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## Impact of functional mandibular advancement appliances on the temporomandibular joint - a systematic review

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### Abstract

**Background:** Although many orthodontists have no doubts about the effectiveness of functional appliances for mandibular advancement, the impact on the temporomandibular joint (TMJ) is still in dispute. The objective of this systematic review is to examine the main effects on the TMJ of using functional appliances, both in healthy patients and in patients with a pre-existing disorder.

**Material and Methods:** A systematic review of the literature was conducted in accordance with the PRISMA guidelines. Only systematic reviews, meta-analyses, randomized clinical trials (RCTs), case-control studies and cohort studies were included. A detailed language-independent electronic search was conducted in the Pubmed, Scopus, Cochrane Library and Embase databases. All studies published between 2000 and 2015 were included.

**Results:** A total of 401 articles were identified. Of these, 159 were duplicates and were excluded. On reading the title and abstract, 213 articles were excluded because they did not answer the research question, leaving a total of 29 articles. These articles were read and assessed. Following critical reading of the full text, eight articles were excluded: seven because they were considered of low quality and one because it published redundant data. As a result, 21 articles were included.

**Conclusions:** After treatment with functional appliances, the condyle was found to be in a more advanced position, with remodelling of the condyle and adaptation of the morphology of the glenoid fossa. No significant adverse effects on the TMJ were observed in healthy patients and the appliances could improve joints that initially presented forward dislocation of the disk.

**Key words:** Temporomandibular joint, TMJ, orthodontic appliances, functional, mandibular advancement, Herbst appliance, bionator.

## Introduction

The use of a mandibular advancement appliance to correct skeletal malocclusions associated with mandibular retrognathism is indicated during the first stage of orthodontic treatment (1). The objective is to stimulate mandibular growth and correct the sagittal misalignment by bringing the condyles forward and downward within the glenoid fossa (2,3), as well as remodelling the condyle and glenoid fossa, causing anterior rotation of the mandible and consequently projecting it forwards (4). During this first stage, mandibular retrognathism can be treated with either fixed or removable functional appliances (3,5). The treatment period lasts approximately 6 to 9 months (4).

When the functional appliance is inserted, the condyles are moved to a higher position in the articular eminence, which is capable of adaptation, so it could be hypothesized that some morphological changes may take place (6).

Although many orthodontists have no doubts about the effectiveness of functional appliances, their impact on the TMJ is still considered a subject of debate. It is therefore of clinical and scientific interest to investigate the most relevant effects of different functional appliances on the TMJ, particularly with current diagnostic methods. Many authors assert that treatment with these devices does not increase the prevalence of temporomandibular disorders (1,7-9). Another important aspect is the positive or negative effect that functional appliances may have on the TMJ of patients with a pre-existing disorder (1).

The main objective of this systematic review is to examine the main effects on the TMJ of different functional appliances for mandibular advancement, both in healthy patients and in patients with a pre-existing disorder.

## Material and Methods

A systematic review of the bibliography was carried out in accordance with the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) recommendations (10) and CONSORT criteria (11).

### - Eligibility criteria

The selection criteria for inclusion in the review were: articles, articles in press and reviews. Only the following types of study were accepted: systematic reviews, meta-analyses, randomized clinical trials (RCTs), case-control studies and cohort studies. Both retrospective and prospective studies were included. The articles that met these criteria and studied changes in the temporomandibular joint following the use of functional appliances for mandibular advancement were included in the review.

### - Search strategy and screening

To identify the relevant studies, irrespective of language, a thorough electronic search was conducted in the Pubmed, Scopus, Cochrane Library and Embase da-

tabases. All studies published between 2000 and 2015 were included. The search was updated on 4 July 2015. The search strategy was implemented through a combination of the following 6 MeSH terms: “Temporomandibular joint”, “TMJ”, “Functional orthodontic appliances”, “Mandibular advancement”, “Herbst appliance”, “Bionator” and “Activator appliances”, and others: “Fränkel Function Regulator”, “Orthodontic Appliances”, “Activator”, “Function Activator”, “Bionator Appliance”, “Functional Orthodontic” and “Twin Block”. The TMJ related terms were combined using the OR Boolean operator, as well as those related to the mandibular advancement devices. Both groups were combined using the AND Boolean operator. Hand-searching in the reference lists of the articles assessed for the review was also carried out.

