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A systematic review of implant-supported overdentures in the edentulous maxilla, compared to the mandible: How many implants?

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Background and aim: There is now overwhelming evidence from systematic reviews that a two-implant overdenture is the first choice of treatment for the edentulous mandible. Conversely, consensus is lacking for implant-supported maxillary overdentures. Therefore, we systematically reviewed the treatment outcome of concepts used for implant-supported maxillary overdentures, focusing on the survival of implants, survival of maxillary overdentures and condition of the implant surrounding hard and soft tissues after a mean observation period of at least 1 year.
Material and methods: MEDLINE (1950 to December 2013), EMBASE (1966 to December 2013) and CENTRAL (1800 to December 2013) were searched to identify eligible studies. Two reviewers independently assessed the articles using specific study design-related quality assessment forms.
Results: Out of 195 primarily selected articles, 24 studies fulfilled the inclusion criteria. A meta-analysis showed an implant survival rate of 98.1% and overdenture survival of 99.5% per year in the case of ≥ 6 implants and a splinted (bar) anchorage. In the case of ≤ 4 implants and a splinted (bar) anchorage, implant survival rate and overdenture survival were 97.0% and 96.9% per year, respectively. In the case of ≤ 4 implants and a non-splinted anchorage (ball, locator, telescopic crown), implant survival rate and overdenture survival were 88.9% and 98.8% per year, respectively. The condition of the peri-implant tissues was not reported in most studies.
Conclusions: An implant-supported maxillary overdenture (all studies ≥ 4 implants) provided with a splinted anchorage is accompanied with a high implant and overdenture survival rate (both >95% per year), while there is an increased risk of implant loss when ≤ 4 implants with a non-splinted anchorage are used.

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Introduction

Edentulous patients often experience serious functional and psychosocial problems related to their conventional dentures because of an impaired load-bearing capacity[1,2]. These problems include pain during mastication, and insufficient stability and retention of the denture. Resolving such problems, particularly before the advent of implants, has been a challenge for both the prosthodontist and surgeon.

More than 20 years ago, van Steenberghe et al[3] first reported on the possibility of using man-

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Table 1 Search strategy.

#1 Search	"Denture, Overlay" [MeSH]
#2 Search	"Dental Prosthesis, Implant supported" [MeSH]
#3 Search	"Dental Implants" [MeSH]
#4 Search	"Dental Implantation, Endosseous" [MeSH]
#5 Search	"Mouth, Edentulous" [MeSH]
#6 Search	"Jaw, Edentulous" [MeSH]
#7 Search	"Maxilla" [MeSH]
#8 Search	#2 OR #3 OR #4
#9 Search	#5 OR #6
#10 Search	#1 AND #7 AND #8 AND #9
Last run of data search: 31 December, 2013	

dibular overdentures supported by two implants to treat problems where usually conventional mandibular dentures would be used. Since then, mandibular overdentures have been extensively studied with respect to a number of implants, a variety of clinical items (including implant survival, health of peri-implant soft tissues and peri-implant bone loss) and patients' satisfaction[4-10]. For the vast majority of patients, an overdenture on two implants in the mandible is the first choice of treatment when complaining about the lack of stability in their mandibular denture[11-13]. Underlining the McGill and York consensus statements, Thomason et al[14] concluded that there is now overwhelming evidence to support the proposal that a two-implant overdenture should become the first choice of treatment for the edentulous mandible. The number of implants in the edentulous mandible for support of an overdenture are well studied[15,16].

Regarding implant-supported maxillary overdentures, consensus is lacking, but implant-supported maxillary overdentures have been shown as a favourable treatment option for patients with persistent complaints of retention and stability of their conventional maxillary denture[1]. Next to sufficient retention and stability, proper phonetics, aesthetics and hygiene access can be achieved with implant-supported maxillary overdentures.

