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Mandibular midline distraction, a systematic review

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ABSTRACT

Introduction

A systematic review on mandibular midline distraction (MMD) was carried out to assess effectiveness, treatment related difficulties, complications and biomechanical effects of this treatment modality objectively.

Material & Methods

Randomized controlled trials (RCT), controlled clinical trials (CCT) and case series concerning MMD with a sample size of >5 were searched electronically in Pubmed/Medline, Embase, Cochrane and CENTRAL up to September 6th 2010.

Results

85 unique articles were found of which 22 met our inclusion criteria. The study designs of the articles found were prospective (10), retrospective (10) or uncertain (2). One clinical trial and no randomized clinical trials were found. The methodological quality was considered low in most articles.

Conclusion

Generally MMD is a safe and effective treatment modality to treat transverse mandibular discrepancies, however controversies still exist: choice of distractor, surgical setting, distraction rate, start of orthodontic treatment and relapse. In addition, little is known on patient experience and quality of life after treatment. Further prospective trials are necessary to address these controversies and questions.

INTRODUCTION

Transverse mandibular and maxillary deficiencies and crowding of the anterior teeth are often seen in orthodontic patients. Traditionally the treatment of arch length and width discrepancies has been managed with orthodontic treatment, and the extraction of teeth (*Guerrero, Bell et al.* 2000; *Proffit, White et al.* 2003).

Around the age of one the mandibular symphysis is fused and cannot be opened with orthodontic devices (*Sperber* 2001). Orthodontists have tried to expand the mandibular arch length and width with different techniques such as: Schwarz appliances, lingual arches and functional appliances (*Conley and Legan* 2003). Long-term results show a high relapse risk of dental alignment, dental arch lengthening and widening with orthodontic treatment, whether or not combined with teeth extractions (*Herberger* 1981; *Little, Riedel et al.* 1990; *Moussa, O'Reilly et al.* 1995; *Little* 1999; *Housley, Nanda et al.* 2003). Little's study of the long-term effects of this treatment modality showed that only 30% of the patients have acceptable long-term postretention results (*Little, Riedel et al.* 1990; *Little* 1999). Some claim this effect to be more prominent in older patients compared to the younger, others do not differentiate in these categories (*Del Santo, Guerrero et al.* 2000). An alternative approach is a vertical symphyseal osteotomy and rotating the hemi-mandible segments laterally with or without using a bone graft (*Alexander, Bloomquist et al.* 1993; *Conley and Legan* 2003). Due to the risk of periodontal problems, lack of adequate rigid fixation, requirement for a bone graft, and a high risk of relapse, this technique is not used often. Since the advent of distraction osteogenesis (DO) the symphyseal osteotomy has gained in popularity.

The unique aspect of distraction is that both bone (osteogenesis) and soft tissue (histogenesis) increases. Although Codivilla lengthened a femur in 1905, it was Ilizarov who rediscovered the technique in 1954 and brought it to a wider attention (*Ilizarov* 1990; *Codivilla* 2008). In 1973, Snyder et al. lengthened a canine mandible using a distraction technique (*Snyder, Levine et al.* 1973). It was not until the early 1990s that widening of the human mandible was described (*McCarthy, Schreiber et al.* 1992; *Perrott, Berger et al.* 1993; *Guerrero, Bell et al.* 1997).

Mandibular midline distraction (MMD), a surgical technique to widen the mandible, is described under various names, such as: mandibular symphyseal distraction osteogenesis, transmandibular symphyseal distraction (osteogenesis), and mandibular midline osteodistraction.

The commonest indications for MMD are severe mandibular anterior crowding (*Guerrero, Bell et al.* 1997), uni- (*King and Wallace* 2004) and bilateral crossbite, severe (maxillary-)mandibular transverse deficiency, impacted anterior teeth with inadequate space and tipped teeth (*Proffit, White et al.* 2003). Other indications for MMD include: reconstruction of the mandible after trauma (*Niederhagen, Braumann et al.* 2000), hypoglossia-hypodactyly syndrome (*Kita, Kochi et al.* 2004), v-shaped mandible with obvious anterior tissue deficiency (*Proffit, White et al.* 2003), Nager syndrome (*Kessler, Wiltfang et al.* 2000) and 18p-syndrome (*Kessler, Wiltfang et al.* 2000). MMD can be combined with various other surgical procedures sucha as: surgically assisted rapid maxillary expansion (SARME) (*Weil, Van Sickels et al.* 1997; *Del Santo, Guerrero et al.* 2000), ramus osteotomy (*Takahashi, Kawamura et al.*) and genioplasty procedure (*Guerrero, Bell et al.* 1997). The indication for a combined maxillary and mandibular expansion for the expansion of airway dimensions is still under debate (*Malkoc, Usumez et al.* 2007; *Won, Li et al.* 2008; *Bonetti, Piccin et al.* 2009).

There are numerous papers regarding MMD, this systematic review provide an overview of the scientific work published so far. We focus on the distractor device, the surgical procedure, distraction sequence, bone quality, relapse, effects on the temporomandibular joint, effects on the airway, treatment related difficulties and complications.

MATERIAL & METHODS

Inclusion/Exclusion criteria

Randomized controlled trials (RCT), controlled clinical trials (CCT) and case series were included. Searches were restricted to English publications involving only humans with a minimum sample size of N> 5. The study population consisted mostly adolescent- or adult-aged subjects. All types of distractors (bone-, tooth-borne or bone-and-tooth borne device (hybrid)) were included. Articles were excluded if other surgical treatment modalities took place, except for SARME, Bilateral Sagittal Split Osteotomy (BSSO), LeFort I osteotomy and genioplasty procedures.

Search strategy

This systematic review of the literature was performed using the following electronic databases:

- Pubmed/MEDLINE (to September 6th 2010);
- Cochrane Database of Systematic Reviews (Issue 8, 2010)
- Cochrane central register of controlled trials CENTRAL (to September 6th 2010)
- Embase (to September 6th 2010)

For our search query we used free text since no MeSH term was available. The following heading sequence was selected: mandibular midline distraction OR mandibular symphyseal distraction osteogenesis OR mandibular symphysis widening. A specific search for randomized controlled trials and clinical trials was performed adding: AND ("Randomized Controlled Trial"[Publication Type] OR "Controlled Clinical Trial"[Publication Type]).

References of the articles found were hand searched for other relevant articles. If the study design was not clear or more than one article from a research group was found the author was personally contacted to clarify by e-mail.

Data extraction

Methodological quality

Articles were assessed for the quality of the methodology. First, a selection based on title and abstract was made, without considering number of patient included in the study. A full-text article was obtained if it appeared to match our inclusion criteria. The full-text article was then completely reviewed for the criteria and included or rejected.

The methods were reviewed and given a quality standard, using modified criteria proposed by Jadad (*Jadad, Moore et al.* 1996) and Petren (*Petren, Bondemark et al.* 2003). The criteria were: study design, sample size, selection description, withdrawals, method/measurement, validity of method, considering of confounding factors, adequate statistics provided and medical committee approval. An adequate selection description describes at least inclusion/exclusion criteria, partly adequate studies present either, time interval when subject were treated at an institution, or the indication for the treatment. Withdrawals were considered 'none' when described or when the study design was a single moment evaluation.

Outcome measure

Outcome measurements of this review are: the effectiveness of MMD as a treatment modality for a transverse small mandible, the effects of MMD on surrounding tissues and structures and the safety of MMD as a treatment modality. Effectiveness was evaluated with regard to the following: type of distractor device, surgical procedure, distraction procedure, biomechanical (including airway) effects and relapse. Safety was assessed by considering treatment related difficulties and complications, for example periodontal health and craniomandibular dysfunction (CMD).