Two independent reviewers assessed the titles and abstracts of all the articles selected. In the event of their disagreeing, a third reviewer was consulted. If the abstract did not provide sufficient information for a decision, the reviewers read the full article before taking the final decision. The reviewers then read the full text of all the resulting articles.

### - Data extraction

For each article assessed, the following variables were recorded: author, year published, type of study (retrospective, prospective, controlled, not controlled), sample size, dropouts, demographic variables (gender, age), type of appliance used, type of advancement (sequential or otherwise), presence or otherwise of pre-existing TMJ disorders, length of treatment, type of radiographic study used to study the changes, follow-up time for each study and quality of the articles accepted (Table 1). The articles were classified as being of high, medium or low quality according to the CONSORT criteria (11) adapted by Mattos *et al.* (12) and used by Fernández-Ferrer *et al.* and Serra-Torres *et al.* (13,14). The quality of the systematic reviews was assessed in accordance with the PRISMA guidelines (10).

## Results

A thorough search identified 201 articles in Medline, 168 in Scopus, none in the Cochrane Library and 32 in Embase, making a total of 401 articles. 159 duplicates were removed, leaving 242. After reading the title and abstract, 213 were removed because they did not answer the research question, leaving a total of 29 articles. These were read and carefully assessed. Detailed critical reading of the full text resulted in the exclusion of 8 articles, 7 because of their low quality (Fig. 1) and 1 because it published redundant data. Consequently, 21 articles that met all the inclusion criteria and were of medium to high quality were included in the review. It should be mentioned that the manual search did not identify any relevant articles.

**Table 1.** Articles included, with information from each.

Author/year	TS	N (dropouts) Gender (W/M)	Age (years)	Pre- existing disorder (Yes/No)	Functional advance- ment appliance	Advance- ment type	Length of use (months)	X-ray study	Assessments during follow-up	Q
