Mandibular changes produced by functional appliances in Class II malocclusion: A systematic review

Paola Cozza,[a] Tiziano Baccetti,[b] Lorenzo Franchi,[c] Laura De Toffol,[d] and James A. McNamara, Jr[e]
Rome and Florence, Italy, and Ann Arbor, Mich

The aim of this systematic review of the literature was to assess the scientific evidence on the efficiency of functional appliances in enhancing mandibular growth in Class II subjects. A literature survey was performed by applying the Medline database (Entrez PubMed). The survey covered the period from January 1966 to January 2005 and used the medical subject headings (MeSH). The following study types that reported data on treatment effects were included: randomized clinical trials (RCTs), and prospective and retrospective longitudinal controlled clinical trials (CCTs) with untreated Class II controls. The search strategy resulted in 704 articles. After selection according to the inclusion/exclusion criteria, 22 articles qualified for the final analysis. Four RCTs and 18 CCTs were retrieved. The quality standards of these investigations ranged from low (3 studies) to medium/high (6 studies). Two-thirds of the samples in the 22 studies reported a clinically significant supplementary elongation in total mandibular length (a change greater than 2.0 mm in the treated group compared with the untreated group) as a result of overall active treatment with functional appliances. The amount of supplementary mandibular growth appears to be significantly larger if the functional treatment is performed at the pubertal peak in skeletal maturation. None of the 4 RCTs reported a clinically significant change in mandibular length induced by functional appliances; 3 of the 4 RCTs treated subjects at a prepubertal stage of skeletal maturity. The Herbst appliance showed the highest coefficient of efficiency (0.28 mm per month) followed by the Twin-block (0.23 mm per month). (Am J Orthod Dentofacial Orthop 2006;129:599.e1-599.e12)

Class II malocclusion is one of the most common orthodontic problems, and it occurs in about one third of the population.[1-3] The most consistent diagnostic finding in Class II malocclusion is mandibular skeletal retrusion. A therapy able to enhance mandibular growth is indicated in these patients.[4,5] A wide range of functional appliances aimed to stimulate mandibular growth by forward posturing of the mandible is available to correct this type of skeletal and occlusal disharmony.[5] Although many studies in animals have demonstrated that skeletal mandibular changes can be produced by posturing the mandible forward,[6-8] the effects on humans are more equivocal and controversial. Many treatment protocols, sample sizes, and research approaches have led to disparate outcomes in studies on human subjects.

A previous systematic review on the efficacy of functional appliances on mandibular growth by Chen et al[9] analyzed the relevant literature from 1966 to 1999 in a Medline search strategy limited to randomized clinical trials (RCTs). The results were inconclusive. The main difficulty when analyzing RCTs was related to inconsistencies in measuring treatment-outcome variables. In addition, treatment durations varied among studies, and treatment groups were compared with either untreated control groups or subjects undergoing other forms of treatment.

RCTs have been recommended as the standard for comparing alternative treatment approaches. To date, very few RCTs on treatment outcomes of functional jaw orthopedics have been published in the orthodontic literature. The difficulty in gathering many patients

[a]Professor and head, Department of Orthodontics, University of Rome "Tor Vergata," Rome, Italy.
[b]Assistant professor, Department of Orthodontics, University of Florence, Florence, Italy; Thomas M. Graber Visiting Scholar, Department of Orthodontics and Pediatric Dentistry, School of Dentistry, University of Michigan, Ann Arbor.
[c]Research associate, Department of Orthodontics, University of Florence, Florence, Italy; Thomas M. Graber Visiting Scholar, Department of Orthodontics and Pediatric Dentistry, School of Dentistry, University of Michigan, Ann Arbor.
[d]Research fellow, Department of Orthodontics, University of Rome "Tor Vergata," Rome, Italy.
[e]Thomas M. and Doris Graber Endowed Professor of Dentistry, Department of Orthodontics and Pediatric Dentistry, School of Dentistry; professor of Cell and Developmental Biology, School of Medicine; research professor, Center for Human Growth and Development, University of Michigan, Ann Arbor; private practice, Ann Arbor, Mich.
Reprint requests to: Lorenzo Franchi, Università degli Studi di Firenze, Via del Ponte di Mezzo, 46-48, 50127, Firenze, Italy; e-mail, t.baccetti@odonto.unifi.it.
Submitted, June 2005; revised and accepted, November 2005.
0889-5406/$32.00

doi:10.1016/j.ajodo.2005.11.010

with a specific occlusion deviation, the ethical issue of leaving a group of patients untreated for a rather long time, and the fact that several items required in quality reviews[10,11] obviously do not apply to orthodontics (eg, patients blinded or observer blinded to treatment) are substantial reasons for the paucity of RCTs in orthodontics. These considerations suggest that a rational systematic review should include longitudinal prospective and retrospective controlled clinical trials (CCTs) to broaden the scientific information about the treatment effects of orthodontic appliances.[12] Furthermore, recent investigations on treatment outcomes of functional appliances should be examined to supplement the data analyzed by Chen et al.[9] It is advisable also to limit the systematic review to clinical trials that compared treated Class II groups with matched untreated Class II samples. It has been demonstrated that mandibular growth in Class II subjects differs significantly from that of subjects with normal occlusion.[13-15] Moreover, the selection of studies that used untreated Class II controls allows the assimilation of the outcomes of CCTs and RCTs, because they include by definition untreated controls with the same malocclusion types as the treated subjects.

This systematic review was undertaken to answer the question: "Does the mandible grow more in Class II subjects treated with functional appliances than in untreated Class II subjects?" Corollaries included "Is the average effect of functional appliances on mandibular length clinically significant?" and "Which functional appliances are more efficient?"

