlusion | T-test            |
|                                              | Minimum | Maximum | Mean (SD) | Minimum | Maximum | Mean (SD) | P value   |
| Sagittal condylar angle (*)                  | Baseline | 26.5     | 59.5     | 41.4 (10.6) | 36.5     | 58.0     | 46.75 (6.8) | 0.204 |
|                                              | 2       | 26.5     | 59.5     | 44.8 (9.2)  | 37.0     | 57.5     | 45.87 (6.8) | 0.797 |
|                                              | 4       | 34.5     | 58.0     | 46.5 (8.1)  | 30.5     | 55.0     | 43.65 (6.8) | 0.415 |
|                                              | 6       | 37.5     | 54.5     | 48.5 (6.1)  | 38.0     | 44.5     | 40.67 (2.3) | 0.014* |
| One-way ANOVA                                | F = 0.893 | P = 0.457 |          | F = 1.356 | P = 0.275 |          |          |
|                                              | PMLT (*) | Baseline | 5.0      | 7.0      | 5.56 (0.88) | 5.0      | 12.0      | 6.85 (2.2) | 0.156 |
|                                              | 2       | 5.0      | 7.0      | 5.37 (0.69) | 5.0      | 12.0      | 6.85 (2.2) | 0.069 |
|                                              | 4       | 5.0      | 7.0      | 5.67 (0.79) | 5.0      | 12.0      | 6.7 (2.3)  | 0.447 |
|                                              | 6       | 5.0      | 7.0      | 5.83 (0.75) | 5.0      | 9.0       | 6.2 (1.47) | 0.955 |
| One-way ANOVA                                | F = 0.422 | P = 0.739 |          | F = 0.225 | P = 0.878 |          |          |
|                                              | IMLT (mm) | Baseline | 0        | 1.0      | 0.16 (0.32) | 0        | 0.2       | 0.05 (0.06) | 0.720 |
|                                              | 2       | 0        | 1.25     | 0.35 (0.51) | 0        | 0.2       | 0.04 (0.07) | 0.534 |
|                                              | 4       | 0        | 1.25     | 0.27 (0.48) | 0        | 0.2       | 0.06 (0.06) | 0.798 |
|                                              | 6       | 0        | 1.25     | 0.31 (0.5)  | 0        | 0.35      | 0.12 (0.13) | 0.870 |
| One-way ANOVA                                | F = 0.267 | P = 0.849 |          | F = 1.299 | P = 0.293 |          |          |

*Statistically significant at 0.05 level of significance
In comparing the GI and GII groups using the t-test, each parameter presented an insignificant difference at baseline before the insertion of the occlusal splint and during the 2-, 4-, and 6-month follow-up after the delivery of the occlusal splint (P ≥ 0.05) except the SCI mean value, which was significantly higher in the GI during the 6-month follow-up period (P = 0.014).

To analyze the combined effects of the variation of the follow-up periods and the type of group on the tested parameters (SCI, PMLT, and IMLT), a two-way ANOVA was employed. Table 2 summarizes the two-way ANOVA results and shows that the combined effects of time and group were insignificant in any of the tested parameters (P > 0.05).

**DISCUSSION**

The results showed that occlusal splint therapy had an insignificant effect on condylar movements in each group during the 2-, 4-, and 6-month follow-up periods compared with the baseline measurements, which were recorded without an occlusal splint. In addition, insignificant differences were found between the two groups in condylar movements at baseline and during the follow-up periods, except in the SCI at 6 months. Thus, the null hypothesis was partially accepted.

Occlusal splint therapy has been reported to be a conservative treatment protocol for patients with TMD. During the maximum contraction of the masticatory muscles, occlusal splints can protect teeth and restorations from damage and subsequently reduce orofacial pain. By improving the occlusal contacts using the occlusal splint, muscular function can be improved, positively changing the patient behavior. A recent study assessed the effect of occlusal splints on the condyle position of patients with bruxism and found a greater change in the condyle position of bruxism patients compared with free bruxism patients. In the current study, an insignificant effect of occlusal splints was found on the SCI, PMLT, and IMLT between the normal and abnormal occlusion subjects, except in the SCI, during the 6-month follow-up.