While two endosseous implants are generally considered to provide sufficient support to a mandibular overdenture, the number of implants needed to support a maxillary overdenture is still not set. Currently, a variety of numbers of implants is applied to support the maxillary overdenture, as well as a variety of anchorage systems[17]. Sadowsky[18] evaluated maxillary implant-supported overdentures with emphasis on the number of implants and anchorage design. He concluded that a number of 4 implants was the minimum to support a maxillary overdenture and recommended 6 implants in case of compromised bone. He could not detect a difference between the treatment outcome of splinted and non-splinted implants in the literature he assessed. Three years later, Slot et al[19] showed in a meta-analysis that the survival of implants used to support a maxillary overdenture is high if concepts were used with at least 4 implants supplied with either a bar or ball anchorage. Finally, from the systematic review of Roccuzzo et al[16], it can be concluded that the question of how many implants should support a maxillary overdenture is still open. Therefore, the aim of this systematic review was to assess the treatment outcome of concepts used for implant-supported maxillary overdentures focusing on survival of implants, survival of maxillary overdentures and the condition of surrounding hard and soft tissues after a mean observation period of at least 1 year.

Material and methods

Design of the study and search strategy

Although randomised controlled trials (RCTs) provide the highest evidence in comparing effectiveness of different therapies, relevant information is not exclusively provided by RCTs. Well-designed clinical trials and case series may also provide valuable information.

A search of the literature was conducted in the databases of MEDLINE (1950 to 31 December, 2013) (via PUBMED) and EMBASE (1966 to 31 December, 2013). The search was supplemented with a systematic search in the Cochrane Central Register of Controlled Trials' (CENTRAL) (1800–31 December, 2013). No language restriction was applied. The search strategy was a combination of MeSH terms (Table 1). The search was completed by checking the references of the relevant review articles and eligible studies.

Full-text documents were obtained for all articles meeting the inclusion criteria. Full text analysis was performed independently by two reviewers (GR, HM). Methodological quality was assessed independently by the reviewers using specific study design-related modified forms designed by the Dutch Cochrane Collaboration[20]. In case of disagreement, a consensus was reached by discussion, if necessary in consultation with a third reviewer (AV). To ensure that datasets were unique, of the studies in which the same patients were analysed at different times, leading to different publications, the study with the longest follow-up was selected for definitive analysis.

The criteria for a paper to be included in the study selection were:

- detailed information on maxillary overdentures supported by root-form endosseous implants; in case of combined data for implant-supported maxillary and mandibular removable overdentures, extraction of data for the maxillary overdenture must be possible
- the treatment of the patients has to be initially planned for a maxillary overdenture
- at least five patients should be described in a paper
- the follow-up period for implants in maxilla should be at least 1 year
- study design: RCTs, clinical trials or case series; retrospective studies were excluded.

Outcome measures

The following outcome measures were assessed:

- survival of implants
- survival of overdentures
- condition of peri-implant hard and soft tissues.

Statistical analysis

For the meta-analysis, the statistical software package 'Meta-analysis' was used (Comprehensive Meta-analysis Version 2.2, Biostat, Englewood, NJ 2005). For the calculation of the overall effects for the included studies, weighted rates together with random effect models were used.

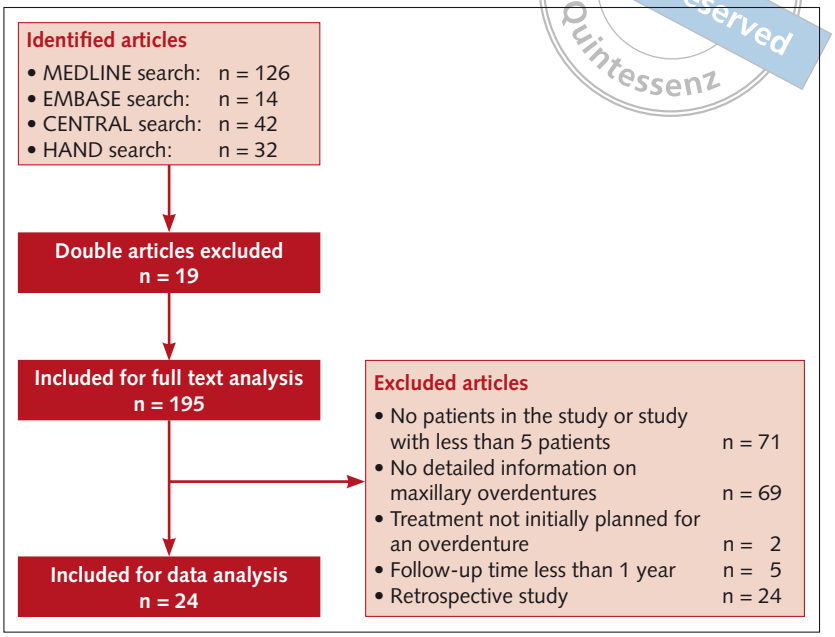

Fig 1 Algorithm of study selection procedure.