RESULTS

Search results

The search is summarized in figure 1 and resulted in 75 Pubmed citations, 71 Embase citations, 0 Cochrane citations and 1 CENTRAL citation, with in total 79 unique articles. After reviewing titles and abstracts full text versions were obtained of 54 topic related articles of which 33 articles did not meet the inclusion criteria. Manual search of the references of the included studies revealed six additional articles of which one proved to be usable (*Mommaerts, Polsbroek et al.* 2005), leaving 22 studies for inclusion. Table

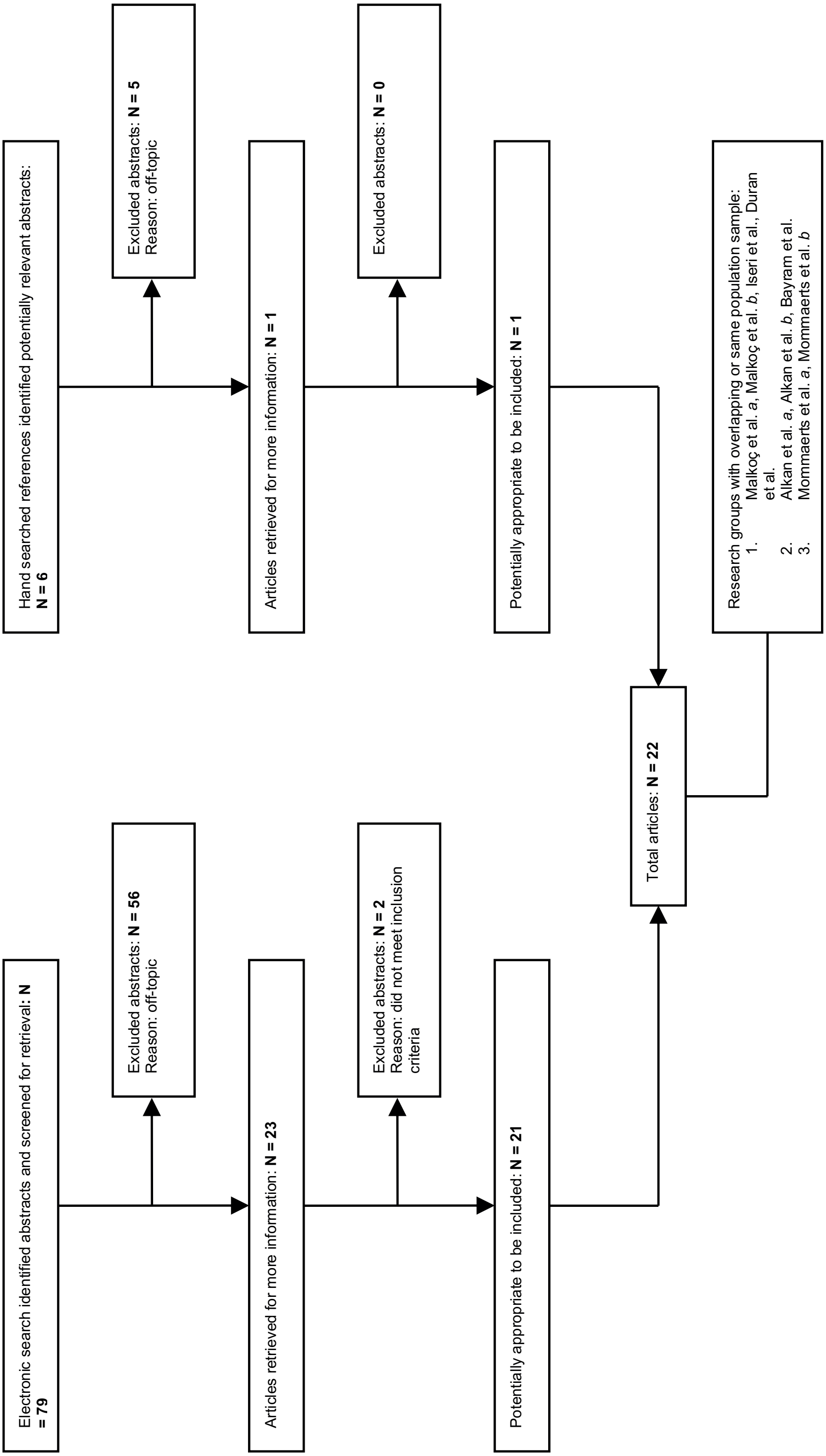

Figure 1. Search result flow chart.

1 shows the characteristics of the included articles. Three research groups focused on MMD. After personal contact with dr. Malkoç, of the first research group, it appeared that patient samples of Iseri et al. and Malkoç et al. *b* (*Iseri and Malkoc* 2005; *Malkoc, Usumez et al.* 2007) are the same and the others (*Duran, Malkoc et al.* 2006; *Malkoc, Iseri et al.* 2006) might have some overlap. For the second research group, after personal contact with dr. Alkan, it appeared that all studies used the same sample population (*Alkan, Arici et al.* 2006; *Alkan, Ozer et al.* 2007; *Bayram, Ozer et al.* 2007). The third research group from Belgium reported overlap between the samples (*Mommaerts, Shteif et al.* 2004; *Mommaerts, Spaey et al.* 2008). For the descriptive statistics we only used the largest study within a research group, concerning other comparisons we only used the article which provided most data on a subject.

Type of included studies

One CCT (*Alkan, Arici et al.* 2006) and no RCT's were found. The other studies were case series, of which ten were prospective and ten were retrospective, in two case series the nature of the study remained unknown. Included studies originated from Europe (including Turkey), The United States of America, Venezuela and South Korea.

Methodological quality of the included studies

The results of the methodological judged quality standard are shown in table 2. Most studies score low, only two studies score medium (*Bayram, Ozer et al.* 2007; *Landes, Laudemann et al.* 2008). The statistical analyses were adequate in half of the studies. Six studies had adequate described selection criteria (*Weil, Van Sickels et al.* 1997; *Del Santo, Guerrero et al.* 2000; *Alkan, Ozer et al.* 2007; *Bayram, Ozer et al.* 2007; *Landes, Laudemann et al.* 2008; *Gunbay, Akay et al.* 2009). Of note are the small sample sizes of the studies implying low power, with only 2 studies having a sample size of over 30 patients (*Alkan, Ozer et al.* 2007; *von Bremen, Schafer et al.* 2008). The medical ethical committee was consulted in six of the studies (*Iseri and Malkoc* 2005; *Duran, Malkoc et al.* 2006; *Malkoc, Iseri et al.* 2006; *Bayram, Ozer et al.* 2007; *Landes, Laudemann et al.* 2008; *Seeberger, Kater et al.* 2010). Only Weil et al. included an error analysis (*Weil, Van Sickels et al.* 1997). No estimate of sample size and power analysis was described in the included literature.

Patients in the included studies

At least 375 individual patients were included in this review. The age of the samples ranged from 7.6 to 62 years, with a male:female ratio of 1:1.22. Raoul et al. and Weil et al. described MMD in congenital deformed patients (*Weil, Van Sickels et al.* 1997; *Raoul, Wojcik et al.* 2009).

Table 1. Article outline.