Chintakanon <i>et al.</i> 2000 (19)	PC	40(0) 13 W, 27 M TG=19, CG=21	11.6 ± 1.3	-	TW	-	6	MR CTr	T0 T3: 6 m	M
Arat <i>et al.</i> 2001 (25)	PC	18 (0) 12 W, 6 M TG=9, CG=9	10.5	No	AC	-	6	MR CTr WX	T1 T3: 6 m	M
Watted <i>et al.</i> 2001 (27)	PNC	15 (0) 7 M, 8 W	11.6±0.6	-	BPE	-	12	MR	T0 T3: 12 m	M
Baltromejus <i>et al.</i> 2002 (5)	PNC	138 (0) 76 M, 62 W AC= 40, H= 98	11.5	-	AC H	-	AC= 31.2 H= 7.2	CTr	T2= AC= 2 y, 7 m H= 7 m	M
Franco <i>et al.</i> 2002 (17)	PC	56 (0) 29 M, 27 W TG=28, CG= 28	8.9 to 12.5	Yes	F	1S	18	MR	T0 T3: 18 m	M
Güner <i>et al.</i> 2003 (2)	PC	17 (0) 9 M, 8 W TG=10, CG= 7	13.9	-	MARS	-	10	SPECT	T0 T3: 10 m	M
Katsavrias <i>et al.</i> 2003 (6)	PNC	35 (0) 18 M, 17 W	8 to 15.1	-	AC	-	16	CTr	T0 T3: 15.96 m	M
Pancherz <i>et al.</i> 2003 (21)	PC	118 (83) 23 M, 12 W TG=23, CG= 12	13.7	-	H	-	7.5	CTr	T0 T3: 7.5 m T4: 2-4 y	M
Pancherz <i>et al.</i> 2004 (22)	PNC	118 (50) 42 M, 26 W	12.4	-	H	-	7	CTr	T0 T3: 7 m T4: 4/6 y	M
Kinzinger <i>et al.</i> 2006 (28)	PNC	15 (0) 8 M, 7 W	15.5	Yes	FAA	-	7.5	MR ME	T0, T1, T2 T3: 7.5 m	M
Kinzinger <i>et al.</i> 2006 (7)	PNC	20 (0) 11 M, 9 W	16	-	FAA	-	7.3	MR	T0, T1 T2: 3.65 m T3: 7.3 m	M
Kinzinger <i>et al.</i> 2006 (8)	PNC	20 (0) 11 M, 9 W	16	Yes	FAA H	-	7.3	MR	T0, T1 T2: 3.65 m T3: 7.3 m	M
Ruf <i>et al.</i> 2007 (26)	PNC	40 (4) 20 M, 20 W	11.9±1.3	-	VB AC	-	2	CTr	T0: 6 m before Tx T1 T4: 12 m	M
Kinzinger <i>et al.</i> 2007 (20)	PNC	20 (0) 10 M, 10 W	15.5	-	FAA	-	7.2	MR	T0, T1 T2: 3.3 m T3: 7.2 m	M
Serbis- Tsarudis <i>et al.</i> 2008 (4)	PC	64 (0) 29 M, 35 W TG= 40, CG= 24	12.3±1.3	-	H	-	7	CTr	T0, T3: 7 m T4: 31 m	A
Wadhawan <i>et al.</i> 2008 (15)	PNC	14 (2) 4 M, 10 W	10-14	No	TW B	-	6	MR	T0, T3: 6 m T4	M
Aidar <i>et al.</i> 2010 (1)	PNC	32 (9) 16 M, 16 W	12.9±1.2	Yes	H M	Seq	38.4±1	MR	T1, T2 T3: 12 m T4	M
Le Cornu <i>et al.</i> 2013 (3)	PC	14 (0) CG= 7, TG= 7	13.2	No	H	Seq	11.4±1	CBCT	T0 T3: 11.42± 1.4 m	M
Chavan <i>et al.</i> 2014 (16)	PC	30 (0) 17 M, 13 W TG= 20, CG= 10	9-14	-	TW B	-	6	MR	T0 T3: 6 m	M
Yildirim <i>et al.</i> 2014 (23)	RNC	30 (0) 16 M, 14 W	12.7	-	TW	-	7.4	CBCT	T0 T3: 7.4 m	M