MATERIAL AND METHODS

Search strategies

The strategy for this systematic review was influenced mainly by the National Health Service Center for Reviews and Dissemination.[16] To identify all studies that examined mandibular growth, a literature survey was carried out by applying the Medline database (Entrez PubMed, www.ncbi.nim.nih.gov). The survey covered the period from January 1966 to January 2005 and used the MeSH term "malocclusion, Angle Class II," which was cross-referenced with the MeSH term "functional, appliances." Additionally, a search in the Cochrane Clinical Trials Register (www.cochrane.org/reviews) was performed.

Selection criteria

The inclusion and exclusion criteria are given in detail in Table I. The following study types that reported data on mandibular growth were included: RCTs, meta-analyses, CCTs, and prospective and retrospective longitudinal studies. The retrieved studies had to analyze cephalometrically the effects of functional therapy on mandibular dimensions (including total mandibular length measured by using the anatomical point condylion) with respect to untreated Class II controls. No restrictions were set for sample size. Articles written in English from January 1966 to January 2005 were included. Abstracts, laboratory studies, descriptive studies, case reports, case series, reviews and opinion articles were excluded.

Table I. Inclusion and exclusion criteria for retrieved studies

Inclusion criteria	*Exclusion criteria*
Meta-analyses, RCTs, prospective and retrospective CCTs	Case reports, case series and descriptive studies, review articles, opinion articles, abstracts
Articles in English	Laboratory studies
Articles published from January 1966 to January 2005	Studies of adults
Studies of growing patients	Studies performed on magnetic resonance imaging
Studies conducted on lateral cephalograms including measurements of total mandibular length (using point condylion)	Measurements of total mandibular length using point articulare
Untreated Class II control subjects	Treatment combined with extractions
	Treatment combined with fixed appliances
	Surgical treatments
	Success of therapy (at occlusal and skeletal levels) as criterion for case selection

Data collection and quality analysis

Data were collected on the following items for the retrieved studies: year of publication, study design, materials (study sample, control sample, type of functional appliance), age at the start of treatment, methods of measurement, appliance wear, treatment/observation duration, success rate, posttreatment observation, and authors' conclusions.

A quality evaluation of the methodological soundness of each article was performed for the RCTs according to the methods described by Jadad et al,[11] with an extension of the quality appraisal to the CCTs.[12] The following characteristics were used: study design, sample size and prior estimate of sample size, withdrawals (dropouts), method error analysis, blinding in measurements, and adequate statistics. The quality of the retrieved studies was categorized as low, medium, or high.

Two independent reviewers (T.B. and L.F.) assessed the articles separately. The data were extracted from each article without blinding to the authors, and intra-examiner conflicts were resolved by discussion of each article to reach a consensus.

Analysis of reported outcomes

To give the reader a quantitative appraisal of modifications in mandibular dimensions and sagittal position in Class II patients treated with functional appliances when compared with untreated Class II controls, the following data were evaluated for each retrieved study: mandibular sagittal position (SNB), total mandibular length (Co-Gn or Co-Pg), mandibular ramus height (Co-Go), and mandibular body length (Go-Gn, Go-Me, or Go-Pg). Studies that used articulare for the measurements of either mandibular length or ramus height were excluded, because that point is not an anatomical landmark that pertains to the mandible exclusively.[9] Because most of the samples in the retrieved studies reported annualized mandibular changes (expressed as annualized mean differences between treated and untreated groups), annualization was applied to the data of the remaining samples (except for samples with a treatment duration that was too short for annualization—less than 9 months). The actual amount of supplementary elongation in total mandibular length after active treatment with the functional appliance was also analyzed.

It is well known that different functional appliances require different treatment durations to reach the goal of Class II correction at the occlusal level. Therefore, this review included an evaluation of both the effectiveness and the efficiency of different types of functional appliances in inducing a supplementary elongation of the mandible with respect to controls. *Effectiveness* can be defined as the ability of the appliance to induce a clinically significant supplementary elongation of the mandible with respect to the controls at the end of the overall treatment period. Because of the average number of patients enrolled in the examined studies (ie, to the power of the retrieved studies),[17] clinical significance in mandibular dimensions was defined as at least a 2.0 mm difference between treated and untreated groups. *Efficiency* consists of an effective treatment in the shortest time. An appraisal of efficiency was performed by dividing the supplementary elongation of the mandible during the overall treatment period with the functional appliance by the number of months of active treatment duration (*coefficient of efficiency*).

RESULTS

The search strategy resulted in 704 articles. After selection according to the inclusion and exclusion criteria (Table I), 22 articles qualified for the final analysis.[18-39]

Table II. Articles included in review

Articles	*Study design*
Jakobsson[18]	RCT, L
Pancherz[19]	P, L, CCT
McNamara et al[20]	R, L, CCT
Jakobsson and Paulin[21]	R, L, CCT
McNamara et al[22]	R, L, CCT
Windmiller[23]	R, L, CCT
Nelson et al[24]	RCT, L
Tulloch et al[25]	RCT, L
Illing et al[26]	P, L, CCT
Franchi et al[27]	R, L, CCT
Tümer and Gültan[28]	R, L, CCT
Toth and McNamara[29]	R, L, CCT
Mills and McCulloch[30]	R, L, CCT
Baccetti et al[31]	R, L, CCT
Chadwick et al[32]	R, L, CCT
de Almeida et al[33]	R, L, CCT
Basciftci et al[34]	R, L, CCT
Pangrazio-Kulbersh et al[35]	R, L, CCT
Faltin et al[36]	R, L, CCT
Janson et al[37]	R, L, CCT
O'Brien et al[38]	RCT, L
Cozza et al[39]	R, L, CCT

RCT, Randomized clinical trial; *L,* longitudinal study; *P,* prospective study; *CCT,* controlled clinical trial; *R,* restrospective study.

Study design

The study designs of the 22 articles are shown in Table II, and the results of the review are summarized in Tables III and IV. The 22 articles included 4 RCTs, 2 prospective CCTs, and 16 retrospective CCTs. No meta-analysis was found.