No.	Author	Year	Origin	N	**Median / mean age** *years (range)*	**Sex: M/F**	**Syndromal**	**Follow-up**	**Methods/ measurement** *Radiograph*	*Monitoring complications*	*Dental casts*	*Other*
1.	Bayram et al.	2007	Turkey	14	**14,6** (13,7-17,3)	9/5		1.3y (10m-2y)	L			
2.	Alkan et al. *a*	2007	Turkey	40	**14,8** (11-18)	15/25		1.8y (9m-3y)		x		
3.	Braun et al.	2002	United States of America	12	**?** (11-15)	9/3			SV	x		Indexing wire on distractor
4.	Chung et al.	2007	South Korea	19	**20,9** (7,6-30,1)	10/9	No	1.5y (0.5-3.1y)	O, PE		x	Healing patterns
5.	von Bremen et al.	2008	Germany	100	**27,6** (11-62)	45/55		2w		x		
6.	Mommaerts et al., *a*	2008	Belgium	23	**19,5** (11-40)	9/14	No	>1y		x		SC for CFDO
7.	Landes et al.	2008	Germany	9	**24.7** (15-43)	4/5	No	3m	CT	x		
8.	Raoul et al.	2009	France	14	**18,5** (14-43)	7/7	Yes	21m (1-2y)	CT, L, AP, O, PE	x	x	Photograph
9.	Ploder et al.	2009	Austria	20	**15.3** (8-38)			3m	AP, P	x	x	Tooth sensitivity; pocket depth
10.	Kewitt et al.	1999	United States of America	15	**25.9** (13-51)	9/6		24.5m (7-45m)	PE	x		Teeth sensitivity; Pocket depth Skin sensibility
11.	Uckan et al.	2006	Turkey	24	**18.1** ± 3.11		No	14m ± 7.3	L	x		
12.	del Santo et al.	2000	United States of America	20	**17,3** (13,5-37,3)	11/9	No	1y3m (6-31m)	L, AP		x	
13.	Guerrero et al.	1997	Venezuela	10	**20** (13-31)	2/8				x		
14.	Işeri et al.	2005	Turkey	20	**20** ± 2.25 (15.8-25)		No	21.5m ± 4.6	AP			Bone implants
15.	Malkoç et al. *b*	2007	Turkey	20	**20 ±** 2.3 (15.3-24.9)	7/13		24.1m ± 4.2	L, AP			
16.	Duran et al.	2006	Turkey	16	**20.4** ± 1.2 (16.4-23.8)	9/7	No	94.9d ± 5.8				Histology

Anesthesia	Distractor	Maxillary expansion and additional surgery	Osteotomy *(N)*	Latency, *day*	Distraction rate, *mm/day*	Activation, *mm (ramge)*	Consolidation	Start orthodontic treatment
	TB	RME (14)		7	1	6.8 (5-7.5)	3m	3m
L	TB(21) BB(5) HB(14)		M(37) CI-LI(1) LI-CU(2)	5-7	1	7,3 (7-11)	3m	3m
	TB(10) BB(2)				1	6,3 (2-8)		
IV, L	TB(17) HB(2)		M(14) LI-CI(1) S(4)	0-10	0,75-1	6	83d (29-210)	RE
	TB	SARME (83)		7	0,25-0,5			
	BB	SARME (21)	M	7	0,4		65d (±22,3)	
G	BB	SARME	CI(9) S	5	0,6		3m	6w
G	BB	SARME(2) BSSO(6) Bimax (3) Bimax + G (1)	M(12) P(2)	7-10		8,78 (6-12)	2-3m	2w
IV	TB		M	5	0,6	5,6 ± 2,9	6w	
	TB	SARME; BSSO LF1 G		5	0,75			
IV, L	HB		M(24)	5-7	1	7,0 ± 1,54	2,5m	
IV, L, G	TB	SARME LF1	M(13); CI-LI(1); LI-CU(2)	8	1	8,1 ± 2,5	60-90d	RE
IV, L	TB(8); BB(2)	G	M(7); LI-CI(1); LI-CU(2)	5-7	1	7,7 (5-14)	45-60d	1,5-2m
IV, L	HB	RME(18) SARME(4)		7	1	8,1 ± 1,68	94,95d ± 5,79	0
X	HB	RME(18) SARME(4)			1	8,1 ± 1,7		
IM, L	HB			7	1	8,1 ± 1,7	94,9d ± 5,8	0

Table 1. Article outline. (continued)

									Methods/ measurement			
No.	**Author**	**Year**	**Origin**	**N**	**Median / mean age** *years (range)*	**Sex: M/F**	**Syndromal**	**Follow-up**	*Radiograph*	*Monitoring complications*	*Dental casts*	*Other*
17.	Malkoç et al. *a*	2006	Turkey	20	**20.1 ±** 2.3 (15.8-23.3)		No	24.1m ± 4.2	AP		x	
18.	Gunbay et al.	2009	Turkey	7	**16.5** (14.3-22.5)	4/3	No	3-4y	CT, L, AP	x	x	SC for CFDO
19.	Alkan et al. *b*	2006	Turkey/ Japan	15 control: 10	**16** (15-19)	5/10	No	1y		x		Bite force, occlusal contact area
20.	Weil et al.	1997	United States of America	9	**23.6** (12-48)		Yes	3m	AP, P	x	x	
21.	Mommaerts et al.,*b*	2005	Belgium	14	**19,9** (12.2-35.2)	3/7	No	1y			x	Teeth mobility, teeth sensitivity and pocket depth
22.	Seeberger et al.	2010	Germany	19	**27.1** (43-15)	7/12	No	3m	CT	x		

Radiograph: AP = Anterior-Posterior; CT = Computer tomography; L = Lateral; NS = not specified; O = Occlusal; P = Panoramic; PE = Periapical; SV = Submental vertex
Methods & Measurement: SC for CFDO = Morphological and functional succes criteria for craniofacial distraction osteogenesis
Distractor: TB = Tooth borne; BB = Bone-borne; HB = hybrid
Anaesthesia: L = Local anaesthesia; G = General anaesthesia; IV = Intravenous sedation; IM = Intramuscular sedation
Maxillary expansion and additional surgery: G = Genioplasty; SARME = Surgically assisted rapid maxillary expansion; LF1 = LeFort I osteotomy; Bimax = bimaxillary surgery
Osteotomy: CI = Central incisor; LI = Lateral incisor; CU = Cuspidate; S = Stepwise; M = Midsymphyseal; PS = Parasymphyseal
Start orthodontic treatment: RE = Radiographic evidence

Follow-up period

The follow-up period depended on the objective of the study and the mean ranged from 2 weeks post-operative (*von Bremen, Schafer et al.* 2008) to 3 years post-consolidation (*Gunbay, Akay et al.* 2009).

Surgical intervention and distraction

In table 1 an overview of the surgical interventions is given. Considering the setting to perform MMD, most authors prefer an ambulatory setting with the use of local anaes-

Anesthesia	**Distractor**	**Maxillary expansion and additional surgery**	**Osteotomy** *(N)*	**Latency,** *day*	**Distraction rate,** *mm/day*	**Activation,** *mm (ramge)*	**Consolidation**	**Start orthodontic treatment**
IM, L	HB	RME(18) SARME(4)	M(19); CI-LI(1)	7	1	8,1 ± 1,7	94,9d ± 5,8	0
L	BB		M(7)	7	1	6,48	4w	1m
L	TB			7	1	8 (6-9)	3m	3m
	TB	SARME(8)		4-5	0,75		3m	3m
	BB	SARME (12)		7	0,5		71,7d	2m
	TB	SARME Bimax	CI (19)	7	0,4	5,68 ± 0,89	3m	4m

thesia or sedation (intravenous or intramuscular) (*Guerrero, Bell et al.* 1997; *Iseri and Malkoc* 2005; *Alkan, Arici et al.* 2006; *Duran, Malkoc et al.* 2006; *Malkoc, Iseri et al.* 2006; *Uckan, Guler et al.* 2006; *Chung and Tae* 2007; *Gunbay, Akay et al.* 2009; *Ploder, Kohnke et al.* 2009). Others favoured a more controlled setting with the use of general anaesthesia (*Landes, Laudemann et al.* 2008; *Raoul, Wojcik et al.* 2009). Del Santo et al. performed a bimaxillary expansion under general anaesthesia and a solitary MMD under intravenous sedation (*Del Santo, Guerrero et al.* 2000). The incision used to approach the anterior mandible was horizontal, vertical or a combination of the two. The midline was the commonest site for the osteotomy, however a paramedian or stepwise osteotomy was not uncommon.