TS = type of study, R/P = retrospective/prospective, C/NC = controlled/not controlled; N = sample size, M/W = men/women, TG = treatment group, CG = control group; TA = type of advancement, 1S = one-step, Seq = sequential; FA = functional appliance, AC = Activator, B = Bionator, BPE = Bionator plus extraoral, F = Fränkel, FAA = functional advancement appliance, FFA = functional fixed appliance, H = Herbst, H M = modified Herbst, TW = Twin Block, MARS = mandibular advancement repositioning splint, VB = Van Beek; RS = radiographic study, CAT = computed tomography, CBCT = cone beam computed tomography, CTr = cephalometric tracing, ME = manual examination, MR = magnetic resonance, SPECT= single proton emission computerized tomography, WX = wrist x-ray; FT = follow-up time, T0 = before treatment, T1 = at start of treatment, T2 = during treatment, T3 = immediately after treatment, T4 = later after treatment, Tx = treatment, d = days, s = weeks, m = months, y = years; Q = quality, M = medium, H = high.

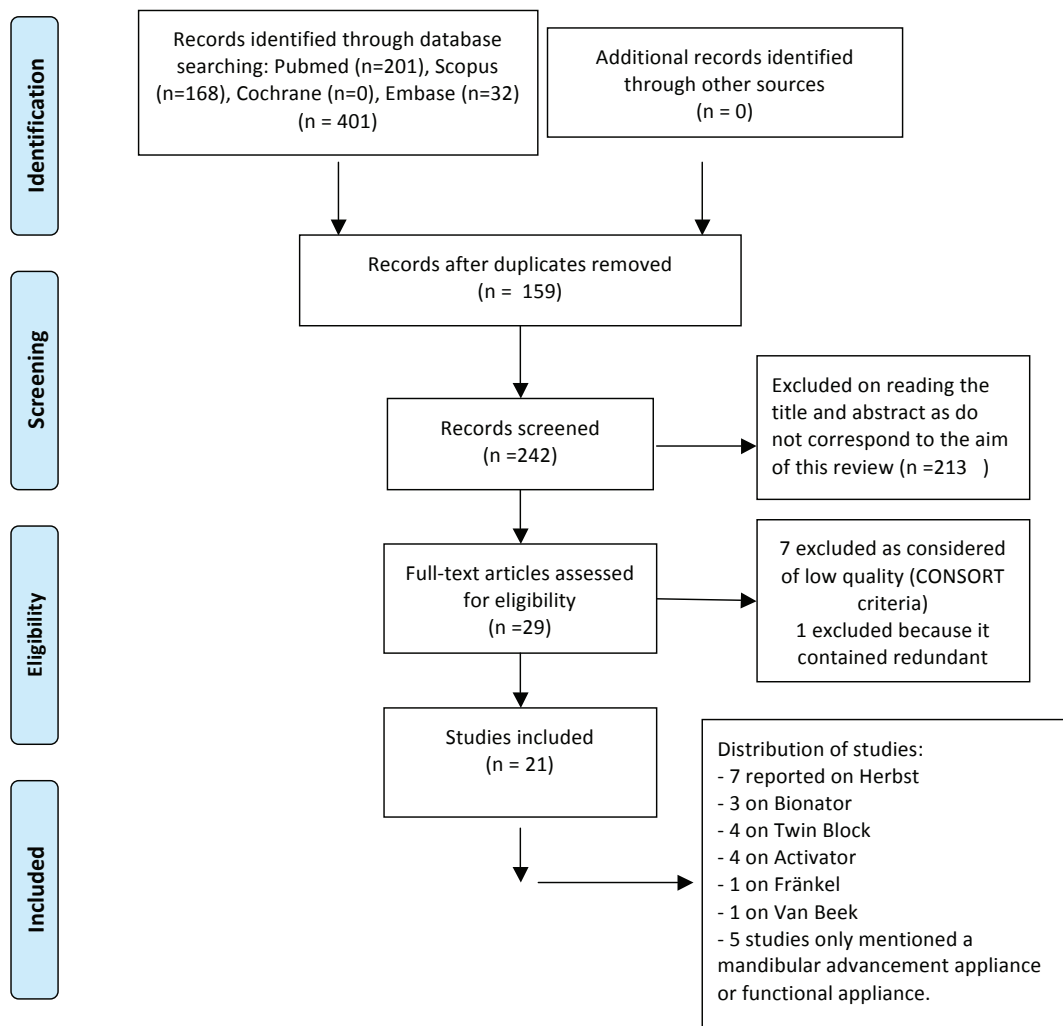


Fig. 1. Flow diagram.

Regarding the type of study reported in the 21 articles, 1 was a systematic review, 1 was a retrospective study and 19 were prospective studies. Of the prospective studies, 8 were controlled and 11 were not controlled (Table 1).

Concerning the state of the joint immediately prior to treatment, leaving aside the systematic review, only 8 of the studies explicitly mentioned its condition. Of these, 4 studied healthy joints and 4 studied joints with certain disorders (Table 2). The remaining 12 studies made no mention of joint status.

With regard to the type of appliance used, 7 studies used the Herbst appliance. Of these, 5 did not use control groups, 1 compared it with a functional advancement device and 1 with the Activator. The Bionator was studied in 3 articles, comparing it with the Twin Block in 2 cases. Two studies concerned the Twin Block alone, a further two the Activator alone and one the Fränkel, while another compared the Activator with the Van Beek. Three other articles did not name the type of

appliance, mentioning only a functional or mandibular advancement appliance.

Only three studies specified the type of mandibular advancement (sequential or one-step).

In relation to the type of diagnostic study, 8 used magnetic resonance, 2 CBCT, 1 SPECT (single-proton emission computed tomography), 6 cephalometric tracing, 1 magnetic resonance together with manual examination, 1 magnetic resonance as well as cephalometric tracing and wrist radiographs, and 1 used magnetic resonance and teleradiography.

