

## Evaluation of the Use of a Force Diagram in the Management of Temporomandibular Joint Sounds: A Prospective Cross-sectional Study

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**Context:** Occlusal splints are widely used in clinical practice as a noninvasive treatment for patients with temporomandibular disorders (TMDs) and for reduction of TMD-related symptoms. A force diagram allows a health care professional to evaluate the interactions of loads caused by muscular effort, which are sensed by the teeth and the temporomandibular joint during the protrusive movement of the mandible.

**Objective:** To evaluate the efficacy of occlusal splints combined with occlusal adjustment (OA) based on a force diagram in the management of joint sounds (clicking and crepitition).

**Methods:** Patients were examined clinically and administered a questionnaire for the diagnosis of TMD and orofacial pain. Patients were then assigned to 1 of 2 splint therapies: (1) an anterior bite plane of the front-plateau type (FP) or (2) a maxillary muscle relaxation appliance (MRA), both combined with OA based on a force diagram performed at 6 visits, with an interval of 24 to 48 hours between each visit. To measure the effects of treatment, at each of the 6 visits, patients also rated the severity of their TMD-related symptoms on a visual analog scale. Data were dichotomized into presence and absence of symptoms and compared using the McNemar test.

**Results:** A total of 199 patients were included in the study. At baseline, 38 patients (19.1%) had crepitition and 161 (80.9%) had clicking. A total of 150 patients were treated with FP+OA, with a statistically significant reduction in the number of patients reporting clicking (42.6%,  $P<.001$ ) and crepitition (42.9%,  $P<.001$ ). Among patients treated with MRA+OA ( $n=49$ ), there was a statistically significant reduction in the number of patients reporting clicking (50%,  $P<.001$ ). All 3 patients with crepitition in the MRA+OA group reported total remission ( $P>.05$ ).

**Conclusion:** The 2 treatment strategies, FP+OA and MRA+OA, improved both clicking and crepitition. Both strategies prioritize the concept of mutually protected occlusion, in which all jaw and temporomandibular joint movements must synchronize, which may be conveniently done using the force diagram.

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**J**oint sounds are one of the most frequent symptoms of temporomandibular disorders (TMDs).<sup>1-8</sup> Researchers investigating a possible association between asymptomatic temporomandibular joint (TMJ) sounds, occlusal force, and masticatory function in older adults concluded that TMJ sounds are related to reduced posterior occlusal support.<sup>9</sup>

Occlusal splints are noninvasive and widely used in clinical practice to treat patients with TMD and reduce TMD-related symptoms. The occlusal force applied to the teeth is transmitted to the TMJ, and the greater the anterior contact with the occlusal splint, the greater the load transmitted to the TMJ.<sup>10</sup> A total remission rate of 41.0% has been reported for patients with chronic pain, joint sounds (except reciprocal clicking), and limited mouth opening when managed with stabilization splints, often combined with occlusal adjustment (OA) and restorative treatment. When including those with some improvement, the treatment success rate has reached 84.0%.<sup>11</sup> Modified occlusal splints can change the masticatory behavior when used to restore the normal disk-condyle relationship, with an improvement rate of up to 71.2%.<sup>12</sup> However, some authors have argued that it is difficult to achieve complete success using an interocclusal appliance for the management of TMJ clicking because many predisposing factors are likely to affect treatment.<sup>6,13-15</sup>

A force diagram allows one to evaluate the interactions of loads caused by muscular effort, which are sensed by the teeth and TMJ during the protrusive movement of the mandible. The present study was therefore designed to evaluate the results of the management of TMJ sounds (clicking and crepitus) using occlusal splints combined with OA based on a force diagram.

## Methods

This prospective cross-sectional study recruited patients seeking dental care at the School of Dentistry of Pontifícia Universidade Católica do Rio Grande do Sul, Brazil, from March 27, 2002, to July 9, 2015. The study was approved by the institution's Research Ethics

Committee (protocol No. 06/03111 and 0002/07), and written informed consent was obtained from each study participant.

