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Systematic Review

Effectiveness of Functional Mandibular Advancer in Patients with Class II Malocclusion: A Systematic Review and Meta-analysis

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Main Points

- The functional mandibular advancer is a rigid, fixed functional appliance with bilateral protrusive bars and inclined planes which directs the mandible to anterior position.
- The design of the appliance is quiet simple and it has similar effects compared to other fixed functional appliances in Class II correction with a combination of skeletal and dentoalveolar effects.
- Evidence regarding the soft tissue and airway changes is limited to draw definitve conclusions.

ABSTRACT

Objective: We aimed to evaluate the effectiveness of functional mandibular advancer (FMA) in treating growing patients with Class II malocclusion.

Methods: Electronic searches were conducted in MEDLINE (via PubMed), Cochrane Library, Web of Science, Scopus, Embase, and Lilacs from 1945 to 30th November 2021. Studies were selected based on the following inclusion criteria: human studies, Class II growing patient treated with FMA, untreated control group or a comparable group treated with another fixed functional appliance, pre- and post-treatment lateral cephalograms/magnetic resonance imaging/cone-beam computed tomography, randomized clinical trials, prospective studies, and retrospective studies. Data extraction of the included articles was independently performed independently by two authors. The risk of bias was assessed using the ROBINS-I tool. Meta-analysis was performed using the inverse generic model.

Results: Seven articles met the criteria and were included in the systematic review and three articles were included in the meta-analysis. Three studies had at low risk of bias and four studies had a moderate risk of bias. All articles reported anterior positioning of the mandible along with an increase in mandibular length. The meta-analysis results indicated a negligible difference between FMA and other functional appliances for the parameters SNA [0.11, 95% confidence interval (CI) of -1.07 and 1.29] and ANB (-1.00, 95% CI of -1.34 and -0.65). The evidence was limited for soft tissue changes.

Conclusion: Class II correction with FMA involved a combination of skeletal and dentoalveolar changes and was similar to other fixed functional appliances.

Keywords: Mandibular retrognathism, functional mandibular advancer, Class II malocclusion, systematic review

INTRODUCTION

The primary treatment objective for correcting mandibular retrognathism in a growing patient is to induce supplementary lengthening of the mandible through functional appliance therapy.[1] Functional appliances are broadly categorized into removable functional appliances (RFAs), fixed functional appliances (FFAs), and hybrid appliances.[2] The key difference among these appliances is patient compliance, with RFAs and hybrid variants relying on patient cooperation, whereas full-time wear is ensured with the fixed type.[2]

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FFAs may be further sub-classified as fixed rigid, fixed flexible, and fixed hybrid.[3] Fixed rigid functional appliances provide constant horizontal forces, particularly when the mouth is closed, and they exhibit an additive headgear effect.[4] The consensus is that condylar growth can be effectively stimulated when functional treatment is performed during the adolescent growth spurt using rigid FFAs.[5]

The functional mandibular advancer (FMA) (Forestadent®, Pforzheim, Germany) is a rigid FFA introduced by Kinzinger et al.[6] in 2002 that resembles the mandibular anterior repositioning appliance.[7,8] The FMA relies on the mechanical principle of an inclined plane, which is inclined at 60° to horizontal, and the guide pins that direct the mandible to the anterior position.[6] Based on biomechanical considerations, the FMA has a more vertical intergnathic force vector and a remarkably shorter lever arm compared with the Herbst appliance.[6]

Studies have evaluated the skeletal, dentoalveolar effects and soft tissue changes in patients with Class II malocclusion treated with FMA, reporting varying conclusions.[9-11] Therefore, the aim of this systematic review was to evaluate the treatment effectiveness of FMA in patients with Class II malocclusion.

METHODS

Protocol and Registration

This systematic review was conducted and reported in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines.[12] The proposal was registered on the International Prospective Register of Systematic Reviews (PROSPERO: CRD42021227317). The research question was, "How effective is the Functional Mandibular Advancer in treating growing patients with Class II malocclusion in terms of skeletal, dental, soft tissue, and airway changes?"

Eligibility Criteria

Inclusion criteria were as follows: human studies, involving growing patients with Class II malocclusion (defined by an ANB angle greater than 4 degrees or an overjet greater than 6 mm) treated with FMA with or without fixed appliances, untreated control group or a comparable group treated with other FFA; pre- and post-treatment lateral cephalograms/magnetic resonance imaging (MRI)/cone-beam computed tomography (CBCT), lateral cephalograms and CBCT-derived lateral cephalograms were used to assess skeletal, dental, and soft tissue changes, whereas lateral cephalograms and MRI were used to assess the airway changes; randomised clinical trials, prospective and retrospective studies. The exclusion criteria were adult patients, patients with craniofacial syndromes, systematic reviews, meta-analysis, case series, case reports, expert opinion, and editorials.