Results

Description of the studies

The MEDLINE search provided 126 hits, the EMBASE search 14 hits and the CENTRAL search 42 hits. Nineteen articles appeared to be duplicated. After scanning titles and abstracts, it was decided to select them all for evaluation as the full text article, because the abstracts did not always give a clear insight in the method of the study and the number of hits was reasonable to assess. This way no article was excluded beforehand. Reference-checking of relevant reviews and included studies revealed 32 additional articles to be screened. This approach resulted in 195 articles to be evaluated by full text analysis. Seventy-one articles were excluded because no patients at all or less than 5 patients were described. Another 69 articles were excluded because there was no detailed information available on maxillary overdentures as a separate treatment. Two articles were excluded because the treatment with implants was not initially planned for an overdenture. Five articles were excluded because the follow-up was less than 1 year. Finally, 24 articles were excluded because they were retrospective studies. The remaining 24 articles were scored (Fig 1).

Table 2 General characteristics of included studies.

Study	Year of publication	Study design	Follow-up in months	No. of patients in study
Zou et al[44]	2013	Prospective	36	30
Slot et al[41]	2014	Prospective (Straumann group)	12	25
		Prospective (Astra Tech group)	12	25
Slot et al[43]	2014	Randomised Controlled Trial	12	66
Slot et al[42]	2013	Randomised Controlled Trial	12	50
El-Ghareeb et al[40]	2012	Prospective	14	6
Van Assche et al[39]	2012	Prospective	24	12
Katsoulis et al[38]	2011	Prospective	24	28
Mangano et al[37]	2011	Prospective	60	38
Akça et al[36]	2010	Prospective	59	11
Pieri et al[35]	2009	Prospective	12	22
Raghoebar et al[34]	2006	Prospective	22	8
Raghoebar et al[33]	2005	Prospective	20	5
Payne et al[32]	2004	Randomised Controlled Trial (Brånemark group)	12	20
		Randomised Controlled Trial (Southern group)	12	19
Raghoebar et al[31]	2003	Prospective	12	10
Ferrigno et al[30]	2002	Prospective	120	35
Zitzmann and Marinello[29]	2000	Prospective	12	10
Zitzmann and Marinello[28]	2000	Prospective	27	10
Bergendal and Engquist[27]	1998	Randomised Controlled Trial (bar group)	60	10
		Randomised Controlled Trial (ball group)	50	8
Naert et al[26]	1998	Prospective	48	13
Watson et al[22]	1997	Prospective	60	30
Jemt et al[21]	1996	Prospective	60	30
Hutton et al[25]	1995	Prospective	36	30
Jemt et al[24]	1994	Prospective	12	6
Johns et al[23]	1992	Prospective	12	30

Two studies were suspected to present the same study population[21,22]. Whether the same study population was used was not clearly stated in the manuscript and for this reason, it was doubtful. As these two studies deliver the same data for the meta-analysis, the data from the most recent manuscript was used for the meta-analysis[22]. Both studies were saved for the tables, however, as regards survival, the focus was on different evaluation items. The two disagreements that occurred were easily resolved in a consensus meeting.

General characteristics of the 24 included studies are depicted in Table 2[21-44]. Authors of two articles[35,38] responded to an email concerning queries regarding the different groups they mentioned in their article. In the latter study, patients with 5 implants were excluded[38]. Four studies were randomised controlled trials (RCTs)[27,32,42,43]. In the study of Payne et al[32] two different implant systems were analysed and in the study of Bergendal and Engquist[27], the difference between a bar and a ball anchorage design was studied. In both studies, the patients that were included received 3 or less implants and a ball anchorage. Only one study was included regarding <4 implants provided with a bar suprastructure[22]. Slot et al[42,43] reported on the 1-year treatment outcome of 4 and 6 bar-connected implants placed with or without pre-implant bone augmentation to support an overdenture in edentulous patients. There was no difference in implant loss between these groups. In a 3-year prospective study, Zou et al[44] evaluated the use of telescopic

crown, bar and locator attachments to support a removable 4 implant-supported maxillary overdenture. No significant differences were observed in the implant survival and success rates. Furthermore, they showed that the locator attachment system was accompanied with the best peri-implant hygiene, frequency of prosthodontic maintenance measures, costs and ease of denture preparation when compared to the telescopic crown and bar attachment systems. Slot et al[41] also reported the results of a 1-year prospective case series in two groups of 25 patients on the treatment outcome of maxillary overdentures supported by 6 implants opposed by natural antagonistic teeth in the mandible. In the 25 patients in whom the implants were placed after augmentation, one implant was lost and in the 25 patients not needing pre-implant augmentation, three implants. The remaining 19 studies described prospectively analysed case series. The number of patients in the studies varied from five patients to 66 patients. The follow-up period varied from 12 to 120 months (Table 2).