Quality analysis

The analysis showed that research quality and methodological soundness was low in 3 studies, medium in 13 studies, and medium/high in 6 studies (Table IV). Withdrawals (dropouts) were declared in 5 studies,[18,24-26,38]and, in these studies, the number of dropouts generally was low.

Three studies[20,23,28] did not include a method error analysis, and 3 studies[26,32,38] used blinding in measurements. Only 8 studies used proper statistical methods.[25-27,31,32,36,37,39] Thirteen studies[18-24,28-30,33-35] applied parametric tests in samples that were not tested for normality, and 1 study[38] did not evaluate statistically the changes in mandibular dimensions.

Descriptive analysis of reported outcomes

In this analysis, a distinction was made between *statistically significant* differences and *clinically signif-*

Table III. Summarized data of 22 studies retrieved

Article material	*Controls*	*Age (y)*	*Methods/measurements*	*Appliance wear (h/day)*
Jakobsson[18]	Karolinska Institutet, Sweden		Cephalometric analysis	11.5
17 act		8.5		
17 contr		8.5		
Pancherz[19]	University of Malmö, Sweden		Cephalometric analysis	Full time
22 Herbst		12	Hand-wrist radiographs	
20 contr		11.1		
McNamara et al[20]	University of Michigan Elementary and		Cephalometric analysis	18
51 FR-2 early	Secondary School Growth Study	8.8		
49 FR-2 late	(UMESSGS)	11.6		
36 ECG		8.4		
21 LCG		11		
Jakobsson and Paulin[21]	Orthodontic County Clinic, Östersund,		Cephalometric analysis	Not declared
22 act M	Sweden	11.6		
31 act F		10.9		
28 contr M		10.5		
32 contr F		10.4		
McNamara et al[22]	UMESSGS		Cephalometric analysis	Full time
45 Herbst		12		
41 FR-2		11.5		
21 contr		11		
Windmiller[23]	UMESSGS		Cephalometric analysis	Full time except for meals
46 Herbst		12.9	Developmental age	
21 contr		11		
Nelson et al[24]	Randomly from Department of Orthodontics,		Cephalometric analysis	Minimum of 14
12 act	University of Otago (New Zealand)	11.6	Height and weight measurements	
13 FR-2		11.6		
17 contr		11.6		
Tulloch et al[25]	University of North Carolina		Cephalometric analysis	Not declared
53 bio		9.4	Hand-wrist radiographs	
61 contr		9.4		
Illing et al[26]	Waiting list		Cephalometric analysis	Full time except for meals and sports
13 Bass		12.5		
18 bio		11.8		
16 TB		11.5		
20 contr		11.2		
Franchi et al[27]	UMESSGS		Cephalometric analysis	Full time
55 Herbst		12.8	Cervical vertebrae maturation analysis	
30 contr		13.1		
Tümer and Gültan[28]	Gazi University, Ankara, Turkey		Cephalometric analysis	16
13 act		11.9	Hand-wrist radiographs	Full time
13 TB		11.5		
13 contr		12.7		
Toth and McNamara[29]	UMESSGS		Cephalometric analysis	Full time except for meals and sports
40 TB		10.4		
40 FR-2		10.2		
40 contr		9.9		
Mills and McCulloch[30]	Burlington Growth Centre, University of		Cephalometric analysis	Full time
28 TB	Toronto	9.1		
28 contr		9.1		
Baccetti et al[31]	UMESSGS		Cephalometric analysis	Full time except for meals and sports
21 TB early		9.9	Cervical vertebrae maturation analysis	
16 ECG		9.1		
15 TB late		12.9		
14 LCG		13.6		
Chadwick et al[32]	Patients declining FR-2 treatment		Cephalometric analysis	Not declared
70 FR-2		11.2		
68 contr		10.9		

Table III. Continued

Treatment/observation duration (mo)	*Success rate*	*Posttreatment observation (duration-final age)*	*Authors' conclusions*
18	Not declared	No	Study does not support hypothesis that activator treatment can affect condylar growth
	100%	No	Class II occlusal correction was mainly result of increase in mandibular length and dentoalveolar modifications
6			
6			
	Not declared	No	Principal skeletal effect was advancement of mandible along direction of facial axis. This advancement resulted in increases in mandibular length and vertical facial dimensions
23			
25			
26			
22			
	Not declared	No	Activator treatment has influence on skeletal structures of face
32			
30			
25			
25			
	Not declared	No	Both appliances determine relevant dentoalveolar and skeletal effects
12			
21			
22			
	Not declared	No	Mechanism of Class II correction with acrylic splint Herbst involves enhancing mandibular growth
11.6			
12			
	Not declared	No	No evidence to support view that both appliances can alter size of mandible
18			
18			
18			
	75%	No	Functional appliance therapy produces greater mandibular changes, but there is considerable variation in effect
15			
15			
	Not declared	No	All appliances produced measurable change in skeletal tissues, with untreated sample showing minimal change
9			
9			
9			
9			
	Not declared	Yes (2.3-15.1) Posttreatment includes fixed appliances	Significant favorable effects were assessed in total mandibular length and ramus height increases
12			
12			
	Not declared	No	Stimulation of mandibular growth and correction of Class II relationships were achieved
10			
7			
14			
	100%	No	FR-2 appears to have primarily skeletal effect; TB produces both skeletal and dentoalveolar adaptations
16			
24			
23			
	100%	Yes (2.7-13.1) 1.5 retention	2/3 of overall mandibular length increase could be attributed to increase in ramus height
14			
13			
	Not declared	No	Clinically significant increments in total mandibular length and ramus height when treatment includes pubertal peak
14			
16			
17			
15			
	Not declared	No	FR-2 does not produce clinically significant skeletal changes
20			
22			