MMD was often accompanied with a rapid transverse expansion of the maxilla (*Iseri and Malkoc* 2005; *Malkoc, Iseri et al.* 2006; *Bayram, Ozer et al.* 2007; *Malkoc, Usumez et al.* 2007) whether or not surgically assisted (*Weil, Van Sickels et al.* 1997; *Kewitt and Van Sickels* 1999; *Del Santo, Guerrero et al.* 2000; *Iseri and Malkoc* 2005; *Malkoc, Iseri et al.* 2006; *Malkoc, Usumez et al.* 2007; *Landes, Laudemann et al.* 2008; *Mommaerts, Spaey et al.* 2008; *von Bremen, Schafer et al.* 2008; *Raoul, Wojcik et al.* 2009; *Seeberger, Kater et al.* 2010). Less frequent a simultaneous genioplasty was described (*Guerrero, Bell et al.* 1997). Following MMD authors reported a

BSSO (*Kewitt and Van Sickels* 1999; *Raoul, Wojcik et al.* 2009), a LeFort I osteotomy (*Kewitt and Van Sickels* 1999) or a bimaxillary osteotomy (*Raoul, Wojcik et al.* 2009; *Seeberger, Kater et al.* 2010).

Distractor types used are: tooth-borne (Hyrax, *Dentaurum Ispringen, Germany*; or custom-made), bone-borne (Modus, *Medartis, Basel, Switzerland*; TMD(-flex), *Surgitec, Brugge, Belgium*; Dynaform, *Stryker, Freiburg, Germany),* and hybrid (Hyrax II, *Dentaurum, Ispringen, Germany*; or custom-made). In four articles more than one type of distractor was used (*Guerrero, Bell et al.* 1997; *Braun, Bottrel et al.* 2002; *Alkan, Ozer et al.* 2007; *Chung and Tae* 2007), whereby only Alkan et al. reviewed all three types (*Alkan, Ozer et al.* 2007). None of the articles reported a statistical comparison of the different distractor type.

Generally, following surgery a latency of 5-7 days was applied by most authors. The mean distraction rate was 0.69 mm/day ranging from 0.25 mm/day (*von Bremen, Schafer et al.* 2008) to 1 mm/day, with the latter being the most common. A mean overall activation of 5.8 mm with a range of 2 mm (*Braun, Bottrel et al.* 2002) to 14 mm (*Guerrero, Bell et al.* 1997) was achieved. The mean consolidation period after the distraction period was 2.6 months ranging from 4 weeks (*Gunbay, Akay et al.* 2009) to 7 months (*Chung and Tae* 2007). The initiation of orthodontic treatment differed widely, ranging from immediately (*Iseri and Malkoc* 2005; *Duran, Malkoc et al.* 2006; *Malkoc, Iseri et al.* 2006) to 4 months (*Seeberger, Kater et al.* 2010) after the end of the distraction phase.

Skeletal and dental effects of MMD

The effects of MMD on skeletal and dental structures was given in table 3. Concerning expansion on the dental level, the results show increases in intercanine distance (ICD) and intermolar distance (IMD) in both the pre- to postdistraction and the predistraction to end of follow-up time frame (*Del Santo, Guerrero et al.* 2000; *Malkoc, Iseri et al.* 2006; *Chung and Tae* 2007; *Gunbay, Akay et al.* 2009; *Ploder, Kohnke et al.* 2009; *Seeberger, Kater et al.* 2010). Chung et al. and del Santo et al. found little relapse in ICD and IMD (*Del Santo, Guerrero et al.* 2000; *Chung and Tae* 2007), where Malkoc et al. found a 2.5 mm relapse at the end of follow-up in ICD (*Malkoc, Iseri et al.* 2006). Alkan et al. found a difference in the amount of expansion at the bone and the dentoalveolar level in tooth-borne distractors and to a lesser extent in bone-borne distractors, Ploder et al. presented similar results with tooth-borne distractors (*Alkan, Ozer et al.* 2007; *Ploder, Kohnke et al.* 2009). To quantify proportionate mandibular vertical widening on anterior-posterior cephalograms the following measurements can be performed: ramal angle (RA); difference between expansion in inter second molar distance (ISMD) and interantegonion distance (AD); mandibular tilt (MT). The RA is the angle between the left and right ramal planes and is defined by the position of the lateral condyle and gonion.

Decreases in RA are an indication of proportionate widening of the anterior mandible. Gunbay et al. found a significant decrease in the RA after distraction, where Iseri et al. found a non-significant decrease (*Iseri and Malkoc* 2005; *Gunbay, Akay et al.* 2009). ISMD and AD are in the same coronal plane and therefore give an indication for proportionate expansion. An unequal expansion of ISMD and AD was found by several authors (*Del Santo, Guerrero et al.* 2000; *Iseri and Malkoc* 2005; *Gunbay, Akay et al.* 2009). Furthermore, Seeberger et al. showed a significant increase in MT (*Seeberger, Kater et al.* 2010). The extent of expansion on tooth level differs between studies. Malkoc et al., del Santo et al. and Chung et al. found a discrepancy in the posterior (ICD) and anterior (IMD) expansion (*Del Santo, Guerrero et al.* 2000; *Malkoc, Iseri et al.* 2006; *Chung and Tae* 2007) others did not (*Braun, Bottrel et al.* 2002; *Gunbay, Akay et al.* 2009; *Ploder, Kohnke et al.* 2009). Both reduction (*Malkoc, Iseri et al.* 2006; *Landes, Laudemann et al.* 2008) and increase (*Del Santo, Guerrero et al.* 2000; *Gunbay, Akay et al.* 2009; *Seeberger, Kater et al.* 2010) of intercondyle distance (ID) after distraction/consolidation was found where relapse was observed at the end of follow-up. Regarding anterior-posterior positioning Mommaerts et al. reported a significant anterior movement of the central incisors (*Mommaerts, Polsbroek et al.* 2005). In addition, Gunbay et al. reported a significant increase in gonion-gnathion distance of 1.7 mm (*Gunbay, Akay et al.* 2009).

Regarding dental tipping Chung et al. reported a difference of expansion between cusp and cementoenamel junction of 1 mm in the premolar region and 0.7 mm in the canine region (*Chung and Tae* 2007). This is in concordance with Ploder et al. who presented differences in expansion between bone and tooth level (*Ploder, Kohnke et al.* 2009). Seeberger et al. demonstrated an increase in lateral angulation of all incisors, premolars and molars (*Seeberger, Kater et al.* 2010). Regarding rotational movement of the condyle Gunbay et al. found a distolateral movement between 2.5-3°, where Landes et al. found a distolateral movement of 0.028° (*Landes, Laudemann et al.* 2008; *Gunbay, Akay et al.* 2009).

One article measured the effect of MMD in combination with rapid maxillary expansion (RME) on airway dimensions (*Malkoc, Usumez et al.* 2007). In this study lateral and anterior-posterior cephalograms were used to measure pharyngeal airway dimensions, tongue and hyoid position. Patients first underwent MMD surgery and after 94.9 (± 5.8) days RME is started. Before and after each treatment modality radiographs were taken. MMD only significantly decreased tongue length and increased mandibular molar and canine widths. After RME significant effects on oropharyngeal width, vertical airway length and the vertical position of the hyoid bone were observed.

Table 2. Methodological quality.