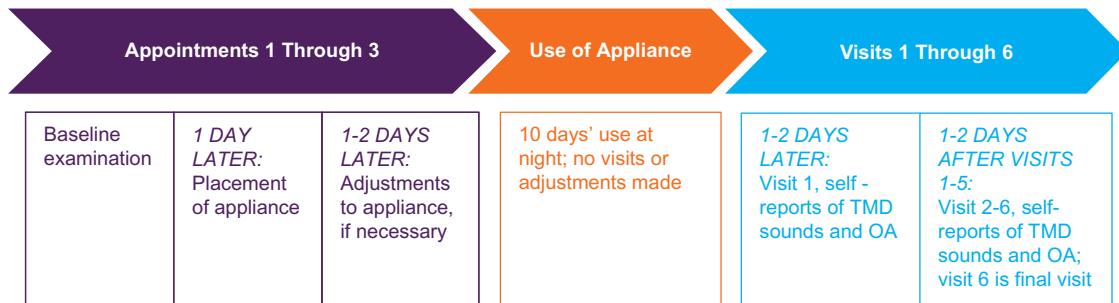
Patients were included if they were completely dentate (Angle Class I or II) or were partially edentulous and wearing removable partial dentures, implant-supported prostheses, or natural tooth-supported fixed partial dentures. Inclusion criteria included having teeth that allowed contacts in centric relation and guidance in lateral or protrusive movements. Patients with psychological or emotional conditions that could compromise the evaluation of potential changes in the level of TMD-related symptoms were excluded.

## Study Phases

The study was conducted in 2 phases: (1) clinical examination and administration of a questionnaire for the diagnosis of TMD and orofacial pain and (2) supplementary diagnosis and application of the treatment strategies. All participants were examined, and all conditions were diagnosed by the same professional (N.S.S.) in both phases of the study. An overview of the timeline is provided in **Figure 1**.

### Phase 1

Eligible participants underwent clinical examination for signs and symptoms of TMD according to the ENESSE questionnaire for the diagnosis of TMD and orofacial pain.<sup>16</sup> The questionnaire is divided in 2 parts. Part I consists of items to be completed on the questionnaire itself during clinical examination to collect patient data and make a preliminary diagnosis. Part II consists of the use of a partial or full-arch splint to confirm or reject the diagnosis obtained in part I. Intraoral and extraoral clinical examination included TMJ palpation and checking for signs and symptoms of TMD. We also sequentially examined premature contacts in centric relation, occlusal interferences in right and left lateral excursions, and protrusive movements. These contacts were assessed by placing a thin (8-12 µm) double-sided articulating film (AccuFilm II; Parkell) on the palatal occlusal surface of all teeth, and the marks were

**Figure 1.**

Timeline of study protocol for patients with temporomandibular disorder (TMD). Patients were assigned to one of 2 splint therapies, or appliances: (1) an anterior bite plane of the front-plateau type or (2) a maxillary muscle relaxation appliance. Both appliances were combined with occlusal adjustment (OA) based on a force diagram.

recorded bilaterally and simultaneously. The second appointment for placement of the appliance occurred 24 hours after the baseline examination.

### Phase 2

For supplementary diagnosis and treatment, patients were assigned to 1 of 2 splint therapies: (1) use of a hard acrylic resin, an anterior bite plane of the front-plateau (FP) type, according to Dawson,<sup>17</sup> or (2) use of a hard acrylic resin, full-arch maxillary flat plane muscle relaxation appliance (MRA). Both therapies were combined with OA based on a force diagram. Patients with class II and III malocclusion in which there was consideration for treatment after OA (ie, patient was unwilling to accept subsequent orthodontics, prosthesis placement, or a combination of orthodontics and orthognathic surgery) were assigned to the MRA group. All other patients who met inclusion criteria were assigned to the FP group, in which the intervention ended after OA.