Table III. Continued

Article material	Controls	Age (y)	Methods/measurements	Appliance wear (h/day)
de Almeida et al[33]	File of longitudinal growth study of University of Sao Paulo at Bauru		Cephalometric analysis	24
22 FR-2		9		
22 bio		10.7		
22 contr		8.6		
Basciftci et al[34]	Rejected orthodontic treatment		Cephalometric analysis	18
50 act		12.6		
20 contr		12.6		
Pangrazio-Kulbersh et al[35]	UMESSGS		Cephalometric analysis	Full time
30 MARA		11.2		
21 contr		11.1		
Faltin et al[36]	UMESSGS		Cephalometric analysis	Not declared
13 bio early		9.7	Cervical vertebrae maturation analysis	
10 bio late		10.8		
11 ECG		9.4		
10 LCG		11.2		
Janson et al[37]	Longitudinal growth study at Orthodontic Department, University of Sao Paulo		Cephalometric analysis	Not declared
18 FR-2		9.2		
23 contr		9.2		
O'Brien et al[38]	National Health Service, United Kingdom		Cephalometric analysis	Full time except for contact sports and swimming
89 TB		9.7	Stage of maturation of cervical spine analysis	
85 contr		9.8		
Cozza et al[39]	Rejected orthodontic treatment		Cephalometric analysis	14
40 act		10		
30 contr		10		

Act, Activator; *Bass,* Bass appliance; *bio,* bionator appliance; *FR-2,* function regulator of Fränkel; *MARA,* mandibular anterior repositioning appliance; *TB,* Twin-block appliance; *contr,* controls; *ECG,* early control group; *LCG,* late control group; *M,* male; *F,* female.

icant differences between treated and untreated groups. A statistically significant difference reported by a given study had to be greater than 2.0 mm to be regarded also as clinically significant. This threshold value for a clinically significant change was calculated on the basis of the average power of these studies.

Functional appliances produced a statistically significant annualized supplementary elongation in 23 of 33 samples for total mandibular length, in 12 of 17 samples for mandibular ramus height, and in 8 of 23 samples for mandibular body length. Outcomes in terms of changes in mandibular position in relation to the cranial base (SNB angle) were not clinically significant in any article except that of Tümer and Gültan,[28] who found a clinically and statistically significant supplementary increase of 2.2° per year (Table V).

When overall treatment duration was considered, 20 of 33 samples in the 22 studies described clinically significant supplementary growth with total mandibular length after active treatment in the treated group when compared with the untreated group.

The average coefficient of efficiency for functional jaw orthopedics (average amount of actual supplementary elongation of the mandible in treated subjects versus Class II controls after the overall treatment period divided by the number of months of treatment in each study) was 0.16 mm per month. The Herbst appliance, as reported in 4 samples, had a coefficient of efficiency of 0.28 mm per month. The coefficient for the Twin-block appliance was 0.23 mm per month, as reported in 7 samples. The coefficient for the bionator (0.17 mm per month) was equal to the average coefficient, as reported in 5 samples; for the activator, it was slightly lower (0.12 mm per month), as reported in 7 samples. The coefficient of efficiency for the Fränkel appliance, as reported in 8 samples, was the lowest (0.09 mm per month) (Table V).

DISCUSSION

Quality of the studies

RCTs have been used rarely in orthodontics, and this systematic review shows that studies on the outcomes of functional appliances are not an exception to this tendency. Among the reasons for the dearth of RCTs in orthodontics are the difficulty in gathering many patients with a specific occlusion deviation and the sensitive ethical issue of leaving a group of patients untreated. Furthermore, several items required in quality reviews[10,11]—patients or observers blinded to treatment—clearly do not apply. These considerations led

Table III. Continued

Treatment/observation duration (mo)	Success rate	Posttreatment observation (duration-final age)	Authors' conclusions
	Not declared	No	Both appliances provide statistically significant increases in mandibular growth and in degree of mandibular protrusion
17			
16			
13			
	Not declared	No	Growth in mandibular length, ramus height, and corpus length appeared significantly influenced by activator treatment
16			
14			
	Not declared	No	MARA is effective in treating patients with Class II malocclusion through dental and skeletal changes
11			
Not declared			
	Not declared	Yes (bio early, 7.7-17.4; bio late, 8.3-19.1) Posttreatment includes fixed appliances	Treatment protocol is effective and stable when it includes pubertal growth spurt
22			
28			
25			
21			
	Not declared	No	Most changes were dentoalveolar with fewer skeletal changes
28			
28			
	Not declared	No	Early functional treatment does not influence Class II pattern to clinically significant degree
15			
15			
	Not declared	No	Activator appliance is effective in treating mandibular deficiency
21			
21			

to the inclusion of both prospective and retrospective longitudinal CCTs in this review. Efforts were often made by authors of CCTs to elevate the methodological soundness of their investigations. Three studies described outcomes in consecutively treated patients[19,32,36]; 1 study assigned patients randomly to compare treatment modalities[26]; 6 studies used nonhistorical Class II controls.[19,21,28,32,34,39]

In the quality analysis, 6 of the 22 studies were judged to be of medium/high quality (Table IV). Four of these 6 articles were RCTs. The reason for a medium/high quality score instead of a high score is that these studies had some methodological limitations. The article by O'Brien et al[38] gaves no statistical analysis for the mandibular skeletal changes. The RCTs by Jakobsson,[18] Nelson et al,[24] and Tulloch et al[25] did not use blinding in measuring the cephalometric parameters. On the other hand, 2 CCTs[26,32] were judged to be of medium/high quality, whereas most CCTs were judged to be of medium quality. The use of blinding in performing cephalometric analysis of craniofacial skeletal changes was the main factor that accounted for a higher score for these 2 CCTs. Only 3 of the 22 studies (Table IV) were considered of low quality because they lacked both method error analysis and blinding in measurements.