No.	Author	Year of publication	Study design	Previous estimate of sample size	N	Selection description	Withdrawals	Valid methods	Confounding factors considered	Adequate statistics provided	Medical ethical committee approval	Judged quality standard
1.	Bayram et al.	2007	CS, P	No/Unknown	14	Adequate		Yes	A, S, OS, OT	Yes	Yes	Medium
2.	Alkan et al. *a*	2007	CS, R	No/Unknown	40	Adequate	Failure (1)	Partly	A, S, OT	No	No	Low
3.	Braun et al.	2002	CS, P*	No/Unknown	12	Inadequate	Unclear	Yes	A, S	No	No	Low
4.	Chung et al.	2007	CS, R	No/Unknown	19	Partly adequate		Yes	A, S, OT	Yes	No	Low
5.	von Bremen et al.	2008	CS, R*	No/Unknown	100	Partly adequate	None	Yes	A, S, OS	No	No	Low
6.	Mommaerts et al. *a*	2008	CS, R	No/Unknown	23	Partly adequate	Failure (1)	Yes	A, S, OS	No	No	Low
7.	Landes et al.	2008	CS, P	No/Unknown	9	Adequate		Yes	A, S, OS, OT	Yes	Yes	Medium
8.	Raoul et al.	2009	CS, R	No/unknown	14	Partly adequate	Failure (1)	Yes	A, S, OS, OT	No	No	Low
9.	Ploder et al.	2009	CCS, P	No/Unknown	20	Partly adequate		Yes	A	Yes	No	Low
10.	Kewitt et al.	1999	CS, R	No/Unknown	15	Partly adequate	Lost to follow-up (7) Exclusion (1)	Yes	A, S, OS	No	No	Low
11.	Uckan et al.	2006	CS, R	No/Unknown	24	Partly adequate		Yes	A	No	No	Low
12.	del Santo et al.	2000	CS, R	No/Unknown	20	Adequate		Yes	A, S, OS, OT	Yes	No	Low

13.	Guerrero et al.	1997	CS, R'	No/Unknown	10	Partly adequate		Partly	A, S, OS, OT	No	No	Low
14.	Işeri et al.	2005	CS, P	No/Unknown	20	Partly adequate		Yes	A, OS, OT	Yes	Yes	Low
15.	Malkoç et al. *b*	2007	CS, P	No/Unknown	20	Partly adequate		Yes	A, S, OS, OT	Yes	No	Low
16.	Duran et al.	2006	CS, P	No/Unknown	16	Partly adequate	None	Yes	A, S, OT	No	Yes	Low
17.	Malkoç et al. *a*	2006	CS, P	No/Unknown	20	Partly adequate		Yes	A, OS, OT	Yes	Yes	Low
18.	Gunbay et al.	2009	CS, R	No/Unknown	7	Adequate		Yes	A, S, OT	Yes	No	Low
19.	Alkan et al. *b*	2006	PCT	No/Unknown	15 control: 10	Partly adequate		Yes	A, S, OS, OT	Yes	No	Low
20.	Weil et al.	1997	CS, R'	No/Unknown	9	Adequate		Yes	A, S, OS, OT	Partly, method analysis included	No	Low
21.	Mommaerts et al. *b*	2005	CS, P	No/Unknown	14	Partly adequate	Exclusion (2)	Yes	A, S, OS, OT	Yes	No	Low
22.	Seeberger et al.	2010	CS, R	No/Unknown	19	Adequate		Yes	A, S, OS, OT	Yes	Yes	Low

Study design:CS = case serie, CCS = consecutive case serie, PCT = Prospective controlled trial; P = Prospective; R = Retrospective; ' = mostlikely; * = after personal contact with author.

Confounding factor: OS = other surgery, OT = orthodontic treatment, S = sex, A= age

Table 3. Biomechanical effects, in mm.

Article	Author	Distractor: N	Follow-up (range)	Horizontal widening and relapse on cast (# = AP cephalogram; ° = CT-scan)		
					$T_{pre\text{-}dist.}$ - $T_{post\text{-}dist./cons.}$	$T_{pre\text{-}dist.}$ - $T_{end\ follow\text{-}up}$
2.	Alkan et al., *a*	TB:21 HB/BB: 19	1.8y (9m-3y)			
3.	Braun et al.	TB/BB: 12			No, posterior/anterior difference; no quantitative analysis	
4.	Chung et al.	TB/HB: 19	1.5y (6m-3.1y)	ICD IMD	4.5 ± 1.64* 3.0 ± 2.04*	4.2 ± 2.07* 2.5 ± 2.30*
7.	Landes et al.	BB: 9	3m	ICD° ID°	3.8 ± 0,18* -1.0 ± 0,1*	
9.	Ploder et al.	TB: 20	3m	ICD IMD	4.2 ± 1,8 NA 4.3 ± 1,7 NA	
12.	del Santo et al.	TB: 20	1,3y (6-31m)	ICD# ISMD# ICD IMD ID	3,2 ± 3.3* 2,2 ± 4.2* 0.7 ± 1,8	3.3NA 0.7NA 2.4 ± 1.9* 5.0 ± 3.2* -0.2 ± 3,1
14.	Işeri et al.	HB: 20	21.5m ± 4.6			
17.	Malkoç et al. *a*	HB: 20	24.1m ± 4.2	ICD IMD ID	7,3* 3,3* -0,7*	4.8* 3.7* 0,6*
18.	Gunbay et al.	BB: 7	(3-4y)	ICD IMD ID	3.85 ± 1.88* 3,71 ± 0.99* 0.35	
20.	Weil et al.	TB: 9	3m	ICD IMD		3.19 ± 2.2NA 4.42 ± 1.1NA
21.	Mommaerts et al., *b*	BB: 12	1y	ICD IMD		5.9 ± 0.16* 1.3 ± 0.13*
22.	Seeberger et al.	TB: 19	3m	IMD° ID°		4.9 ± 1.30* 0.67 ± 1.67

* = significant $P < 0.05$, NA = no statistical analysis
Horizontal widening: ICD = intercanine distance, IMD = inter first molar distance, IPD: inter first premolar distance
Vertical widening:ID = intercondyl distance, AD = interantegonion distance, ISMD = inter second molar distance, RA = ramal angle, MT = mandibular tilt

Vertical widening on AP cephalogram (° = CT-scan; # = unknown: measurement)		**Anterior – posterior displacement (° = cast; # = lateral cephalogram)**		**Dental tipping, on cast (SD), (° = CT-scan, # = lateral cephalogram)**		**Distolateral rotation condyle on CT-scan**
	T$_{pre\text{-}dist.}$ - $T_{post\text{-}dist./cons.}$			$T_{pre\text{-}dist.}$ – $T_{post\text{-}dist./cons}$		$T_{pre\text{-}dist.}$ - $T_{post\text{-}dist./cons}$
(1): TB; (2): BB/HB Bone level#: Dento-alveolar level#:	 (1): 3.7 ± 1.1 (2): 4.6 ± 0,9 (1): 4.9 ± 0,9 (2): 5 ± 0.8					
				Cusp-CEJ ICD IPD	 0.7 NA 1.0 NA	
						0,028° ± 4,34
				TL – BL: ICD IMD	 0.8 1.1*	
AD ISMD	1,2 ± 4,1 2.2 ± 4,2*					
AD ISMD RA	0,21 0,78* -0,37					
			$T_{pre\text{-}dist.}$ - $T_{post\text{-}dist./cons.}$			
AD ISMD RA	2.28 ± 0.48* 4.0 ± 0.86* -1.64 ± 1.31*	Go-Gn#	1.7*			2,5-3°
			$T_{pre\text{-}dist.}$ - $T_{end\ follow\text{-}up}$			
		CI: Left° Right°	 1.3* 1.5*			
MT°	2.30 ± 1.97*			PMA° MA°	3.32 ± 1.57* 2.63 ± 1.75*	

Anterior-posterior displacement: Go-Gn = distance between gonion and gnathion, CI = Central incisor anterior displacement
Dental tipping: Cusp = measurement at cusp, CEJ = measurement at cementoenamel junction, TL – BL = difference expansion in tooth and bone level

Treatment related difficulties and complications

The findings are presented in table 4. Of the reviewed articles, 10 monitored complications/difficulties with MMD and 13 described their findings on the effect of MMD on craniomandibular dysfunction (CMD). We subdivided the difficulties and complications into: appliance, soft tissue lesions, dental, surgical, distraction procedure and CMD.