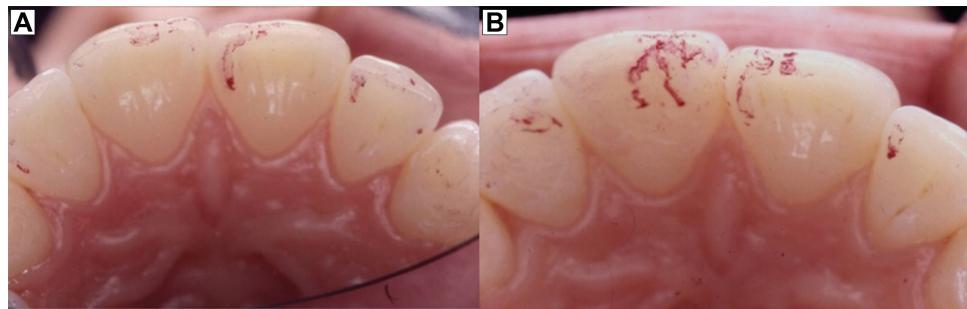
Between 24 and 48 hours after first use of the appliance (FP bite plane or MRA), patients returned for any adjustments, if necessary. Patients were then instructed to wear the appliance only at night for 10 days before undergoing any other procedure. No adjustments were made during this period.

After this 10-day period, 6 patient visits for OA were scheduled 24 to 48 hours apart. At each of these 6 visits, occlusal contacts were adjusted between the

teeth (FP+OA) or on the appliance (MRA+OA) both in centric relation and in lateral excursion and protrusion within the TMJ anatomical relationships. These adjustments occurred to obtain an ideal occlusion, in which the occlusal contacts of the habitual maximum intercuspal position coincide with the centric relation of the TMJ, resulting in a centric occlusion relationship.<sup>8</sup> Once the excursive movements began, tooth contact should only have occurred between the teeth used as a guide to lateral excursions (ie, the lower canines against the palatal surface of the upper canines) and protrusion (last phase of OA, between the incisal edges of the lower incisors and the palatal surface of the upper incisors), bilaterally and simultaneously, from the position of centric occlusion relationship. This movement should lead to decreased muscle stress and friction on the TMJ structures, promoting the harmony of the stomatognathic system (**Figure 2**).

### Evaluation and Poststudy Treatment

At each of the 6 visits for OA, before performing any adjustments, the effects of treatment were assessed by asking patients to rate the severity of their TMD-related symptoms on a visual analog scale (VAS) from 0 to 10, where 0 corresponds to no TMJ sound at all and 10 corresponds to maximum TMJ sound as reported by the patient at the baseline examination. Because the appliance was used only at night,

**Figure 2.**

A 25-year-old patient with unilateral (right side) temporomandibular joint (TMJ) clicking (A) before occlusal adjustment and (B) after occlusal adjustment. The patient reported no TMJ sounds and had bilateral balance in protrusive movements after treatment. The red markings indicate tracing made by friction between the upper and lower teeth on carbon paper.

patients were asked to rate the level of TMJ sound in the morning of the day of the scheduled visit before removing the appliance. After removal of the appliance, protective reflexes, which have been “recorded” in the central nervous system, are reactivated by dental occlusion and lead to muscle contractures or spasms triggered by occlusal dysfunction, making the mandible return to the habitual maximum intercuspal position.

At the sixth (final) visit, if the initial diagnosis by clinical examination (Phase 1) was confirmed by the use of a partial or full-arch splint (Phase 2), leading to changes in the level of TMD-related symptoms, the patient was eligible for occlusal treatment according to the concept of mutually protected occlusion (ENESSE questionnaire – Part II).<sup>16</sup> The proposed procedures were OA by grinding or addition (using prosthetic dentistry or oral rehabilitation) and, in some cases, orthodontics, orthognathic surgery, or a combination of part or all of these treatments, depending on the complexity of the TMD.

#### Statistical Analysis

Categorical variables were expressed as counts and percentages. Data on the outcome of patients with TMJ sounds were dichotomized into presence and absence of TMD-related symptoms from the first visit (initial VAS rating) to the sixth visit (final VAS rating). The McNemar test was used to compare the presence of symptoms before and after treatment in all patients

according to treatment strategy. For a symptom to be absent, the patient had to rate the severity of that symptom as 0. The Wilcoxon signed rank test was used to compare paired data between the initial and final VAS ratings. Statistical analyses were performed using SPSS (IBM) version 22.0, and significance was set at  $P<.05$ .