Effectiveness, efficiency, and long-term effects of functional appliances on mandibular growth

In this systematic review, the literature search aimed to select all RCTs and CCTs with untreated Class II controls that evaluated treatment outcomes of functional jaw orthopedics in Class II malocclusion. Four RCTs were found. Eighteen CCTs evaluated the effects of functional appliances versus no treatment, and they showed controversial results in terms of quantitative change in mandibular dimensions. All studies agreed in pointing out that mandibular position to the cranial base as measured by the SNB angle was not impacted in a clinically significant way by functional jaw orthopedics, with the exception of that by Tümer and Gültan.[34] The SNB angle is a poor indicator of the effectiveness of functional jaw orthopedics. In most patients, the initial correction of a Class II relationship involves not just posturing the mandible in a forward position; vertical opening of the bite typically is involved, and a deep overbite is corrected. A millimeter of increased lower anterior facial height camouflages a millimeter of

Table IV. Quality evaluation of studies

Article sample size	*Previous estimate of sample size*	*Withdrawals*	*Method error analysis*	*Blinding in measurements*	*Adequate statistics provided*	*Judged quality standard*
Jakobsson[18]	Yes		Yes	No	No*	Medium/high
17 act		3 act				
17 contr		2 contr				
Pancherz[19]	No/unknown	None	Yes	No	No*	Medium
22 Herbst						
20 contr						
McNamara et al[20]	No/unknown	None	No	No	No*	Low
51 FR-2 early						
49 FR-2 late						
36 ECG						
21 LCG						
Jakobsson and Paulin[21]	No/unknown	None	Yes	No	No*	Medium
22 act M						
31 act F						
28 contr M						
32 contr F						
McNamara et al[22]	No/unknown	None	Yes	No	No*	Medium
45 Herbst						
41 FR-2						
21 contr						
Windmiller[23]	No/unknown	None	No	No	No*	Low
46 Herbst						
21 contr						
Nelson et al[24]	Yes		Yes	No	No*	Medium/high
12 act		5 act				
13 FR-2		3 FR-2				
3 FR-2						
17 contr						
Tulloch et al[25]	Yes	9	Yes	No	Yes	Medium/high
53 bio						
61 contr						
Illing et al[26]	No/unknown		Yes	Yes	Yes	Medium/high
13 Bass		5 Bass				
18 bio		3 bio				
16 TB		3 TB				
20 contr		0 contr				
Franchi et al[27]	No/unknown	None	Yes	No	Yes	Medium
55 Herbst						
30 contr						
Tümer and Gültan[28]	No/unknown	None	No	No	No*	Low
13 act						
13 TB						
13 contr						
Toth and McNamara[29]	No/unknown	None	Yes	No	No*	Medium
40 TB						
40 FR-2						
40 contr						
Mills and McCulloch[30]	No/unknown	None	Yes	No	No*	Medium
28 TB						
28 contr						
Baccetti et al[31]	No/unknown	None	Yes	No	Yes	Medium
21 TB early						
16 ECG						
15 TB late						
14 LCG						

Table IV. Continued

Article sample size	*Previous estimate of sample size*	*Withdrawals*	*Method error analysis*	*Blinding in measurements*	*Adequate statistics provided*	*Judged quality standard*
Chadwick et al[32] 70 FR-2 68 contr	No/unknown	None	Yes	Yes	Yes	Medium/high
de Almeida et al[33] 22 FR-2 22 bio 22 contr	No/unknown	None	Yes	No	No*	Medium
Basciftci et al[34] 50 act 20 contr	No/unknown	None	Yes	No	No*	Medium
Pangrazio-Kulbersh et al[35] 30 MARA 21 contr	No/unknown	None	Yes	No	No*	Medium
Faltin et al[36] 13 bio early 10 bio late 11 ECG 10 LCG	No/unknown	None	Yes	No	Yes	Medium
Janson et al[37] 18 FR-2 23 contr	No/unknown	None	Yes	No	Yes	Medium
O'Brien et al[38] 89 TB 85 contr	Yes	14 TB 1 contr	Yes	Yes	No (no statistical analysis of mandibular skeletal changes)	Medium/high
Cozza et al[39] 40 act 30 contr	No/unknown	None	Yes	No	Yes	Medium

Act, Activator; *Bass,* Bass appliance; *bio,* bionator appliance; *FR-2,* function regulator of Fränkel; *MARA,* mandibular anterior repositioning appliance; *TB,* Twin-block appliance; *contr,* controls; *ECG***,** early control group; *LCG,* late control group; *M,* male; *F,* female.
*Use of parametric tests in samples that were not tested for normality.

increased mandibular length,[5] so the advancement of the chin point at pogonion might not be evident if the vertical dimension is increased along with mandibular length.

The amount of supplementary growth of the mandible when compared with untreated Class II controls varied widely among the studies. With regard to the changes in total mandibular length (measured by Co-Gn or Co-Pg), two-thirds of the samples in these studies described clinically significant supplementary growth after active treatment in the treated group when compared with the untreated group.

Interestingly enough, none of the 4 RCTs reported a clinically significant change in mandibular length induced by functional appliances. To further explain this finding, the influence of treatment timing (skeletal maturity at the start of functional therapy) on treatment results should be analyzed. It has previously been demonstrated that the effectiveness of functional treatment of mandibular growth deficiencies strongly depends on the biological responsiveness of the condylar cartilage, which in turn depends on the growth rate of the mandible (expressed as prepeak, peak, and postpeak growth rates with regard to the pubertal growth spurt).[40-42] Only 7[19,25,27,28,31,36,38] of the 22 studies in this review reported information about their subjects' skeletal maturity with a biological indicator (eg, hand-wrist analysis, cervical vertebral maturation method). In these 7 studies, 10 samples of patients treated with functional appliances were investigated: 4 samples[25,31,36,38] received treatment before the pubertal peak in skeletal growth, whereas, in 6 samples,[19,27,28,31,36,38] treatment included the pubertal peak. The amount of actual supplementary mandibular growth induced by treatment (measured by Co-Gn or Co-Pg) was clinically significant (> 2.0 mm) in all the "peak" samples, except those reported by Tümer and Gültan[34] (1.5 and 1.4 mm in the samples treated with the activator and the Twin-block, respectively). How-