Appliance

Appliance difficulties were seen in both tooth- and bone-borne distractors. In tooth-borne appliances the most described problem was related to the distractor screw. An unspecified case of distractor failure was also described (*Weil, Van Sickels et al.* 1997; *Kewitt and Van Sickels* 1999; *von Bremen, Schafer et al.* 2008). In bone-borne appliances an infection around the osteosynthesis screw of the appliance and breakage of three bone-borne distractors were reported (*Alkan, Ozer et al.* 2007; *Mommaerts, Spaey et al.* 2008).

Soft tissue lesions

Most of the difficulties and complications found with MMD were soft tissue related and the incidence was highest amongst bone-borne and hybrid appliances. In hybrid and bone-borne distractors a high occurrence of mild irritation or mild gingivitis of mucosa and lips and even one case of necrotizing gingivitis was reported (*Uckan, Guler et al.* 2006; *Mommaerts, Spaey et al.* 2008; *Gunbay, Akay et al.* 2009; *Raoul, Wojcik et al.* 2009). Gingival recession was described, which was seen independently of the appliance type (*Uckan, Guler et al.* 2006; *Alkan, Ozer et al.* 2007; *von Bremen, Schafer et al.* 2008).

Dental

On the dental level the commonest complications were: loss of vitality of teeth or damaged teeth after surgery (*Kewitt and Van Sickels* 1999; *Mommaerts, Spaey et al.* 2008; *von Bremen, Schafer et al.* 2008; *Gunbay, Akay et al.* 2009; *Ploder, Kohnke et al.* 2009). Additionally, an apical radiolucency (asymptomatic), a mobile tooth, root exposure and a deep pocket were observed (*Kewitt and Van Sickels* 1999; *Mommaerts, Spaey et al.* 2008; *Raoul, Wojcik et al.* 2009).

Surgical

Cases of (transient) sensory disturbances after surgery were described in two articles (*Kewitt and Van Sickels* 1999; *Raoul, Wojcik et al.* 2009). In Kewitt et al. the surgical outome was hampered because of reoperation and subsequent damage of the mental nerve. Further, Alkan et al. reported a case with chin ptosis and another with an incomplete osteotomy (*Alkan, Ozer et al.* 2007). Other complications were wound related: wound dehiscence and scar stricture (*von Bremen, Schafer et al.* 2008; *Gunbay, Akay et al.* 2009).

Table 4. Treatment related difficulties and complications, (N).

No.	Author:	N	Distractor	Treatment related difficulties					
				Appliance	*Soft tissue*	*Dental*	*Surgical*	*Distraction*	*CMD*
2.	Alkan et al. *a*	40	TB(21); BB(5); HB(14)	Breakage(3)	Ecchymosis(2) Secondary infection(2) Severe mucosal irritation(1) Gingival recession (1)	-	Chin ptosis(1); Incomplete osteotomy (1)	-	No new cases or progression
3.	Braun et al.	12	TB(10); BB(2)						No new cases or progression
5.	von Bremen et al.	100	TB	Instable distractor screw(4)	Abces(1) Mandibular swelling(1) Gingival recession(1)	Tooth fracture(2)	Scar strictures(2)	Premature bone union(3)	-
6.	Mommaerts et al.*b*	23	BB	Infection around fixation screw(1)	Necrotising gingivitis(1) Chin infections(7)	Loss of vitality(1) Iatrogenic apical resection(1) Subluxation(2)	Post-op hematoma mouth floor(1) Incomplete osteotomy(1)	Delayed union(3)	Transient CMD(1)
7.	Landes et al.	9	BB	-	-	-	-	-	No new cases or progression
8.	Raoul et al.	14	BB	-	Mild/severe mucosal irritation(8/1)	Root exposure(1)	Transient paresthesia (6)	-	Pre-op CMD, resolved with MMD and BSSO(1) Transient CMD(1)
9.	Ploder et al.	20	TB	-	-	Transient decreased vitality tooth(1)	-	-	Transient CMD(2)

Table 4. Treatment related difficulties and complications, (N). (continued)

No.	Author:	N	Distractor	Treatment related difficulties					
				Appliance	*Soft tissue*	*Dental*	*Surgical*	*Distraction*	*CMD*
10.	Kewitt et al.	15	TB	Appliance failure(1)	-	Deep pocket(1) Loss of vitality(2) Post-op asymptomatic apical radiolucency(1) Increased mobility (2)	Paresthesia (1)	-	Pre-op CMD complain(7): Resolved (3) Improved(2) Temporary worsening, with complete resolution(1) Post-op closed-lock -> arthrocentesis(1)
11.	Uckan et al.	24	HB	-	Mild irritation mucosa and lip (24) Gingiva recession(4)	-	-	-	No new cases or progression
13.	Guerrero et al.	10	TB(8)/BB(2)	-	-	-	-	-	Transient CMD (1)
18.	Gunbay et al.	7	BB	-	Chronic gingivitis(7)	Damage to CI(1)	Wound dehiscence(3)	-	Transient CMD(3)
20.	Weil et al.	9	TB	Instable distractor screw (4)	-	-	-	Premature bone union(4)	No new cases or progression
22.	Seeberger et al.	19	TB	-	-	-	-	-	No new cases or progression

TB: Tooth-borne; BB: bone-borne; HB: hybrid; CI: central incisor; CMD: craniomandibular dysfunction

Distraction

The most frequently described complications of the distraction itself were premature bone healing (*Weil, Van Sickels et al.* 1997; *von Bremen, Schafer et al.* 2008) and delayed bone union (*Mommaerts, Spaey et al.* 2008). Both complications are uncommon.

CMD

Regarding CMD, six articles did not report new cases or progression of pre-existing CMD (*Weil, Van Sickels et al.* 1997; *Braun, Bottrel et al.* 2002; *Uckan, Guler et al.* 2006; *Alkan, Ozer et al.* 2007; *Landes, Laudemann et al.* 2008; *Seeberger, Kater et al.* 2010). Five articles described cases of transient CMD which occurred somewhere during the treatment and resolved with or without additional physio- or splint therapy treatment (*Guerrero, Bell et al.* 1997; *Mommaerts, Spaey et al.* 2008; *Gunbay, Akay et al.* 2009; *Ploder, Kohnke et al.* 2009; *Raoul, Wojcik et al.* 2009). Improvement and complete resolution of complaints were reported by Kewitt et al. and Raoul et al. (*Kewitt and Van Sickels* 1999; *Raoul, Wojcik et al.* 2009).

Bone quality and histology in MMD

Two articles paid attention to bone histology and quality (*Duran, Malkoc et al.* 2006; *Chung and Tae* 2007). Duran et al. analysed the histology of the distraction gap. Chung et al. examined healing patterns using radiographs and a classification system proposed by Samchukov et al. (*Samchukov, Cope et al.* 2001). Duran et al. showed that after 94.9 (± 5.8) days of consolidation the distraction gap was filled with bone that, from a histological perspective, was woven (*Duran, Malkoc et al.* 2006). Chung et al. demonstrated that at the end of the follow-up period (11-12 weeks) in all patients progress of mineralization was seen, however the speed of filling the distraction gap with regenerate was heterogeneous (*Chung and Tae* 2007).

DISCUSSION

This systematic review provides an update of the scientific evidence on MMD. Unfortunately, no RCT's or large CCT's were found. Of the articles found most score low on methodological quality. Due to the heterogeneity in the acquired publications with consequent results and an unknown overlap in some patient samples, a meta-analysis of the data was not possible. For the readability a list of the used abbrevations is added, Table 5.

Table 5. Abbreviations used in text.