#### Results

The sample consisted of 199 patients with TMJ sounds, 161 (80.9%) with clicking and 38 (19.1%) with crepitus. Most patients were women (71.3%), and the group aged 41 to 60 years had the highest prevalence of TMJ sounds (43.2%). The characteristics of the sample are shown in **Table 1**.

**Table 2** shows the outcomes by treatment strategy. Of 115 patients with TMJ clicking who were assigned to the FP+OA strategy, 49 (42.6%) reported total remission and 66 (57.4%) reported a partial reduction or no improvement in the level of clicking. Of 46 patients with clicking assigned to the MRA+OA strategy, 23 (50.0%) reported total remission and 23 (50.0%) had partial or no improvement in symptoms. Of 35 patients with crepitus who were assigned to the FP+OA strategy, 15 (42.9%) reported total remission and 20 (57.2%) reported partial or no improvement in symptoms. All 3 patients with crepitus in the MRA+OA group reported total remission (**Table 2**).

**Table 1.**  
**Sociodemographic Characteristics of Patients With Temporomandibular Joint Sounds (N=199)<sup>a</sup>**

Variable	Crepitation (n=38)	Clicking (n=161)
<b>Sex</b>		
Male	15 (39.5)	42 (26.1)
Female	23 (60.5)	119 (73.9)
<b>Age, y</b>		
≤20	2 (5.3)	11 (6.8)
21-40	10 (26.3)	63 (39.1)
41-60	17 (44.7)	69 (42.9)
61-80	8 (21.1)	17 (10.6)
≥81	1 (2.6)	1 (0.6)
<b>Level of Education</b>		
Elementary	3 (7.9)	17 (10.6)
High school	16 (42.1)	58 (36.0)
College (bachelor's degree)	19 (50.0)	86 (53.4)

<sup>a</sup> Data provided as No. (%).

There was no significant difference between the 2 treatment strategies in the reduction of crepitition. However, among patients with clicking, improvement rates were significantly higher with the use of the MRA+OA strategy (50%) than with the use of the FP+OA strategy (42.6%) ( $P<.001$ , McNemar test) (Table 2).

Overall, regardless of the type of TMJ sound or treatment strategy, significant reduction was found in the number of patients reporting TMJ sounds in each group after treatment ( $P<.001$ , Wilcoxon signed rank test).

## Discussion

The present results indicate that the 2 treatment strategies using splint therapy combined with OA, FP+OA and MRA+OA, are effective in reducing TMJ sounds (both clicking and crepitition) as long as they provide bilateral contact balance between the incisal edges of the lower incisors and the palatal surface of the upper

incisors in the protrusive movement of the mandible. This finding is consistent with previous studies reporting that occlusion has an influence on the anterior region, resulting in TMJ disk placement.<sup>18-20</sup>

Occlusal interferences that occur in protrusion have been found to be positively related to clicking, and occlusion is frequently cited as a major cause of TMD—with TMJ sounds being one of the TMD-related signs.<sup>18,19,21</sup> However, studies examining factors related to incisal overbite and overjet, posterior crossbite, and lateral excursions based on retruded contact position to maximum intercuspatation suggest that, in patients with TMD, occlusal factors may be less important than previously believed.<sup>22,23</sup>

Multilocular bone cyst, leading to surface irregularities in the posterior part of the left eminence of the temporal bone, has also been reported as a factor that may cause TMJ clicking.<sup>24</sup> In 2 studies, the Research Diagnostic Criteria for Temporomandibular Disorders were used to distinguish between anterior disk displacement with reduction and symptomatic hypermobility during protrusive mouth opening and closing; in both studies, the authors found it challenging to make such a distinction with any certainty.<sup>25</sup>