Information Sources and Search Strategy

Electronic searches in MEDLINE (via PubMed), the Cochrane Library, Web of Science, Scopus, Embase, and Lilacs were conducted from 1945 to 30th November 2021. Search terms were based on both Medical Subject Headings (MeSH) and free text with combinations and were prepared for MEDLINE via PubMed and adapted for LILACS, Web of Science, Scopus, Ovid, Embase, and Cochrane electronic databases. The keywords and the search database summary are presented in Table 1.

Table 1. Summary of the search database

Keywords	Database	No of articles
((Class II malocclusion)) [Title/Abstract] AND ((Fixed Functional Appliance)[Title/Abstract] OR (Functional Mandibular Advancer))[Title/Abstract] AND ((Skeletal)[Title/Abstract] OR (Dental)[Title/Abstract] OR (Soft tissue)[Title/Abstract]OR (Airway)[Title/Abstract]OR (Condyle)[Title/Abstract]OR (Mandibular fossa) [Title/Abstract]OR (TMJ)[Title/Abstract])	Pubmed (From 1980 to 30th Nov 2022)	785
(Class II malocclusion) AND (Fixed Functional Appliance)	Lilac (From 1980 to 30th Nov 2022)	39
((Class II malocclusion)) AND ((Fixed Functional Appliance) OR (Functional Mandibular Advancer)) AND ((Skeletal) OR (Dental) OR (Soft tissue) OR (Airway) OR (condyle) OR (Mandibular fossa) OR (TMJ))	Ovid (From 1946 to 30th Nov 2022)	1550
"Class II malocclusion" in Title Abstract Keyword AND "Fixed Functional Appliance" in Title Abstract Keyword OR "Functional Mandibular Advancer" in Title Abstract Keyword AND "Skeletal" in Title Abstract Keyword AND "Dental" in Title Abstract Keyword.	Cochrane (From 1945 to 30th Nov 2022)	25
TITLE-ABS-KEY((Class II malocclusion)) AND TITLE-ABS-KEY ((Fixed Functional Appliance) OR TITLE-ABS-KEY (Functional Mandibular Advancer)) AND TITLE-ABS-KEY ((Skeletal) OR TITLE-ABS-KEY (Dental) OR TITLE-ABS-KEY (Soft tissue) OR TITLE-ABS-KEY (Airway) OR TITLE-ABS-KEY (condyle) OR TITLE-ABS-KEY (mandibular fossa) OR TITLE-ABS-KEY (TMJ))	Scopus (From 1960 to 30th Nov 2022)	308
ALL FIELDS:((Class II malocclusion)) AND ALL FIELDS: ((Fixed Functional Appliance) OR ALL FIELDS:(Functional Mandibular advancer)) AND ALL FIELDS: ((Skeletal) OR ALL FIELDS:(Dental) OR ALL FIELDS:(Soft tissue) OR ALL FIELDS:(Airway) OR ALL FIELDS:(Condyle) OR ALL FIELDS:(Mandibular fossa) OR ALL FIELDS:(TMJ))	Web of science (From 1952 to 30th Nov 2022)	161
TOTAL		2868
DUPLICATES		118
TOTAL AFTER DUPLICATES REMOVAL		2750

Study Records

The selection of the studies consisted of two phases. The initial screening of articles identified in the databases involved independent screening of titles and abstracts by two reviewers based on the research question and against the inclusion and exclusion criteria. In cases where the title and abstract failed to provide sufficient information, the full text was reviewed to assess relevance. In the second phase, full-text articles were retrieved from these potentially eligible studies. To ensure that no relevant studies were missed, the reference lists of the remaining articles were hand-searched. Articles identified using this process were added to the pool of full-text articles for evaluation. This pool was then assessed for eligibility for both quantitative and qualitative reviews.

Data Items and Collection

Data extraction from the included articles was independently performed by two authors using a pre-determined and standardized table. The predefined data to be extracted included the title, author, study type, age, gender, population, sample size, assessment method, skeletal and dental cephalometric findings, including mandibular and maxillary dimensions, mandibular and maxillary anteroposterior positions, vertical dimensions, sagittal intermaxillary relationship, mesiodistal position of maxillary and mandibular first molars, inclination of maxillary and mandibular incisors, and P values.

Outcome

The outcomes for which data would be sought included skeletal, dental, soft tissue, and airway changes.

Risk of Bias/Quality Assessment

For non-randomized studies the risk-of-bias was assessed using the ROBINS-I tool for non-randomized studies (risk of bias in non-randomised studies of interventions).[13] The following domains were evaluated; 1. Confounding bias, 2. Selection bias, 3. Bias in classification of interventions, 4. Bias due to deviation from intended interventions, 5. Missing data, 6. Measurement of outcomes, 7. Bias in selection of reported result.

Two reviewers independently assessed all included studies, and disagreements were resolved through discussion and consensus, or the decision of the third reviewer.