Regarding the quality of the articles, 19 were of moderate quality and one of high quality. The systematic review was considered of high quality. The main conclusions drawn by the authors of the studies included in the present review are shown in table 3.

### Discussion

- Changes in disk shape and position

According to Wadhawan *et al.* (15), the anterior repo-

**Table 2.** Articles included, with information on pre-existing conditions.

Author/year	Prior TMJ status (no. of joints affected)	Subsequent TMJ status
Franco <i>et al.</i> 2002 (17)	<b>Control group</b> 7.1% AMDD 1.8% DDWR 5.3% DDNR 82.1% DB 10.7% DNB <b>Treatment group</b> 89.3% DB 10.7% DNB	<b>T3:</b> <b>Control group</b> 7.1% AMDD 10,7% DNB <b>Treatment group</b> 100% DNB
Kinzinger <i>et al.</i> 2006 (28)	<b>Mouth closed and open</b> 7 PADDWR 3 TADDWR 1 TADDNR	<b>T3:</b> <b>Joints with no disorder:</b> No change <b>Joints with a disorder:</b> 6 PADDWR 1 TADDWR 1 TADDNR
Kinzinger <i>et al.</i> 2006 (8)	<b>Mouth closed and open</b> 24 DDPR 3 TDDWR 12 PDDWR 1 TDDNR	<b>T3:</b> 30 DDPR 1 TDDWR 8 PDDWR 1 TDDNR
Aidar <i>et al.</i> 2010 (1)	<b>T1:</b> 11 ALDD	<b>T3:</b> 11 LDD <b>T4:</b> change from biconcave to not biconcave in 4 joints

AMDD = antero-medial disk displacement, ALDD = antero-lateral disk displacement, LDD = lateral disk displacement, PADDWR = partial anterior disk displacement with reduction, TADDWR = total anterior disk displacement with reduction, TADDNR = total anterior disk displacement with no reduction, TDDWR = total disk displacement with reduction, PDDWR = partial disk displacement with reduction, TDDNR = total disk displacement with no reduction, DDWR = disk displacement with reduction, DDNR = disk displacement with no reduction, DDPR = disk displacement with partial reduction; DB = disk biconcave, DNB = disk not biconcave.

sitioning of the condyle in the glenoid fossa caused by functional appliances results in stretching of the retro-discal tissue that could lead to changes in the shape of the disk or its posterior displacement, which agrees with the study by Chavan *et al.* (16). However, Aidar *et al.* (1) found no significant changes in disk position after treatment with the Herbst appliance. Franco *et al.* (17) observed no changes in comparison with the control group whether in healthy patients or in patients with antero-medial disk displacement, coinciding with the systematic review by Popowich *et al.* (18) and the study by Chintakanon *et al.* (19). Aidar *et al.* (9), in a previous study, made the same observation following 12 months' use of the Herbst appliance in adolescents whose disks were within the normal limits prior to treatment. In patients with prior disk displacement, these authors observed that it was not recaptured. However, Kinzinger *et al.* (20), using magnetic resonance, observed significant improvements in joints with an initial forward disk dislocation, agreeing with Kinzinger *et al.* (8), who also observed a lack of adverse effects in patients with a

good initial condyle-disk relationship, as did Katsavrias *et al.* (6). Panherz *et al.* (21) performed the same observation and indicated that the improvement in disk position depended on the extent of the initial displacement.

Concerning disk shape, Aidar *et al.* (9) reported a lack of adverse effects on articular disk morphology. Subsequently, the same authors (1) reached the same conclusion despite finding adverse effects in some patients at the end of the treatment, such as a change in disk shape from biconcave to not biconcave. Franco *et al.* (17), using magnetic resonance, observed that at the end of the treatment the number of biconcave discs had increased significantly in the patients treated with Fränkel appliances. As a result, they indicated that the use of this appliance at the beginning of the growth stage could help avoid future intra-TMJ problems.