Studying condylar movements is important because these movements have a major effect on the reconstruction of teeth occlusal surfaces. Therefore, the reproduction of these movements is recommended to program semi-adjustable or fully adjustable articulators. Different methods have been suggested to evaluate condylar movements, including intraoral occlusal records and extraoral graphic tracing. Electronic pantographic devices have been introduced to minimize errors associated with other methods and to mimic the path of condylar movements more accurately. Torabi et al. clinically assessed the difference between intraoral occlusal records and the Cadiax pantograph in recording condylar movements. A substantial difference was observed between the two methods, particularly in SCI and PMLT. The present study was conducted using the Cadiax Compact II to maintain the recording accuracy of condylar movements for all subjects, and one well-trained operator was assigned to ensure standard recordings.
The recording of condylar movements includes the assessment of SCI as an important parameter for the fabrication of removable or fixed dental prostheses. SCI is defined as the angle formulated between the protrusive path of the condyle and the Frankfort horizontal plane.\(^{25,26}\) The effect of SCI on the occlusal surfaces of the posterior teeth is mainly on the cusp height, in which a steeper SCI is recorded and longer cusps can be fabricated.\(^{27}\) The normal range of SCI has been reported to be from 8°, which is a low value, to approximately 70°, with mean values between 30° and 45°.\(^{28,29}\) In the present study, the SCI mean values were between 40° and 49°, which could be considered within the normal range for both the normal occlusion and abnormal occlusion groups. However, SCI was the only parameter that showed a significant difference between the two groups during the 6-month follow-up period after wearing the occlusal splint. This could be explained by the late response of muscular activities to the occlusal splint, or it could be related to some biological changes in the structures of the temporomandibular joints.

PMLT, previously called the Bennett angle, is defined as the angle between the sagittal plane and the path of the orbiting condyle on the nonworking side, which can be viewed from the horizontal plane.\(^{30}\) The effects of PMLT on the occlusal morphology of the posterior teeth include the position of the grooves and ridges on both the working and nonworking sides.\(^{31}\) Five degrees of error during the recording of PMLT could cause variations in the positions of grooves and ridges from 0.18 mm to 0.37 mm.\(^{32}\) Cimic et al.\(^{33}\) assessed PMLT among participants with different angle occlusion types and observed an insignificant difference between the groups, with mean values ranging from 6.4° to 8.2°. The results of the current study were consistent with those of Cimic et al.\(^{33}\) as insignificant differences were found between the GI and GII groups and within each group during the follow-up periods. The variation in the mean values could be related to the use of an occlusal splint in the current study, the anatomical variations between the subjects, and the measuring tools.

The IMLT is defined as a translation movement of the balancing condyle during lateral mandibular movement, as it moves medially and straight upon leaving the CR position.\(^{30}\) Arguments have been raised about existing IMLT and its clinical significance.\(^{34}\) Canning et al. found that the IMLT values in 55% of the subjects on the right side and 70% on the left side were 0 mm, whereas the other subjects had IMLT values of 0.1–1 mm.\(^{16}\) In the current study, three subjects (15% of the subjects) had IMLT, with a 0 mm value at baseline and during the follow-up periods. However, the IMLT recording of six other subjects (30% of the subjects) was 0 mm at baseline, and it increased to 0.1 mm during the follow-up period after the delivery of the occlusal splints. This may be due to the effects of occlusal splints on the temporomandibular joint, muscular activity, or the accuracy of the recording procedures.

The effects of different occlusal relationships on condylar movements have been investigated in limited studies.\(^{16,33,35}\) Cimic et al.\(^{33}\) assessed the effect of different angle occlusion types on the Bennett angle and found that the different angle occlusion types had an insignificant effect on the Bennett angle. Canning et al.\(^{16}\) observed a difference between the different skeletal patterns only in the SCI. Ko et al.\(^{35}\) found an insignificant difference in the Bennett angle between participants with skeletal class III and normal individuals. The results of the current study coincided with those of previous studies, as the difference between the abnormal and normal occlusion participants was found only in the SCI 6 months after the delivery of occlusal splints.

Based on the findings of the current study, occlusal splint therapy can be used clinically for up to 6 months without significant effects on the recording of condylar movements and articulator settings in patients with normal or abnormal occlusion.

This study is limited by the low number of participants and the limited duration of time. In addition, all participants with different abnormal occlusal relationships were included in one group. Therefore, further investigations with an increased number of participants and longer follow-up periods are required. The effects of occlusal splints on participants with different abnormal occlusal relationships should also be assessed.

**Conclusion**

Occlusal splint therapy had insignificant effects on SCI, IMLT, and PMLT up to 6 months of follow-up in subjects with either normal or abnormal occlusion, and the values were within the reported values. However, during the 6-month follow-up period, a substantial difference was found in the SCI between the normal and abnormal subjects.

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**CONFLICTS OF INTEREST**
There are no conflicts of interest.

**AUTHORS CONTRIBUTIONS**
All authors are qualified for the authorship and made a remarkable contribution in this study. AMA and MMG: conception, design of the study, and writing of the article. NA and RA: data collection and analysis. FAA, NNA, and SQK: data analysis and interpretation, reviewing and critiquing the article.

**ETHICAL POLICY AND INSTITUTIONAL REVIEW BOARD STATEMENT**
Written consents were obtained from all participants, and the ethical approval for this study was obtained from the Institutional Review Board (IRB) Committee of Imam Abdulrahman Bin Faisal University (IRB-2019-02-127).

**PATIENT DECLARATION OF CONSENT**
Not applicable.

**DATA AVAILABILITY STATEMENT**
Not applicable.

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