Data Synthesis

The studies were grouped based on the assessed data. For each article that met the inclusion criteria, data were extracted and compiled into a table of evidence. Analysis was performed according to the Cochrane Handbook for Systematic Reviews. Data were analyzed using Review Manager (RevMan) 5.3.[14] Continuous data are presented as mean difference and 95% confidence interval. An inverse variance method for pooling the data with a random-effects model was used for the meta-analysis. Heterogeneity was assessed with I2 statistics that ranged from 0% to 100%.[15] An I2 index less than 25% is indicative of low heterogeneity, between 25% and 75% represents average heterogeneity, and more than 75% indicates considerable heterogeneity.[16] The coefficient of efficiency of FMA was assessed by dividing the supplemental elongation of the mandible obtained during the overall active treatment period with the functional appliance by the number of months of active treatment.[5]

RESULTS

Study Selection

The search selection process is depicted in the PRISMA flowchart (Figure 1). According to the electronic search, 2,868 records were screened across all databases. After removal of duplicates, 2750 records were screened, of which 2,728 articles were eliminated after reading the title and abstracts. Of the 22 full-text articles, 15 studies were excluded from the review, and the reasons for exclusion are depicted in the PRISMA flow chart (Figure 1).

Study Characteristics

Of the seven included studies that met the inclusion and exclusion criteria, Kinzinger et al.[17] compared the airway and skeletal changes caused by FMA. Three studies[11,18,19] have evaluated the skeletal and dental changes caused by FMA and compared them with other FFAs. Hourfar et al.[10] compared soft tissue changes, Kinzinger et al.[9] evaluated the skeletal and dental effects caused only by FMA, and Aras et al.[20] evaluated the airway changes produced by the type of advancement (either single step or stepwise) of FMA.

Four studies were prospective[9,11,19,20] and three were retrospective.[10,17,18] The total number of FMA patients across the seven studies was 163 (81 males and 82 females), with a minimum sample of 16 patients[9] and a maximum sample of 21 patients.[18] In five studies,[9,10,17,18,20] participants were selected based on chronologic age, and their age ranged from a minimum of 13.15 years to a maximum of 16.2 years. One study was based on the cervical vertebral maturation index by Baccetti et al.[21] with 20 participants at cervical stage 2 and 18 participants at cervical stage 3.[19] Another study was based on hand-wrist radiographs by Hagg and Taranger[22] with a growth period just before or at the peak of pubertal growth.[11] The summarized results of individual studies are shown in Table 2.

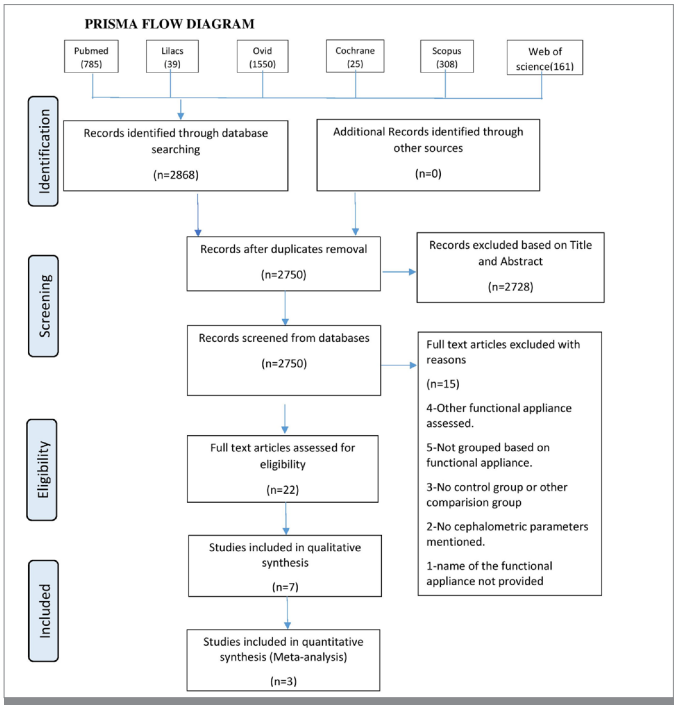

Figure 1. Literature search Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) flow diagram