Table 3 summarises the treatment procedures of the included studies. The number of implants placed to support the overdenture varied from 2 to 8 implants. Onlay block graft procedures and elevation of the floor of the maxillary sinus were carried out in some studies before insertion of the implants or together with the placement of the implants. Also, the placement of implants without bone graft procedures was described. The position of the implants, in relation to the availability of a bone volume sufficient to reliably insert endosseous implants, was often not well described. Furthermore, different implant systems were used (the majority were Brånemark and Straumann implants) as well as various anchorage systems. As regards anchorage systems, both splinted (bar) and non-splinted (ball, locator and telescopic crown) designs were used. With ≥ 6 implants, the anchorage design was splinted in all cases. With ≤ 4 implants both designs were used. In the majority of the studies, the kind of opposing dentition was not described; other studies described that there were all kinds of opposing dentition. Only in three RCTs[32,42,43] was it mentioned that all patients had a 2-implant or 4-implant overdenture in the mandible.

Table 4 gives the outcomes of the studies included in this review. For the survival rates of implants and overdentures, see the meta-analysis paragraph. The condition of the surrounding hard and soft tissues was mentioned in nine out of the 24 studies. In 13 studies, a change in mean marginal bone level was mentioned. When reported, a variety of outcome parameters were used, as measurements were done on either non-standardised rotational panoramic radiographs and intraoral radiographs, or on standardised intraoral radiographs. Loss of marginal bone varied from 0.22 mm in 12 months to 1.25 mm in 60 months. In 7 studies, the condition of the peri-implant mucosa was mentioned, but unfortunately a variety of indices was used to score this condition. In 8 studies, bleeding on probing was noted. Finally, in 7 studies probing depth was mentioned, varying from 3.2 mm to 4.8 mm.

Meta-analysis

Due to the methodological diversity of the studies, only the number of implants, anchorage design, survival of implants and survival of the overdenture could be meaningfully combined in a meta-analysis. It was chosen to include ≥ 6 implants and ≤ 4 implants in the meta-analysis to have a clear distinction between these two groups.

Figs 2, 3 and 4 depict the results of the weighted meta-analysis, expressed as event rates per year. Event rates were used to describe failures and were calculated by the ratio of the number of failures or complications (e.g. events) to the total exposure time of the construction. The exposure time was the time the implants or the overdenture was followed. Distinct event rates were calculated for both implants and dentures. In case of an implant failure or dentures that were lost during the observation time, the time to the event was used for the analysis. The survival rate (SR) is the complement of the event rate (ER), and was calculated as SR = 1-ER.

Survival of implants

Implant survival was defined as the percentage of implants initially placed that was still present at follow-up. A total of 1876 implants in 406 patients was analysed. The survival rates of the implants varied from 100% to 72.4% (Table 4). The event rate for implant loss in the case of ≥ 6 implants and a splinted

Table 3 Treatment procedures in the included studies.