Table V. Descriptive analysis of reported outcomes

Articles	Appliance	Active treatment duration (mo)	Annualized changes: SNB	Annualized changes: Co-Gn (or Co-Pg) mm	Annualized changes: Co-Go mm	Annualized changes: Go-Gn (or Go-Me; or Go-Pg) mm	Actual change: Co-Gn (or Co-Pg) mm	Actual change: Coefficient of efficiency (mm/mo)
Jakobsson[18]	act	18	—	0.5 (NS)	—	—	0.7	0.04
Pancherz[19]	Herbst	6*	1.4‡	2.2 (S)†	—	—	***2.2***†	0.37
McNamara et al[20]	FR-2 E	24	0.3 (S)	1.2 (S)	1.0 (S)	0.0 (NS)	***2.4***	0.10
	FR-2 L	24	0.4 (S)	1.8 (S)	1.5 (S)	0.1 (NS)	***3.6***	0.15
Jakobsson and Paulin[21]	act M	32	0.6 (S)	1.2 (S)	—	—	***3.2***	0.10
	act F	30	0.1 (NS)	0.2 (NS)	—	—	0.5	0.02
McNamara et al[22]	Herbst	12	1.6 (S)	2.7 (S)	2.1 (S)	0.2 (NS)	***2.7***	0.22
	FR-2	21	0.5 (NS)	2.2 (S)	1.8 (S)	0.3 (NS)	***3.8***	0.18
Windmiller[23]	Herbst	12	1.3 (S)	3.5 (S)	2.9 (S)	0.3 (NS)	***3.5***	0.30
Nelson et al[24]	FR-2	18	0.2 (NS)	0.5 (NS)	0.0 (NS)	0.7 (NS)	0.7	0.04
	act	18	0.2 (NS)	0.9 (NS)	−0.7 (NS)	1.2 (S)	1.3	0.07
Tulloch et al[25]	bo	15	0.6 (S)	1.3 (S)	—	—	1.6	0.11
Illing et al[26]	Bass	9	1.5 (NS)	0.5 (NS)	—	—	0.4	0.04
	bio	9	1.1 (NS)	3.5 (S)	—	—	***2.6***	0.29
	TB	9	1.3 (NS)	3.2 (S)	—	—	***2.4***	0.27
Franchi et al[27]	Herbst	12	—	2.7 (S)	1.2 (S)	1.1 (NS)	***2.7***	0.22
Tümer and Gültan[28]	act	10	2.2 (S)	1.8 (S)	—	0.2 (NS)	1.5	0.15
	TB	7*	1.5 (S)	1.4 (S)	—	–0.5 (NS)	1.4	0.20
Toth and McNamara[29]	TB	16	1.0 (S)	2.2 (S)	1.3 (S)	0.7 (S)	***3.0***	0.19
	FR-2	24	0.3 (NS)	1.4 (S)	1.0 (S)	0.1 (NS)	***2.8***	0.12
Mills and McCulloch[30]	TB	14	1.9 (S)	3.6 (S)	2.5 (S)	1.1 (S)	***4.2***	0.30
Baccetti et al[31]	TB E	14	—	1.9 (S)	0.3 (NS)	1.0 (NS)	***2.2***	0.16
	TB L	17	—	4.7 (S)	2.7 (S)	1.7 (S)	***6.7***	0.39
Chadwick et al[32]	FR-2	20	0.4 (S)	0.3 (NS)	—	—	0.6	0.03
de Almeida et al[33]	bio	16	1.3 (S)	1.7 (S)	—	1.1 (S)	***2.3***	0.14
	FR-2	17	0.4 (NS)	0.8 (S)	—	0.8 (S)	1.2	0.07
Basciftci et al[34]	act	16	0.7 (NS)	3.9 (S)	—	2.2 (S)	***5.2***	0.32
Pangrazio-Kulbersh et al[35]	MARA	11	1.0 (S)	2.7 (S)	2.7 (S)	0.1 (NS)	***2.7***	0.23
Faltin et al[36]	bio	22	—	0.4 (NS)	0.0 (NS)	0.2 (NS)	1.9	0.09
	bio	28	—	2.1 (S)	2.1 (S)	0.0 (NS)	***4.3***	0.15
Janson et al[37]	FR-2	28	1.4 (NS)	0.0 (NS)	0.1 (NS)	0.7 (S)	0.5	0.02
O'Brien et al[38]	TB	15	—	1.2†,‡	—	—	1.5	0.10
Cozza et al[39]	act	21	0.8 (S)	1.5 (NS)	—	0.1 (NS)	***2.7***	0.13

Act, Activator; *Bass,* Bass appliance; *bio,* bionator appliance; *FR-2,* function regulator of Fränkel; *MARA,* mandibular anterior repositioning appliance; *TB,* Twin-block appliance; *contr,* controls; *ECG,* early control group; *LCG,* late control group; *M,* male; *F,* female; *S,* statistically significant; *NS,* not significant as reported by authors.
Statistically and clinically significant differences (at least 2 mm) shown in bold and italics.
*Outcomes were not annualized.
†Measured as Pg/OLp + Co/OLp.
‡Not evaluated statistically by author.

ever, the average active treatment duration for both samples in that study was about half that reported by the other studies in this review for the same type of appliances. None of the samples treated in the prepeak period had a clinically significant amount of supplementary mandibular growth. The inclusion of the pubertal growth spurt in the treatment period can be regarded as a key factor in the attainment of clinically significant supplementary mandibular growth with functional jaw orthopedics. This observation corroborates previous research and emphasizes the role of treatment timing on treatment outcomes for functional appliances.[40-42]

With regard to treatment timing as reported by the RCTs, 2 of them did not include an adequate appraisal of skeletal maturity,[18,24] whereas both Tulloch et al[25] and O'Brien et al[38] described the results of functional appliances used at prepeak stages. The lack of clinical significance in the outcomes of these 2 RCTs might correlate with the prepubertal treatment timing of the reported samples. Similarly, the RCT by Jakobsson[18] reported outcomes of activator treatment at an average age of 8.5 years (a very early age for the peak in mandibular growth). An RCT on the effects of the functional appliances used at the pubertal growth spurt is needed.