Table 2. Characteristics of the included studies

	Journal name/year	Study type	Participants	Mean age of participants	Treatment duration for participants	Control/ comparision group	Mean age of control/ comparision	Treatment duration for control/ comparision
Kinzinger et al.[9]	J Orofac Orthop 2005	Prospective study	FMA-16 patients	15 years and 5 months males-16 years, 1 month females-14 years, 9 months	7.5 months	Bhatia & Leighton in 1993	No data	No data
Kinzinger et al.[17]	J Orofac Orthop 2011	Retrospective study	FMA-18 patients	15 years and 7 months	FMA and MBA treatment= 18 months.	HERBST-25 patients	13 years and 8 months	Herbst and MBA treatment- 19.5 months
Aras et al.[11]	Angle Orthodontist 2017	Prospective study	FMA SSG-17 patients	Hand-wrist radiographs-just before or at the peak of pubertal growth	10 months	FMA SWG-17 patients	Hand-wrist radiographs-just before or at the peak of pubertal growth	10 months
Kinzinger et al.[18]	Clin Oral Invest 2018	Retrospective study	FMA-21 patients	Male-16 years and 2 months female-15 years and 9 months	1.32 ± 0.71 years.	HERBST-21 patients	Males-12 years and 1 month females-13 years and 2 months	1.46±0.38 years
Bozkurt et al.[19]	AJODO 2020	Prospective study	FMA-19 patients	Cervical Stage 2- 9 patients (5 boys and 4 girls) Cervical Stage 3-10 patients (6 boys and 4 girls)	2±0.2 years	FORSUS-19 patients	Cervical Stage 2- 11 patients (5 boys and 6 girls) Cervical Stage 3- 8 patients (5 boys and 3 girls)	2.3±0.5 years
Aras et al.[20]	J Orofac Orthop 2016	Prospective study	SSG-17 patients SWG-17 patients	SSG- 13.15±0.77 years SWG- 13.48±0.88 years	Functional phase-10 months second phase- SSG-20.48±2.15 months SWG-19.16±2.67 months	Untreated-17 patients	13.76±0.62 years	18.9±3.8 months
Hourfar et al.[10]	Clin Oral Invest 2018	Retrospective study	FMA-21 patients	Males-16 years and 2 months Females-15 years and 9	1.32 ± 0.71 years.	HERBST-21 patients	Males-12 years and 1 month. Females-13 years and 2 months	1.46±0.38 years

Three studies compared FMA with the Herbst appliance,[10,17,18] one study compared FMA with the Forsus appliance,[19] two other studies had untreated Class II patients as control group[9,20] and one study compared the single-step and step- wise advancement of FMA.[11] The study duration was until the end of the functional appliance phase in five studies ranging from a minimum of 7.5 to a maximum of 13.2 months.[9-11,18,20] The study duration was until the end of the fixed appliance phase in two studies, ranging from a minimum of 18 to a maximum of 24 months[17,19] (Table 3).

Risk of Bias in the Studies

The ROBINS-I tool was used to assess the risk of bias.[13] In terms of overall risk of bias, four of these studies were assessed as having a moderate risk of bias.[10,17,18,20] Lower scores were obtained from these studies in the domains of confounding bias, selection bias, and intervention classification. Three studies had a low risk of bias[9,11,19] (Table 4).

Synthesis of the Results

Skeletal Changes

The maximum and minimum sagittal increases in mandibular length (Co^{dorsal}-Pog) were 3.4 3.4±4.69 mm (18 months) and 0.69±3.5 mm (13.2 months) respectively.[17,18] The maximum increase in the SNB angle was 2.41±0.91°[19] and the minimum increase in the SNB angle was 1.29±1.34°.[17] The maximum decrease in the ANB angle was -2.64±0.61°[19] and the minimum decrease in the ANB angle was -0.98±1.34°.[17] Kinzinger et al.[17] reported an increase in the SNA angle by 0.32±1.44° whereas Bozkurt et al.[19] reported a decrease by -0.23±0.46°. The maximum

Table 3. Risk of bias in studies-the table displays for each included study the risk-of-bias judgement for each of six domains of bias and for the overall risk of bias with ROBINS 1 tool

No	Author	Bias due to confounding	Bias in selection of participants into the study	Bias in classification of interventions	Bias due to deviations from intended interventions	Bias due to missing data	Bias in measurement of outcomes	Bias in selection of the reported result	Overall bias
1	Kinzinger et al.[9]	Moderate	Moderate	Low	Low	Low	Low	Low	Low
2	Kinzinger et al.[17]	Moderate	Moderate	Moderate	Low	Low	Low	Low	Moderate
3	Aras et al.[11]	Moderate	Low	Low	Low	Low	Low	Low	Low
4	Kinzinger et al.[18]	Moderate	Moderate	Moderate	Low	Low	Low	Low	Moderate
5	Bozkurt et al.[19]	Moderate	Low	Low	Low	Low	Low	Low	Low
6	Arasl et al.[20]	Moderate	Moderate	Low	Low	Low	Low	Low	Moderate
7	Hourfar et al.[10]	Moderate	Moderate	Moderate	Low	Low	Low	Low	Moderate