- Changes in condyle size and position

In a case-control study of treatment with the Herbst appliance, Le Cornu *et al.* (3) observed forward adaptive displacement of the condyles followed by remodelling

**Table 3.** Studies by observations.

TMJ	Author/year	Q
After treatment with the Twin Block, the condyle occupied a more anterior position. There was no evidence that the Twin Block had a positive or negative effect on disk position, or that the disk was recaptured after the treatment.	Chintakanon <i>et al.</i> 2000 (19)	M
The functional appliances did not cause temporomandibular disorder. The condyles were displaced forwards. Although changes in disk position took place, the differences were not statistically significant.	Arat <i>et al.</i> 2001 (25)	M
No significant changes were found following treatment (Bionator). The TMJ and condyle-disk relationship retained their normal physiological status after treatment.	Watted <i>et al.</i> 2001 (27)	M
Favourable changes in the TMJ were observed in the sagittal plane, but were faster and better oriented for correcting the sagittal problem in the Herbst group than in the Activator group.	Baltromejus <i>et al.</i> 2002 (5)	M
There was no change in the position of the disk, but its shape improved (nearer to its normal biconcave form). The Fränkel appliance can help to avoid future TMJ problems.	Franco <i>et al.</i> 2002 (17)	M
Condylar growth was observed after using the functional appliance.	Güner <i>et al.</i> 2003 (2)	M
Changes in the angle and height of the articular eminence were observed, but were not statistically significant.	Katsavrias <i>et al.</i> 2003 (6)	M
The amount and direction of growth in parts of the TMJ such as the glenoid fossa and condyles were favourably affected, temporarily, in an anterior direction (Herbst).	Pancherz <i>et al.</i> 2003 (21)	M
The changes in the condyle and glenoid fossa were minor and not clinically relevant. The nature of the remodelling of condyle and fossa was not established.	Popovich <i>et al.</i> 2003 (18)	H
Antero-inferior displacement of the glenoid fossa and postero-superior condylar growth were observed. The latter was greater in hyperdivergent patients (Herbst).	Pancherz <i>et al.</i> 2004 (22)	M
No adverse effects were encountered in patients with no pre-existing disorder, and in patients with disorders the disk position improved.	Kinzinger <i>et al.</i> 2006 (28)	M
No change in the condyle-fossa relationship were observed following treatment, and the TMJ remained in a healthy state.	Kinzinger <i>et al.</i> 2006 (7)	M
The treatment has no adverse effects on patients without pre-existing disorders, and in patients with partial or total disk displacement prior to treatment, an improvement in disk position may take place.	Kinzinger <i>et al.</i> 2006 (8)	M
The Van Beek activator contributes to changes in the direction of condylar, maxillary and chin growth.	Ruf <i>et al.</i> 2007 (26)	M
Significant improvements in joints that presented forward disk dislocation.	Kinzinger <i>et al.</i> 2007 (20)	M
The condyle was shifted in a postero-superior direction in the group treated with the Herbst appliance. There were no adverse changes.	Serbesis-Tsarudis <i>et al.</i> 2008 (4)	H
The changes that took place returned to their initial state when the treatment ended, although the condyle and glenoid fossa were remodelled in a more forward position.	Wadhawan <i>et al.</i> 2008 (15)	M
In patients without a pre-existing disorder, no adverse changes took place. There were no changes in disk position or shape following treatment. However, adverse effects in disk shape (from biconcave to not biconcave) were observed in some patients.	Aidar <i>et al.</i> 2010 (1)	M
More anterior condyle position with adaptation of the glenoid fossa morphology and restricted maxillary growth (Herbst).	Le Cornu <i>et al.</i> 2013 (3)	M
The condyles moved forward during the treatment and returned to their initial position when it ended, although somewhat anterior to their pre-treatment location, while the disks presented a more posterior repositioning.	Chavan <i>et al.</i> 2014 (16)	M
Increased condyle volume, mandibular length and inter-condyle distance were observed, but no adverse effects.	Yildirim <i>et al.</i> 2014 (23)	M

Q = quality, M = medium, H = high.

of the glenoid fossa, compared with a control group that was only treated with fixed devices and class II elastic bands. These findings agree with those of Chintakanon *et al.* (19) and Chavan *et al.* (16). The latter conducted a controlled study using magnetic resonance and observed a more forward condyle position, although they recommended long-term follow-up to investigate the stability of their findings. In the same way, Pancherz *et al.* (22) observed that changes in condyle growth were greater

in men than in women and highlighted that treatment with the Herbst appliance temporarily stimulated condyle growth. A year later, in a new study of 118 patients classified according to their growth pattern, Pancherz *et al.* (22) concluded that condyle growth took place and was more posterior in hyperdivergent than in hypodivergent subjects.