Different functional appliances require different treatment durations to reach the goal of correcting a Class II malocclusion at the occlusal level. It was interesting, therefore, to appraise the *efficiency* of different types of functional appliances in inducing a supplementary elongation of the mandible with respect to controls. Efficiency was appraised by dividing the supplementary elongation of the mandible obtained during the overall treatment period with the functional appliance by the number of months of active treatment (*coefficient of efficiency*). The average coefficient of efficiency for functional jaw orthopedics was 0.16 mm per month, with an average duration of active treatment of approximately 17 months. The Herbst appliance had the highest coefficient of efficiency (0.28 mm per month) followed by the Twin-block (0.23 mm per month). Both the bionator and the activator had intermediate scores of efficiency (0.17 and 0.12 mm per month, respectively). The Fränkel appliance had the least efficiency (0.09 mm per month).

Only 1 of the 22 studies described changes observed in the posttreatment period until completion of growth to verify whether the gain in mandibular length achieved during active treatment was maintained.[36] The long-term study by Faltin et al[36] reported the effects of Class II treatment with the bionator about 8 years after active therapy (average age, about 18 years). The posttreatment period comprised a short phase with fixed appliances to refine occlusion (without Class II elastics). In the long term, the "early-treated" sample (bionator treatment before the peak in mandibular growth) did not show significant differences in mandibular growth when compared with the controls with the same skeletal maturity (1.9 mm). On the contrary, a statistically and clinically significant amount of supplementary mandibular growth (5.1 mm) was observed in the group treated during the pubertal growth spurt with respect to the controls. These results should be considered cautiously because of the restrospective nature of the study and the limited number of subjects in the samples. Two other studies[27,30] reported a posttreatment observation (Table III) that, however, was not considered valid for an appraisal of actual outcomes in the long term because the final age of the patients at the posttreatment observation was less than 16 years.

CONCLUSIONS

This study was undertaken to answer the question "Does the mandible grow more in Class II subjects treated with functional appliances than in untreated Class II subjects?" Corollaries included "Is the average effect of functional appliances on mandibular length clinically significant?" and "Which functional appliances are more efficient?"

On the basis of the analysis of 22 retrieved articles, it can be concluded that:

1. The quality standard of these investigations ranged from low to medium/high. Four RCTs were available, and 2 CCTs showed methodological soundness higher than average. Three of the 22 studies were judged of low quality.
2. Two-thirds of the samples in the 22 studies reported clinically significant supplementary elongation in total mandibular length as a result of overall active treatment with functional appliances.
3. The short-term amount of supplementary mandibular growth appears to be significantly larger when the functional treatment is performed at the adolescent growth spurt.
4. None of the 4 RCTs reported clinically significant supplementary growth of the mandible induced by functional appliances. When analyzed in terms of treatment timing, 3 of the 4 RCTs described outcomes of treatment at a prepubertal stage of skeletal maturity.
5. The Herbst appliance showed the highest coefficient of efficiency (0.28 mm per month) followed by the Twin-block (0.23 mm per month).

For a commentary and author's response to this article, visit www.mosby.com/AJODO.

REFERENCES

1. Kelly JE, Harvey C. An assessment of the teeth of youths 12-17 years. DHEW Publication No (HRA) 77-1644. Washington, DC: National Center for Health Statistics; 1977.
2. McLain JB, Proffit WR. Oral health status in the United States: prevalence of malocclusion. J Dent Educ 1985;49:386-96.
3. Proffit WR, Fields HW, Moray LJ. Prevalence of malocclusion and orthodontic treatment need in the United States: estimates from the N-HANES III survey. Int J Adult Orthod Orthog Surg 1998;13:97-106.
4. McNamara JA Jr. Components of a Class II malocclusion in children 8-10 years of age. Angle Orthod 1981;51:177-202.
5. McNamara JA Jr, Brudon WL. Orthodontics and dentofacial orthopedics. Ann Arbor: Needham Press; 2001. p. 67-80.
6. McNamara JA Jr. Neuromuscular and skeletal adaptations to altered function in the orofacial region. Am J Orthod 1973;64: 578-606.