Table 4. Results of individual studies

Kinzinger et al.[9]	**SKELETAL EFFECTS**			**DENTAL EFFECTS**	
	Maxilla	**Mandible**		**Maxilla**	**Mandible**
	No treatment effect on the maxilla occurred and the position of the maxillary base remained stable	Effective increase in mandibular length sagitally and sagittal-diagonally. Bony chin advanced significantly (N-Pog on FH). Gonial angle changes also significant		Central incisors were retracted. Molars were distalized.	Central incisors had protruded. Molars tipped mesially. Reduction in overjet.
Kinzinger et al.[17]	**SKELETAL EFFECTS**				
	Maxilla	**Mandible**	**Pharyngeal distance**		
	Significant increases in the vertical length of the maxilla (S-ANS, S-PNS and N-ANS). No significant changes in the position of the anterior maxillary base relative to the anterior cranial base (SNA).	Linear: S-Go, N-Gn, N-Pog, and N- Me increased. Diagonal: Ba-Pog and Codorsal-Pog increased. Forward development of the mandible (SNB, SN-Pog). No significant difference in gonial angle ANB angle statistical decrease in FMA group.	No significant changes.		
Aras et al.[11]	**SKELETAL EFFECTS**			**DENTAL EFFECTS**	
	Mandible			**Maxilla**	**Mandible**
	Positioned anteriorly. SNB, mandibular length and ramus height increased, Pg and ANB angle decreased horizontally. Gonial angle no significant difference.			Palatal tipping of maxillary incisors. No distal movement of maxillary molars (due to palatal arch).	Mesial movement of mandibular molars, labial tipping of the mandibular incisors, and decrease in overjet and overbite. No significant intergroup differences were found for dental changes.
Kinzinger et al.[18]	**SKELETAL EFFECTS**			**DENTAL EFFECTS**	
	Maxilla	**Mandible**		**Maxilla**	**Mandible**
	Increased N-ANS and N-PNS. NO change in maxillary length (N-ANS on FH and Ba-PNS).	S-Go and N-Me increased. Codorsal-PTV - decreased		Greater retroclination of upper incisors. Mesial tipping of Upper molars. Greater antero-caudal cant of the occlusal plane.	Greater proclination of lower incisors, and mesial tipping of lower first molars.

Table 4. Continued

Bozkurt et al.[19]	**SKELETAL EFFECTS**			**DENTAL EFFECTS**	
	Maxilla	**Mandible**		**Maxilla**	**Mandible**
	No skeletal maxillary effect	Increase in SNB and Co-Gn. Co-Go and SNGoGn no significant change. ANB and WITS - decreased.		No significant change in position of maxillary incisors, horizontal and vertical position of maxillary molars.	Significant changes in proclination of mandibular incisors, overjet, overbite and mesial movement of mandibular molars.
Aras et al.[20]	**AIRWAY**				
	Nasopharyngeal	**Oropharyngeal**	**Hypopharyngeal**		
	Increased significantly in the SSG and SWG ($p<0.05$)	Oropharyngeal airway, minimal distance between the base of the tongue and the posterior pharyngeal wall (PASmin) in the SWG and SSG increased significantly ($p<0.05$).	Hypopharyngeal airway, soft palate length and thickness- NOT SIGNIFICANT		
Hourfar et al.[10]	**SOFT TISSUE**				
	Significant lower lip protrusion (Li-Sn on FH) ($p<0.01$) Straightening of the profile (N'-Sn-Pog', soft tissue profile excluding nose) ($p<0.05$)				

and minimum sagittal decreases in anterior maxillary length (N-ANS on FH) were 0.38 -0.38±2.63 mm and -0.07±0.24 mm.[18,19] The average coefficient of efficiency for FMA was 0.19 mm per month.[9] The results are depicted in Tables 5 and 6.

Dental Changes

The maximum retraction of the upper incisors and distalization of the upper molars were 1.79±2.58 mm and 2.24±3.47 mm respectively.[18] The minimum retraction of upper incisors and distalization of upper molars were 1.76±1.81 mm and 1.62±1.38 mm respectively.[9] The maximum proclination of lower incisors and mesialization of lower molars were 2.66±1.85 mm and 2.26±2.05 mm respectively.[9] The minimum proclination of lower incisors and mesialization of lower molars were 2.42±2.69 mm and 1.62±3.2 mm respectively.[18]

Soft Tissue Changes

Hourfar et al.[10] was the only study evaluating soft tissue changes. There was an improvement in the lower lip position and facial convexity angle by -0.14±1.93 mm and 2.72±4.69°, respectively.

Airway Changes

Aras et al.[20] assessed airway changes with single-step and stepwise advancement of FMA. The mean improvements in the nasopharyneal, oropharyngeal, and hypopharyngeal airways in the single step group were 1.39±2.31 mm, 1.59±2.01 mm and 1.05±2.24 mm respectively. The mean improvements in the nasopharyneal, oropharyngeal, and hypopharyngeal airways in the stepwise group were 1.35±2.51 mm, 1.69±2.08 mm and 0.98±2.04 mm respectively. Kinzinger et al.[17] assessed the posterior airway space at six levels [palatal plane (P1), occlusal plane (P2), second cervical vertebra (P3), mandibular plane (P4), third cervical vertebra (P5), and fourth cervical vertebra (P6)] and reported a decrease in posterior airway space at P1, P2, P3, and P4 levels by 0.47±2.8 mm, 0.85±2.56 mm, 0.32±3.25 mm and 0.4±2.58 mm respectively. The posterior airway space increased at P5 and P6 levels by 0.63±3.28 mm and 1.85±5.32 mm respectively.[17]