The lateral pterygoid muscle is responsible for traction on the disk-condyle complex, thus displacing the disk and causing joint sounds,<sup>5</sup> which is related to the anatomy of the TMJ as reported in the present study. However, in many studies this muscle has not been palpated.<sup>26</sup> In a study investigating the relationship between TMJ disk displacement and osteoarthritis, magnetic resonance images of the TMJ showed no influence of body length or mandibular height on the occurrence of disk displacement.<sup>27</sup> However, magnetic resonance images have shown that there is a relationship between muscle tension, disk anatomy, and presence of joint sounds.<sup>26,28</sup>

For the management of TMJ sounds, studies have used stabilization splint therapy, often combined with OA and restorative treatment.<sup>11</sup> Other studies have interrelated TMJ sounds with occlusion during the protrusive movement of the mandible.<sup>20,29</sup>

**Table 2.**  
**Outcomes of Patients With TMJ Sounds by Treatment Strategy**

<b>Treatment Strategy</b>	<b>TMJ Sound</b>	<b>Presence of Symptoms by VAS Score<sup>a</sup></b>		<b>Symptoms Gone, No. (%)</b>	<b>P Value<sup>b</sup></b>
		<b>First (Initial) Visit</b>	<b>Sixth (Final) Visit</b>		
FP+OA (n=150)	Clicking	115	66	49 (42.6)	<.001
	Crepitation	35	20	15 (42.9)	<.001
MRA+OA (n=49)	Clicking	46	23	23 (50)	<.001
	Crepitation	3	0	3 (100)	NS

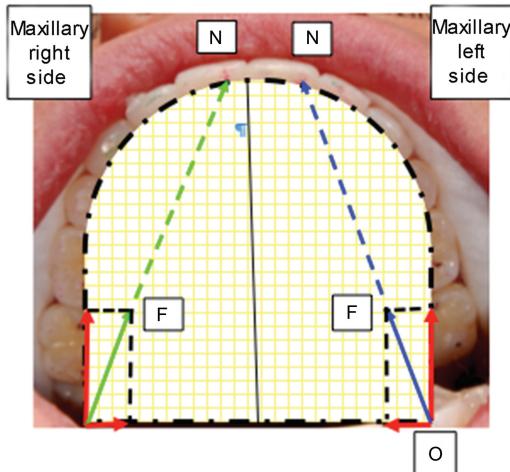
<sup>a</sup> A score of 1 to 10 indicated presence of symptoms. A score of 0 indicated no symptoms.  
<sup>b</sup> McNemar test; significant at  $P<.05$ .

**Abbreviations:** FP+OA, use of an anterior bite plane (Front-Plateau type) combined with occlusal adjustment; MRA+OA, use of a maxillary muscle relaxation appliance combined with occlusal adjustment; NS, nonsignificant; TMJ, temporomandibular joint, VAS, visual analog scale.

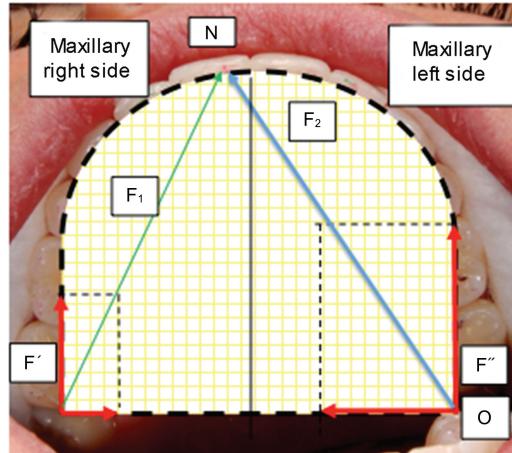
In the present study, the need for OA in the protrusive movement of the mandible can be explained by a force diagram schematically describing the occlusal forces applied to the teeth,<sup>30</sup> as shown in **Figure 3**. The simultaneous bilateral contact of the lower incisors in protrusion with the palatal surface of the upper incisors generates equal forces (F) on both sides. Conversely, if unilateral rather than bilateral contacts occur between the lower and upper incisors, they will generate asymmetric force components (F1 and F2) that run perpendicular to the midline and do not cancel each other out, as demonstrated by the force diagram schematically shown in **Figure 4**. The resultant force F2 starts at point O, which is the left-side TMJ of a patient with clicking, and ends at point N, coinciding with the right-side central incisor and being higher than the resultant force F1. Both forces (F1 and F2) run in the same direction as the lateral pterygoid muscles. Thus, based on the direction and intensity of force F2, we can conclude that the left lateral pterygoid muscle bundle has more freedom to displace the ipsilateral TMJ disk, because the mandibular hemiarch on this side is in contact only with the condyle on the articular eminence, with no support on the incisors. This lack of support can result in potential energy left over to the