7. McNamara JA Jr, Carlson DS. Quantitative analysis of temporomandibular joint adaptations to protrusive function. Am J Orthod 1979;76:593-609.
8. Xiong H, Hägg U, Tang G-H, Rabie ABM, Robinson W. The effect of continuous bite-jumping in adult rats: a morphological study. Angle Orthod 2004;74:86-92.
9. Chen JY, Will LA, Niederman R. Analysis of efficacy of functional appliances on mandibular growth. Am J Orthod Dentofacial Orthop 2002;122:470-6.
10. Antczak AA, Tang J, Chalmers TC. Quality assessment of randomized control trials in dental research I. Methods. J Periodont Res 1986;21:305-14.
11. Jadad AR, Moore RA, Carroll D, Jenkinson C, Reynolds DJ, Gavaghan DJ, et al. Assessing the quality of reports of randomized clinical trials: is blinding necessary? Control Clin Trials 1996;17:1-12.
12. Petrán S, Bondemark L, Söderfeldt B. A systematic review concerning early orthodontic treatment of unilateral posterior crossbite. Angle Orthod 2003;73:588-96.
13. Harris E. A cephalometric analysis of mandibular growth rate. Am J Orthod 1962;48:161-73.
14. Buschang PH, Tanguay R, Turkewicz J, Demirjian A, La Palme L. A polynomial approach to craniofacial growth: description and comparison of adolescent males with normal occlusion and those with untreated Class II malocclusion. Am J Orthod Dentofacial Orthop 1986;90:437-42.
15. Buschang PH, Tanguay R, Demirjian A, LaPalme L, Turkewicz J. Mathematical models of longitudinal mandibular growth for children with normal and untreated Class II, Division 1 malocclusion. Eur J Orthod 1988;10:227-34.
16. Alderson P, Green S, Higgins JPT, editors. Formulating the problem. Cochrane Reviewers' Handbook 4.2.2 [updated December 2003]; Section 4. http://www.cochrane.org/resources/handbook/hbook.htm (accessed January 30, 2005).
17. Phillips C. Sample sizes and power: what is enough? Semin Orthod 2002;8:67-76.
18. Jakobsson S. Cephalometric evaluation of treatment effect on Class II, Division 1 malocclusion. Am J Orthod 1967;53:446-56.
19. Pancherz H. The mechanism of Class II correction in Herbst appliance treatment. A cephalometric investigation. Am J Orthod 1982;82:104-13.
20. McNamara JA Jr, Bookstein FL, Shaughnessy TG. Skeletal and dental changes following functional regulator therapy on Class II patients. Am J Orthod 1985;88:91-110.
21. Jakobsson S-O, Paulin G. The influence of activator on skeletal growth in Angle Class II:1 cases. A roentgenocephalometric study. Eur J Orthod 1990;12:174-84.
22. McNamara JA Jr, Howe RP, Dischinger TG. A comparison of the Herbst and Fränkel appliances in the treatment of Class II malocclusion. Am J Orthod Dentofacial Orthop 1990;98:134-44.
23. Windmiller EC. The acrylic-splint Herbst appliance: a cephalometric evaluation. Am J Orthod Dentofacial Orthop 1993;104:73-84.
24. Nelson C, Harkness M, Herbison P. Mandibular changes during functional appliance treatment. Am J Orthod Dentofacial Orthop 1993;104:153-61.
25. Tulloch JFC, Phillips C, Koch G, Proffit WR. The effect of early intervention on skeletal pattern in Class II malocclusion: a randomized clinical trial. Am J Orthod Dentofacial Orthop 1997;111:391-400.
26. Illing HM, Morris DO, Lee RT. A prospective evaluation of Bass, Bionator and Twin Block appliances. Part I—the hard tissues. Eur J Orthod 1998;20:501-16.
27. Franchi L, Baccetti T, McNamara JA Jr. Treatment and posttreatment effects of acrylic splint Herbst appliance therapy. Am J Orthod Dentofacial Orthop 1999;115:429-38.
28. Tümer N, Gültan S. Comparison of the effects of monobloc and Twin-block appliances on the skeletal and dentoalveolar structures. Am J Orthod Dentofacial Orthop 1999;116:460-8.
29. Toth LR, McNamara JA Jr. Treatment effects produced by the Twin-block appliance and the FR-2 appliance of Fränkel compared with an untreated Class II sample. Am J Orthod Dentofacial Orthop 1999;116:597-609.
30. Mills CM, McCulloch KJ. Posttreatment changes after successful correction of Class II malocclusions with the Twin-block appliance. Am J Orthod Dentofacial Orthop 2000;118:24-33.
31. Baccetti T, Franchi L, Toth LR, McNamara JA Jr. Treatment timing for Twin-block therapy. Am J Orthod Dentofacial Orthop 2000;118:159-70.
32. Chadwick SM, Aird JC, Taylor PJS, Bearn DR. Functional regulator treatment of Class II Division 1 malocclusions. Eur J Orthod 2001;23:495-505.
33. de Almeida MR, Henriques JFC, Ursi W. Comparative study of Fränkel (FR-2) and bionator appliances in the treatment of Class II malocclusion. Am J Orthod Dentofacial Orthop 2002;121:458-66.
34. Basciftci FA, Uysal TU, Büyükerkmen A, Sari Z. The effects of activator treatment on the craniofacial structures of Class II Division 1 patients. Eur J Orthod 2003;25:87-93.
35. Pangrazio-Kulbersh V, Berger JL, Chermak DS, Kaczynski R, Simon ES, Haerian A. Treatment effects of the mandibular anterior repositioning appliance on patients with Class II malocclusion. Am J Orthod Dentofacial Orthop 2003;123:286-95.
36. Faltin K Jr, Faltin RM, Baccetti T, Franchi L, Ghiozzi B, McNamara JA Jr. Long-term effectiveness and treatment timing for bionator therapy. Angle Orthod 2003;73:221-30.
37. Janson GRP, Toruno JLA, Martins DR, Henriques JFC, de Freitas MR. Class II treatment effects of the Fränkel appliance. Eur J Orthod 2003;25:301-9.
38. O'Brien K, Wright J, Conboy F, Sanjie Y, Mandall N, Chadwick S, et al. Effectiveness of early orthodontic treatment with the Twin-block appliance: a multicenter, randomized, controlled trial. Part I: dental and skeletal effects. Am J Orthod Dentofacial Orthop 2003;124:234-43.
39. Cozza P, De Toffol L, Colagrossi S. Dentoskeletal effects and facial profile changes during activator therapy. Eur J Orthod 2004;26:293-302.
40. Hägg U, Pancherz H. Dentofacial orthopaedics in relation to chronological age, growth period and skeletal development. An analysis of 72 male patients with Class II Division 1 malocclusion treated with the Herbst appliance. Eur J Orthod 1988;10:169-76.
41. Malmgren O, Ömblus J, Hägg U, Pancherz H. Treatment with an appliance system in relation to treatment intensity and growth periods. Am J Orthod Dentofacial Orthop 1987;91:143-51.
42. Petrovic A, Stutzmann J, Lavergne J. Mechanism of craniofacial growth and modus operandi of functional appliances: a cell-level and cybernetic approach to orthodontic decision making. In: Carlson DS, editor. Craniofacial growth theory and orthodontic treatment. Monograph 23. Craniofacial Growth Series. Ann Arbor: Center for Human Growth and Development; University of Michigan; 1990. p. 13-74.