Quantitative Analysis

A meta-analysis was planned for homogeneous data. There was an increase in the SNA angle by 0.11 degrees in the FMA group when compared with other FFAs (95% CI of-1.07 to 1.29). The I^2 was 67%, showing moderate heterogeneity. The N-ANS distance increased by 0.14 mm in the FMA group when compared with other FFAs (95% CI of -0.77 to 1.04). The I^2 was 47%, showing low heterogeneity. The N-PNS distance decreased by -0.17 mm in the FMA group compared with other FFAs (95%

Table 5. The table displays maxillary changes achieved with functional mandibular advancer

	SNA			N - ANS on FH			Ba - PNS		
	MD	**SD**	**p-value**	**MD**	**SD**	**p-value**	**MD**	**SD**	**p-value**
Kinzinger et al.[9]	NA	NA	NA	-0.07	0.24	0.262	-0.08	0.41	0.435
Kinzinger et al.[18]	NA	NA	NA	-0.38	2.63	0.517	0.19	2.04	0.6674
Kinzinger et al.[17]	0.32	1.44	0.3633	NA	NA	NA	NA	NA	NA
Bozkurt et al.[19]	-0.23	0.46	0.018	NA	NA	NA	NA	NA	NA

Student's t-test, NA, not applicable; MD, mean difference; SD, standard deviation; NA, not applicable; SNA, Sella-Nasion-A, Statistical significance $p<0.05$

Table 6. The table displays mandibular changes achieved with functional mandibular advancer

	Horizontal distances								Diagonal distances				Gonial angle			
	SNB		N - Pog on FH		Co^{dorsal} - PTV				Co^{dorsal} - Pog		$Co^{superior}$ - Gn		Ar - Go - Me		Co^{dorsal} - Go - Pog	
	MD	SD	p-value	MD	SD	p-value	MD	SD	p-value	MD	SD	p-value	MD	SD	p-value	MD	SD	p-value
Kinzinger et al.[9]	NA	NA	NA	1.28	0.52	0	0.43	0.93	0.084	1.42	1.51	0.002	1.53	2.15	0.012	1.14	1.34	0.004	0.97	1.51	0.022
Kinzinger et al.[17]	1.29	1.34	0.0008	NA	NA	NA	NA	NA	NA	3.4	4.69	0.0069	NA	NA	NA	-1.29	6.35	0.399	NA	NA	NA
Kinzinger et al.[18]	NA	NA	NA	0.58	4.42	0.5534	-0.66	1.98	0.1451	0.69	3.5	0.3757	0.66	2.81	0.296	1.55	3.47	0.054	1.19	3.26	0.1115
Bozkurt et al.[19]	2.41	0.91	0.001	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA

(Student's t test, MD, mean difference; SD, standard deviation; NA, not applicable; SNB, Sella-Nasion-B., Statistical significance $p<0.05$)

CI of -1.49 to 1.14). I^2 was 60%, showing moderate heterogeneity (Figure 2).

The ANB angle brought about a greater reduction by 1 degree in FMA group compared with other FFAs (95% CI of -1.34 to -0.65). I^2 was 0%, showing low heterogeneity (Figure 3).

The SNB angle had a greater increase by 0.81 degrees in FMA group when compared with other FFAs (95% CI of -0.78 to 2.39). The I^2 was 89%, showing considerable heterogeneity. The Co^{dorsal}-Pog distance decreased by -1.00 mm in the FMA group when compared with other FFAs (95% CI of -2.65 to 0.65). The I^2 was 0%, showing low heterogeneity. The gonial angle brought about a greater increase by 0.74 degrees in FMA group when compared to other FFAs (95% CI of -1.22 to 2.71). The I^2 was 0%, showing low heterogeneity. The S-Go distance brought about a greater decrease by 0.29 mm in the FMA group when compared to other FFAs (95% CI of -1.46 to 0.88). The I^2 was 0%, showing low heterogeneity. The N- Me distance brought about a greater decrease by -0.74 mm in the FMA group when compared with other FFAs (95% CI of -2.66 to 1.17). The I^2 was 0%, showing low heterogeneity (Figure 4).