left lateral pterygoid muscle, facilitating disk traction and generating joint sounds on this side because, during the protrusive movement, friction occurs only on the condyle on the left TMJ eminence—there is no friction between the teeth on this side. Therefore, according to the force diagram, the possible cause of disk displacement in this case (**Figure 4**) is the lack of contact between the left-side incisors. Also, friction between the condyle, the disk, and the articular eminence is reduced on this side, requiring less effort from the ipsilateral pterygoid muscle, which, with potential energy left over, can displace the disk from the condyle surface, thus causing joint sounds (clicking in this case).

For the management of severe TMJ clicking, injection of botulinum toxin A into the lateral pterygoid muscle was able to decrease the muscle action potential.<sup>31</sup> Studies have also demonstrated a tendency for the percentage of patients with clicking to decrease after orthognathic surgery, but improvements in crepitus were considered questionable.<sup>32</sup> Schiffman et al,<sup>33</sup> after the application of 4 treatment strategies (medical management, nonsurgical rehabilitation, arthroscopic surgery, and arthroplasty), found that nonsurgical treatment should be used for patients with TMJ closed lock

**Figure 3.**

Force diagram showing the simultaneous bilateral contact of the lower incisors in protrusion with the palatal surface of the left and right upper incisors (N), generating equal forces (F) on both sides. Abbreviation: O, left-side temporomandibular joint.

**Figure 4.**

Force diagram showing the forces acting on the maxillary teeth before occlusal adjustment with the mandibular teeth in a patient with clicking. The unilateral contact occurring between the lower and upper incisors generates asymmetric force components (F<sub>1</sub> and F<sub>2</sub>) that run perpendicular to the midline and do not cancel each other out, generating forces of different intensities (F' and F''), causing the joint sound (clicking). Abbreviations: O, left-side temporomandibular joint; N, right-side central incisor.

because there was no significant difference in outcomes between the examined treatment strategies.

In the present study, we focused on tooth support in the anterior region, protrusive movement, and the need to correct the bilateral balance between the anterior teeth, which was achieved by OA in centric relation and lateral excursions, facilitating the action of the muscles involved in each mandibular movement. We also highlight the importance of the occlusal contact that occurs on the opposite side of the joint sound during the protrusive movement of the mandible. Based on the observation of occlusal contacts in protrusion, we were able to accurately identify in more than 94% of cases that the joint sound was either on the right or on the left side during protrusive movements.

Both treatment strategies prioritized the concept of mutually protected occlusion, in which all jaw and TMJ movements are reciprocally interrelated and must synchronize, which may be conveniently done by using the force diagram. Additional studies on this topic should be conducted to investigate other forms of cause and effect that are associated with joint sounds in different treatment modalities.

## Conclusion

The 2 treatment strategies, FP+OA and MRA+OA, improved the level of TMJ sounds (both clicking and crepitus). These findings indicate that, in the management of TMJ sounds, it is necessary to correct the function between the mandibular and maxillary teeth in the absence of synchronization between the functions of the occlusal plane and of the 2 TMJs so that the muscles, tendons, and ligaments are spared, that they spend less energy, and that their tissue tone is maintained at normal levels. Occlusal adjustment in protrusion also allows the articular disks to remain on the condyle surfaces.

## Author Contributions

All authors provided substantial contributions to conception and design, acquisition of data, or analysis and interpretation of data; all authors drafted the article or revised it critically for important intellectual content; all authors gave final approval of the version of the article to be published; and all authors agree to be accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved.

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