In contrast to the above observations, Kinzinger *et al.* (20) found no significant differences in the glenoid

fossa-condyle relationship before and after treatment. Wadhawan *et al.* (15), using magnetic resonance, observed that the condyle and disk were displaced during treatment but returned to their initial position when the treatment ended. The systematic review by Popowich *et al.* (18) also concluded that the changes in condyle position were not clinically significant.

- Changes in the glenoid fossa

Pancherz *et al.* (21) observed antero-inferior displacement of the glenoid fossa as a reaction to the Herbst treatment. These authors asserted that the Herbst had an effect on the physiological growth of the fossa, temporarily displacing it forwards. However, the review by Popowich *et al.* (18) concluded that remodelling of the glenoid fossa had not been established, which agrees with the findings of Chintakanon *et al.* (19). Focusing on patients with different growth patterns, Pancherz *et al.* (22) concluded that there were no significant changes in the glenoid fossa between hyper- and hypodivergent subjects.

- Changes in the articular eminence and other changes

Reports on adaptations of the articular eminence caused by functional appliances are scarce. Katsavrias *et al.* (6) highlighted that the height of the articular eminence was not affected and that its angle suffered minor changes, but that these were insignificant.

With regard to other changes that may take place, according to the study by Le Cornu *et al.* (3) the Herbst appliance wearers exhibited restricted maxillary growth compared to the control group. Also, no great differences were found in the mandibular body and the growth of the ramus, in condyle flexibility or in changes in gonial angle. In contrast, Yildirim *et al.* (23) observed that treatment with the Twin Block increased the volume of the condyle, the length of the mandible and the intercondyle distance due to stimulation of condyle growth upwards and backwards.

- Limitations of this review

The scientific evidence collected on changes in the TMJ following the use of functional appliances was not abundant despite the thorough systematic search for articles that met the strict inclusion criteria and presented medium to high quality according to the CONSORT criteria.

TMJ status is a particularly important subject, yet this review has shown a lack of randomized controlled trials with long-term follow-up using diagnostic tests such as magnetic resonance and computed tomography to establish the effects of the functional appliance in a reliable way.

The articles included in the review show a lack of methodological homogeneity. For instance, Aidar *et al.* (9), Kinzinger *et al.* (20) and Wadhawan *et al.* (15) used magnetic resonance as a diagnostic method, while others such as Le Cornu *et al.* (3) and Arici *et al.*

(24) used CBCT. Yet others, like Baltromejus *et al.* (5) and Güner *et al.* (2), used cephalometric tracing. Many others, such as Arat *et al.* (25), preferred to use several methods to increase the accuracy of the results.

They also employed different appliances: while the great majority used the Herbst, others studied removable appliances such as Twin Block, Bionator (15,16), Fränkel (17) or Activator (25). Only one of the studies (5) compared fixed and removable appliances, namely Activator and Herbst, concluding that the Herbst appliance corrected the sagittal problems in less time than the Activator.

Additionally, the sample size was small in most of these studies: Le Cornu *et al.* (3) studied 14 patients, Ruf *et al.* (26) 40 patients and Katsavrias *et al.* (6) 35 patients. Watted *et al.* (27) and Kinzinger *et al.* (28) studied 15 patients. The study with the largest sample size was Baltromejus *et al.* (5), with 138 cases.

## Conclusions

- Following this review, it may be concluded that observations after treatment with functional appliances for mandibular advancement have found the condyle in a more advanced position, condyle remodelling and adaptation of the morphology of the glenoid fossa.
- No significant adverse events concerning the temporomandibular joint have been found in healthy patients, and this treatment could improve joints that initially presented forward disk dislocation.

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#### **Conflict of Interest**

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