DISCUSSION

In this systematic review, the study group consisted of patients with Class II malocclusion treated with an FMA appliance, and

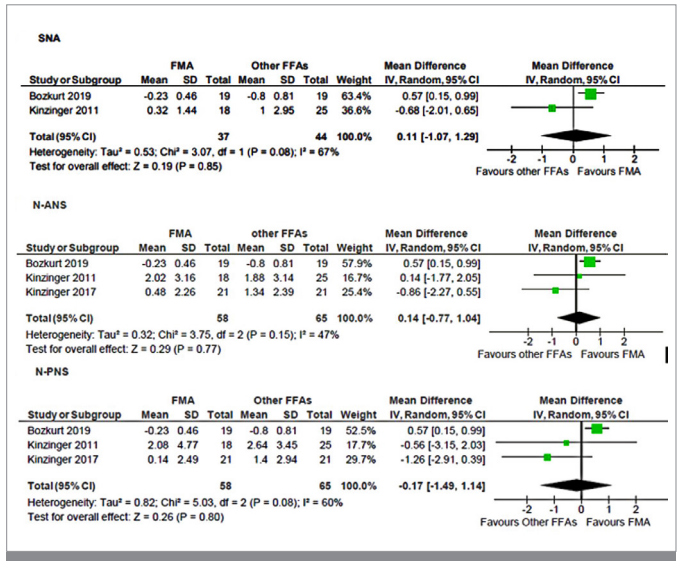

Figure 2. Forest plots comparing Maxillary changes- SNA angle, N-ANS, N-PNS for FMA versus other FFAs

df, degrees of freedom; CI, confidence interval.

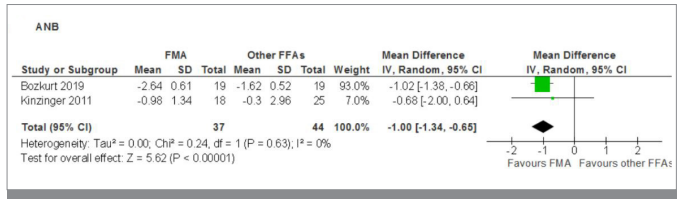

Figure 3. Forest plots comparing maxillo-mandibular changes- ANB angle for FMA versus other FFAs

df, degrees of freedom; CI, confidence interval.

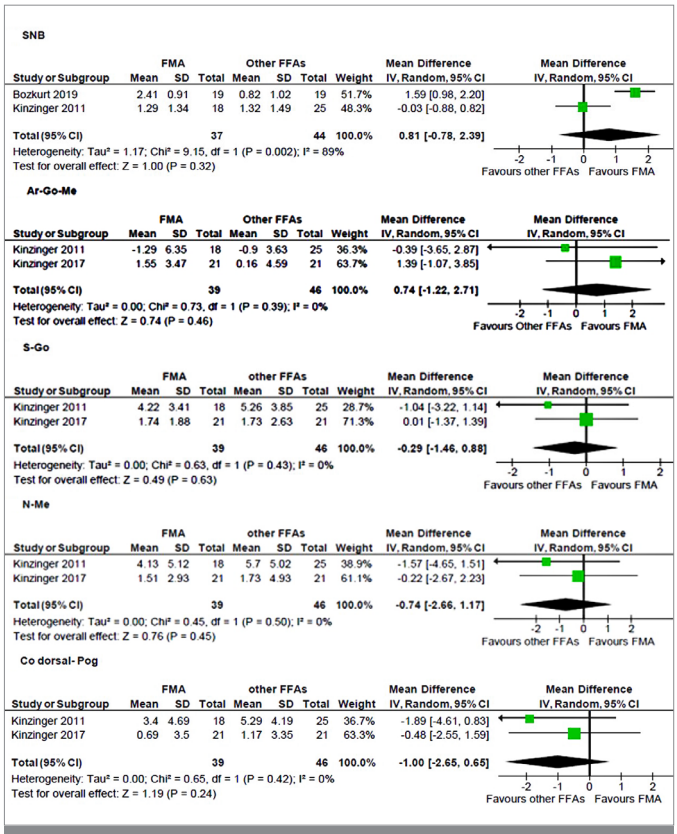

Figure 4. Forest plots comparing Mandibular changes-SNB angle, Gonial angle (Ar-Go-Me), S-Go, N-Me, Codorsal-Pog for FMA versus other FFAs
df, degrees of freedom; CI, confidence interval.

the control group consisted of patients with either untreated Class II malocclusion or those treated with a fixed appliance or with other FFAs. The research question of this systematic review was to evaluate "how effective is the FMA in treating growing patients with Class II malocclusion?".

The risk of bias in the seven selected articles was assessed by two authors using the ROBINS-I tool for non-randomized studies.[13] Three studies[9,11,19] were graded as having a low risk of bias and four studies[10,17,18,20] were graded as having a moderate risk of bias due to the risk of confounding, selection of participants into the study, and classification of interventions. Seven studies were included in the systematic review[9-11,17-20] and three studies were included in the meta-analysis.[17-19] Four studies were excluded from the meta-analysis because two studies[9,11] did not have a control group and two studies[10,20] had no comparable data to be combined for a meta-analysis.

Skeletal Changes

The meta-analysis of the maxillary and mandibular changes showed no significant difference between FMA and other FFAs. The studies included in the above meta-analysis evaluated effects only with FFAs and a combination of FFAs and FAs; hence, the results should be interpreted with caution.