MMD	Mandibular midline distraction
DO	Distraction osteogenesis
RCT	Randomized controlled trial
CCT	Clinical controlled trial
SARME	Surgical assisted rapid maxillary expansion
RME	Rapid maxillary expansion
BSSO	Bilateral sagittal split osteotomy
CMD	Craniomandibular dysfunction
ICD	Intercanine distance
IMD	Inermolar distance
RA	Ramal angle
ISMD	Inter second molar distance
AD	Antegonion distance
MT	Mandibular tilt
ID	Intercondyle distance
TMJ	Temporomandibular joint

Surgical setting

MMD surgery is a relatively short procedure and can be performed in different settings. Our study shows that an ambulatory setting with IV or IM sedation or local anaesthesia is used more often than general anaesthesia. Proponents of an ambulatory setting argue that it is safer because of the additional risks that associated with general anaesthesia. In addition, the absence of hospitalization and lower costs, together with the above would make the indication for MMD more interesting for the patient (*Guerrero, Bell et al.* 1997; *Chung and Tae* 2007; *Raoul, Wojcik et al.* 2009). Alkan et al. and Gunbay et al. state that surgery under local anaesthesia is well tolerated by patients with the caveat that patients need to be cooperative (*Alkan, Ozer et al.* 2007; *Gunbay, Akay et al.* 2009). Performing MMD solely under local anaesthesia is not comfortable for patient nor surgeon. No consensus exists, and the choice may depend on the surgeon's experience and training and patient preferences.

Surgical technique

The operation technique used for MMD was first described by Guerrero et al.(*Guerrero, Bell et al.* 1997). Three incisions are described of which the most common is a horizontal (4-6mm labial of the vestibule) incision. The others, less commonly described, are a vertical incision in the midline and a combination of the two incisions. A vertical incision can be used when using a tooth-borne distractor and a midline osteotomy site (*Ploder, Kohnke et al.* 2009). Preferable a midline osteotomy is made, however since crowding is an indication for MMD, space between apices can be very limited. Dorfman and Turvey suggested to have a 3-5 mm space between the apices of the teeth to safely perform the interdental osteotomy without damaging periodontal health and tooth vitality (*Dorfman and Turvey* 1979). To induce bone formation and an adequate regenerate it is necessary to have bone at both osteotomy sides without root exposure (*Bell, Harper et al.* 1997). To create more space between the apices, pre-treatment orthodontics, or a stepwise paramedian osteotomy can be considered. A stepwise paramedian osteotomy increases the risk of a unilateral crossbite and a shift in the dental midline (*Mommaerts, Polsbroek et al.* 2005; *Tae, Kang et al.* 2006).

Many authors describe combining MMD and SARME in one procedure, thus creating the bony fundament for the expansion of both mandibular and maxillary dental arches. Patients only have to undergo one surgical procedure and orthodontists can adjust both lower and upper arch to the desired position. MMD is primarily indicated to widen the mandible, however a small significant anterior movement is reported and therefore it possibly reduces the necessity for a mandibular advancement (*Basciftci, Korkmaz et al.* 2004; *Mommaerts, Polsbroek et al.* 2005; *Gunbay, Akay et al.* 2009). MMD can offer an in between treatment for cases who require little advancement of the mandible. This would be interesting for future research. If MMD, whether or not combined with SARME, is not sufficient to completely improve occlusal deformities or facial aesthetics, additional surgery (e.g. BSSO, Lefort I osteotomy, genioplasty) is indicated.

Distraction procedure

In DO the quality of the newly formed bone largely depends largely on mechanical and biologic factors including: latency period; distraction rhythm and rate; consolidation period (*Rowe, Mehrara et al.* 1998). Surgery is generally followed by a latency period of approximately 1 week after which distraction starts at a rate of 1 mm/day. In this week a fibrovascular hematoma and collagen fibres are formed within the osteotomy gap (*Koudstaal, Poort et al.* 2005). A too slow distraction rate increases premature bone union, whereas a too fast rate reduces bone quality and might lead to non- or delayed bone union (*Meyer, Kruse-Losler et al.* 2006; *Long, Tang et al.* 2009). Comparison of the studies shows that most authors use a rate of 0.5-1 mm/day. Von Bremen et al. suggest that the premature bone union they encountered was due to a too long latency period of 7 days (*von Bremen, Schafer et al.* 2008). Authors using a latency period of more than 5 days did not encounter premature bone union unless it was caused by distractor failure. Rates below 0.5 mm/day are more likely to increase the risk of premature bone union and are not recommended (*Weil, Van Sickels et al.* 1997; *Mommaerts, Spaey et al.* 2008; *von Bremen, Schafer et al.* 2008). Following the distraction phase a consolidation period is considered, when the distractor remains in position so the regenerate can mature. This maturation process tends to be heterogeneous and after

3 months the regenerate showed immature and still developing bone (*Duran, Malkoc et al.* 2006; *Chung and Tae* 2007). A disadvantage of MMD, and DO at large, is the consolidation period and consequently the treatment period. In order to shorten treatment several authors describe the start of orthodontic treatment directly or shortly (within a month) after the distraction period (*Malkoc, Iseri et al.* 2006; *Gunbay, Akay et al.* 2009; *Raoul, Wojcik et al.* 2009). Supported by the findings of Liou et al., they argue that with early orthodontic treatment bone maturation accelerates (*Liou, Polley et al.* 1998). In addition, when no orthodontic forces are applied to the teeth next to the distraction gap they, physiologically, move towards the gap, the 'walking teeth' phenomenon (*Guerrero, Bell et al.* 1997). This could imply that arch alignment of teeth with controlled orthodontics is in concordance with normal physiology. On the contrary, this is opposite to what other investigators propagate when they argue that periodontal or bony defects, neurapraxia and loss of teeth can occur when applying orthodontics if no evidence of radiologic bone formation is seen (*Del Santo, Guerrero et al.* 2000; *Mommaerts, Polsbroek et al.* 2005).

Distractor devices and biomechanical effects

A wide range of distractor devices can be used for MMD, divided in: tooth-borne, bone-borne and hybrid devices. The main differences between the devices are the location of the fixation points and the rigidity of the appliance itself.

Relapse and vertical widening

Tooth-borne devices are fixated to the teeth, bone-borne devices directly to the bone and the hybrid devices to both teeth and bone. As a result of the position of the fixation points each type of distractor creates a different vector. Bone-borne devices apply their vector on basal bone level, whereas tooth-borne devices apply their vector more on the dentoalveolar level, in between is the hybrid distractor. This difference results in a more disproportionate widening of the anterior mandible in tooth-borne devices compared to bone-borne and hybrid distractors. Furthermore, tooth-borne devices will create less basal bone compared to hybrid and bone-borne distractors. In theory, basal bone expansion would decrease the long-term relapse (*Del Santo, Guerrero et al.* 2000; *Conley and Legan* 2003). However, no long-term RCT or CCT has been conducted to evaluate relapse for more than 5 years, nor compared different distractor outcomes. Since teeth on the long-term are subject to orthodontic therapy, relapse is very difficult to measure objectively on dental casts. Alkan et al. compared different types of distractors and showed that tooth-borne distractors created a more disproportionate widening. These results are in line with the, tooth-borne, dental cast analysis of Ploder et al. (*Alkan, Ozer et al.* 2007; *Ploder, Kohnke et al.* 2009). Unfortunately, Alkan et al. did not describe how they did the measurement and did not perform statistical analysis. Concerning RA, a decrease in hybrid and significant decreases in bone-borne devices were seen, however none of the tooth-borne studies measured RA (*Iseri and Malkoc* 2005; *Gunbay, Akay et al.* 2009). A difference in expansion of ISMD and AD is found in all distractors. However, the validity of the antegonional notch, one of the measuring points on anterior-posterior cephalograms, is disputed and therefore conclusion must be taken with care (*Legrell, Nyquist et al.* 2000). In addition, anterior-posterior cephalogram analysis is subject to vertical and horizontal rotational variations of the patient and therefore less reliable. Mandibular tilting was measured with the use of CT-scans and special computer packages, and the results in tooth-borne appliances show an increased angle. Overall the results indicate that bone-borne devices create a more proportionate vertical expansion than hybrid and tooth-borne devices (*Del Santo, Guerrero et al.* 2000; *Iseri and Malkoc* 2005; *Gunbay, Akay et al.* 2009; *Seeberger, Kater et al.* 2010). However, patient samples are small and measuring methods are inaccurate and difficult to reproduce.