The meta-analysis with maxillomandibular changes showed a significantly greater reduction by 1 degree, indicating a better Class II correction with the FMA group. This conclusion of the meta-analysis is further strengthened, more reliable, and less prone to bias as the phase of FAs would be common to both groups. Subgroup/sensitivity and GRADE analyses were planned but could not be performed. Subgroup and Sensitivity analysis could not be performed because none of the included studies were classified as high risk of bias.[23] GRADE analysis could not be performed because the studies included in the meta- analysis were non-randomized clinical trials, and the GRADE baseline rating for non-RCTs starts with low.[24]

Kinzinger et al.[18] reported an increase in the gonial angle with FMA, leading to clockwise rotation of the mandible. There was a greater improvement in the mandibular position, as shown by SNB. However, FMA had a lesser effect on mandibular length than other FFAs. The increase in the gonial angle displaces the cephalometric reference point pogonion caudally and dorsally, which would have influenced the treatment-related change in the length of the mandible.[18]

Five studies reported that there was no treatment-induced effect of FMA on maxillary length, and the position of the maxilla remained stable even after treatment.[9,11,17-19] Similar findings were reported in systematic reviews of RFAs.[25,26] On the contrary, systematic reviews of FFAs showed a restraining effect on maxilla.[27,28] Kinzinger et al.[9] was the only study to assess the total mandibular length after active treatment with FMA when compared with the untreated control group, and the coefficient of efficiency was 0.19 mm per month. This was lesser when compared with the Herbst appliance (0.28 mm per month) and twin block (0.23 mm per month) but greater than bionator (0.17 mm per month), activator (0.12 mm per month), and Frankel appliance (0.09 mm per month), which were reported by Cozza et al.[5]. Because all the studies were conducted on growing patients, the skeletal changes were always based on the cumulative effect of natural growth processes and treatment-induced effects.[9]

Dental Changes

In the mandibular arch, four studies reported proclination of the incisors with mesial tipping of molars and a decrease in overjet.[9,11,18,19] In the maxillary arch, three studies reported retroclination of incisors.[9,11,18] Bozkurt et al.[19] reported that there was no change in the position of maxillary incisors and molars in the FMA group. The probable reason could be that the measurements were a combination of functional and fixed appliance therapy, which would have influenced the position of the maxillary incisors and molars.[19] Kinzinger et al.[18] reported that the maxillary molars tipped mesially in contrast to another study by the same author where the molars tipped distally.[9] These findings suggest that dentoalveolar changes also contribute to Class II correction. This was in accordance with systematic reviews on FFAs, which showed that maxilla-mandibular correction is a combination of skeletal and dental changes with proclination of mandibular incisors, mesial movement of lower molars, retroclination of maxillary incisors, and distal movement of maxillary molars.[25,26,29,30]

Soft Tissue and Airway Changes

Hourfar et al. reported straightening of the profile, retrusion of the upper lip and protrusion of the lower lip, an increase in lower lip thickness, and an increase in lower facial height in patients with patients.[10] The lip changes were evaluated using the E line as the reference line, which might have contributed to the difference in the results.[21] A recent systematic review also reported straightening of the soft tissue profile after treatment with FFAs.[29]

Aras et al.[20] showed that the nasopharyngeal and oropharyngeal airway increased in both the SWG and SSG groups because of the forward positioning of the mandible without any change in the hypopharyngeal airway. Kinzinger et al.[17] reported that there was no change in the pharyngeal distance in patients treated with FMA. Both studies assessed the airway using lateral cephalograms, which permits only a two-dimensional evaluation of the three-dimensional object. Because the airway possesses an oval, non-rigid three-dimensional cross sections, it limits the reliability of conclusions about airway space.[17]

Study Limitations

While the included studies had standardized their measurements for each radiograph to a real size in order to correct the radiographic magnification, there were a few limitations to this systematic review. Only English studies were included. There was variation in the study designs of participant characteristics, treatment duration, and growth pattern. Most of the studies included participants based on chronologic age rather than skeletal maturity, which allows only a limited assessment of growth status. The literature search revealed the absence of randomized clinical trials in this area of research. RCTs are considered the gold standard among all research designs in the evidence pyramid. Therefore, the results must be viewed with caution.

CONCLUSION

FMA has the following effects:

- The quality of the included studies ranged from low to moderate, with three studies at low risk of bias and four studies at moderate risk of bias.
- Class II correction was a combination of skeletal and dentoalveolar changes.
- The SNA and SNB angles increased by 0.11 and 0.81 degrees, respectively, and there was a greater reduction in the ANB angle by 1 degree compared with other FFAs.
- Maximum proclination of the lower incisors by 2.66mm, retroclination of the upper incisors by 1.79 mm, and mesial movement of the lower molars by 2.26 mm with a decrease in overjet by 5.06 mm were observed. The position of the upper molars is inconclusive because of varying results from the included studies.
- Analyzing the soft tissue and airway changes, the evidence is limited and further studies are required.

Ethics

Ethics Committee Approval: Not applicable.

Informed Consent: Not applicable.

Peer-review: Externally peer-reviewed.

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