A fine element analysis by Boccaccio et al. showed that expansion on dentoalveolar level in tooth-borne and hybrid devices is more congruent with the nominal aperture of the distractor compared to bone-borne devices (*Boccaccio, Lamberti et al.* 2008). Bone-borne distractors apply their vector more on basal level and have less effect on dentoalveolar level. It is more likely that the result of Boccaccio et al. is an effect of the disproportionate widening of the mandible in tooth-borne or hybrid devices.

Device rigidity, horizontal widening and TMJ

The rigidity of a distractor defines the parallel movement of segments and the quantity of micromotion between segments. Bell et al. state that micromotion of the segments improves vascularisation and thus osteogenesis (*Bell, Gonzalez et al.* 1999). Concerning parallel widening in the axial plane results differ, both anterior-posterior discrepancies (*Del Santo, Guerrero et al.* 2000; *Malkoc, Iseri et al.* 2006; *Chung and Tae* 2007) and parallel expansions were found (*Braun, Bottrel et al.* 2002; *Gunbay, Akay et al.* 2009; *Ploder, Kohnke et al.* 2009). Larger anterior-posterior differences seem to occur in tooth-borne and hybrid distractors, with the annotation that Ploder et al. used a special tooth-borne distractor to keep anterior-posterior differences low (*Ploder, Kohnke et al.* 2009). Mommaerts et al. claim that bone-borne devices with low axial rigidity minimize lateral displacement of the condyle and thereby reduce the risk of CMD (*Mommaerts, Polsbroek et al.* 2005). Gunbay et al. show, using an axially low rigid distractor (*Mommaerts* 2001) non-significant lateral condyle displacement. In other studies using 'rigid' bone-borne and hybrid distractors, condyles initially displace significantly medial instead of lateral (*Iseri and Malkoc* 2005; *Malkoc, Iseri et al.* 2006; *Landes, Laudemann et al.* 2008; *Gunbay, Akay et al.* 2009). Only tooth-borne devices show lateral displacement of the condyles (*Del Santo, Guerrero et al.* 2000; *Seeberger, Kater et al.* 2010). The temporomandibular joint (TMJ) accommodates very well, in both medial and lateral displaced condyles and relapse occurred towards the initial position (*Del Santo, Guerrero* *et al.* 2000; *Iseri and Malkoc* 2005; *Malkoc, Iseri et al.* 2006). The medial displacement of the condyle, seen in rigid bone-borne distractors, is most likely the result of the soft tissue envelope surrounding the posterior mandible, especially the joint capsule, muscles and disk, and the fixation point of the distractor (*Landes, Laudemann et al.* 2008). The soft tissue envelope resists the pure lateral expansion of the anterior mandible in the posterior mandible, which results in a medially displacement of the condyle. This is supported by the high stress levels in ramal and condylar regions found by Bascifti et al. in a finite element analysis on bone-borne distractors (*Basciftci, Korkmaz et al.* 2004). An explanation for the increased ID in tooth-borne distractors would be the combination of the increased vertical angle of the mandible and transversal widening. As a result of the increased angle and vertical widening the pressure of the soft tissue envelope in the ramal region will not change as much as in bone-borne devices. Consequently, the posterior mandible will not be 'pushed' medially but as a result of the widening it causes a lateral displacement of the posterior mandible. This is in concordance with findings of Boccaccio et al. who found that masticatory muscles have a greater effect on the distraction gap in bone-borne device than hybrid and tooth-borne devices (*Boccaccio, Lamberti et al.* 2008). When expanding the mandible, without increasing ID, a distolateral rotation of the condyle will occur. Harper et al. concluded that these rotational movements result in histological changes of TMJ cartilage (*Harper, Bell et al.* 1997). The rotational movements found by Gunbay et al. and Landes et al. are not in line with each other. This can be explained by the low rigidity of the distractor Gunbay et al. used, in addition, adaptation of the condyle also affected the results where Gunbay et al. measured directly after distraction and Landes et al. after 3 months consolidation. In this review CMD is not commonly found in patients and if it occurred physiotherapy and conservative treatment resolved the symptoms (*Guerrero, Bell et al.* 1997; *Mommaerts, Spaey et al.* 2008; *Gunbay, Akay et al.* 2009; *Ploder, Kohnke et al.* 2009). Some authors describe resolution of CMD after MMD (*Kewitt and Van Sickels* 1999; *Raoul, Wojcik et al.* 2009). No study has examined the long-term effects of MMD on CMD or compared biomechanical effects of the different distractors directly.

Dental tipping

Regarding dental tipping in MMD data is sparse and because of the various factors influencing angulation of teeth in MMD it is difficult to measure. Factors that can affect tipping are: orthodontic treatment, disproportionate widening of the hemi-mandible segments and type of distractor used. Bell et al. described tipping in dogs using tooth-borne devices (*Bell, Harper et al.* 1997). Lateral tipping is more likely to occur in tooth-borne and hybrid appliances since distraction forces are applied directly to the teeth. The results show that proclination or lateral tipping of the incisors in tooth-borne and hybrid distractors, especially in patients with no pre-treatment orthodontic wiring (*Chung and Tae* 2007; *Ploder, Kohnke et al.* 2009; *Seeberger, Kater et al.* 2010).

Effects on airway

Concerning the effects of solely MMD on the airway it seems of minimal clinical importance, and when combined with SARME the improvements are likely to be attributed to the SARME procedure (*Malkoc, Usumez et al.* 2007; *Bonetti, Piccin et al.* 2009).

Treatment related difficulties and complications

Overall, MMD can be considered as a safe form of treatment, although some caution must be taken. In this study, bone-borne and hybrid devices show more soft tissue lesions (e.g. mucosal irritation/gingivitis, gingival recession) compared to tooth-borne devices. This is a result of distractor rod position, which interferes with cleaning of the mucosa and the distractor legs which pass through the mucosa. Although not mentioned in the articles, theoretical, tooth-borne appliances have a higher risk of root resorption, because of the continuous high forces applied on the teeth during distraction and consolidation phase (*Weltman, Vig et al.* 2010). Since patients are also treated with extensive orthodontic therapy after MMD this might not be beneficial. The small numbers of complications found in the literature show a proportionate distribution between the distractor types.

Costs

Tooth-borne and hybrid appliances must be customized for a patient where bone-borne appliance can be generic. Tooth-borne appliances only require one operation whereas bone-borne and hybrid appliances require an additional operation for their removal. Alkan et al. showed a shorter operation time for tooth-borne appliances (*Alkan, Ozer et al.* 2007). Regarding patient friendliness all distractors to some extent are uncomforatble to a patient. Hybrid and bone-borne devices tend to irritate the lip, where the tooth-borne distractors, because of its lingual position, irritate the tongue. Although experiences with the use of MMD are widely described to our knowledge no study exists on patient satisfactory.

CONCLUSION

After almost two decades of mandibular midline distraction numerous studies were conducted. Since articles found are of low statistical power, conclusions must be taken with caution. Generally, MMD is a safe and effective treatment modality to treat transverse mandibular discrepancy. Controversies still exist including choice of distractor, setting to perform surgery, distraction rate, start of orthodontic treatment and relapse. Little is known on patient experience and quality of life after treatment and further prospective trials are necessary to address these controversies and questions.

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