Study	Year of publi-cation	Implants per patient	Pre-implant bone augmentation	Implant system	Anchorage design	Opposing dentition
Zou et al[44]	2013	4	No	Straumann Standard SLA	Bar	#
		4	No	Straumann Standard SLA	Locator	#
		4	No	Straumann Standard SLA	Telescopic crown	#
Slot et al[41]	2014	6	No	Astra Tech AB	Bar	Natural teeth
		6	Maxillary sinus floor augmentation	Straumann Standard SLA	Bar	Natural teeth
Slot et al[43]	2014	4	Maxillary sinus floor augmentation	Straumann Standard SLA	Bar	Implant overdenture
		6	Maxillary sinus floor augmentation	Straumann Standard SLA	Bar	Implant overdenture
Slot et al[42]	2013	4	No	Astra Tech AB	Bar	Implant overdenture
		6	No	Astra Tech AB	Bar	Implant overdenture
El-Ghareeb et al[40]	2012	4	Nasal floor augmentation	Brånemark MK III(20 implants) and Straumann Bone Level (4 implants)	Bar	All kinds of opposing dentition
Van Assche et al[39]	2012	6	No	SLActive Standard Plus	Bar	All kinds of opposing dentition
Katsoulis et al[38]	2011	4	No	Replace Select tapered	Bar	All kinds of opposing dentition
		5	No	Replace Select tapered	Bar	All kinds of opposing dentition
		6	No	Replace Select tapered	Bar	All kinds of opposing dentition
Mangano et al[37]	2011	4	No	Leone implant system	Bar	#
Akça et al[36]	2010	4	No	Straumann	Bar	All kinds of opposing dentition
Pieri et al[35]	2009	4	No	PrimaConnex	Bar	All kinds of opposing dentition
		5	No	PrimaConnex	Bar	All kinds of opposing dentition
Raghoebar et al[34]	2006	6–8	Sinus floor augmentation and onlay block	Brånemark	Bar	#
Raghoebar et al[33]	2005	6	Sinus floor augmentation	Brånemark	Bar	#
Payne et al[32]	2004	3	No	Brånemark	Ball	Two implant overdenture
		3	No	Southern implant system	Ball	Two implant overdenture
Raghoebar et al[31]	2003	6–8	Sinus floor augmentation	Osseotite (3i)	Bar	All kinds of opposing dentition
Ferrigno et al[30]	2002	4–6	Some	ITI	Bar	#
Zitzmann and Marinello[28]	2000	6–8	#	#	Bar	#
Zitzmann and Marinello[29]	2000	6–8	No graft procedures	Brånemark	Bar	#
Bergendal and Engquist[27]	1998	2–5	No	Brånemark	Bar	All kinds of opposing dentition
		2–3	No	Brånemark	Ball	All kinds of opposing dentition
Naert et al[26]	1998	4	No	Brånemark	Bar	All kinds of opposing dentition
Watson et al[22]	1997	3–4	#	Brånemark	Bar	Natural teeth or implant supported prosthesis
Jemt et al[21]	1996	3–4	#	Brånemark	Bar	All kinds of opposing dentition
Hutton et al[25]	1995	#	No	Brånemark	Bar	All kinds of opposing dentition
Jemt et al[24]	1994	4–6	#	Brånemark	Bar	#
Johns et al[23]	1992	#	No	Brånemark	Bar	All kinds of opposing dentition

= no (detailed) information provided

Table 4 Outcomes in the included studies.

Study	Year of publi-cation	No. of im-plants in study	No. of lost im-plants	No. of lost patients in study	Treatment (No. implants, mesostruc-ture)	Survival rate implants (%)	Survival rate over-dentures (%)	Change in marginal bone level (mean ± SD; mm)	Gingival index (mean ± SD)	Bleeding index (mean ± SD)	Probing depth (mean ± SD)
Zou et al[44]	2013	40	0	0	4, bar	100	100	1.0 (0.6)	0.21	0.22	3.3 (0.7)
		40	0	0	4, locator	100	100	0.9 (0.4)	0.14	0.16	3.4 (0.5)
		40	0	0	4, telescopic crown	100	100	0.9 (0.3)	0.19	0.20	3.2 (0.8)
Slot et al[41]	2014	150	3	0	6, bar	98	100	0.22	0.2	0.3	4.3
		150	1	0	6, bar	99.3	100	0.5	0.1	0.6	4.3
Slot et al[43]	2014	132	0	0	4, bar	100	100	0.35	0	0	4.8
		198	1	0	6, bar	99.5	100	0.46	0	1	4.4
Slot et al[42]	2013	100	0	1	4, bar	100	100	0.24	0.2	0.4	4.6
		150	1	0	6, bar	99.3	100	0.25	0.3	0.4	3.6
El-Ghareeb et al[40]	2012	24	0	0	4, bar	100	100	#	#	#	#
Van Assche et al[39]	2012	72	1	0	6, bar	98.6	100	1.3	#	0.28	3.4
Katsoulis et al[38]	2011	88	1	0	4, bar	98.9	100	#	#	#	#
		25	0	0	5, bar	100	100	#	#	#	#
		6	0	0	6, bar	100	100	#	#	#	#
Mangano et al[37]	2011	152	4	0	4, bar	97.4	100	#	#	#	#
Akça et al[36]	2010	44	1	#	4, bar	97.7	88	1.15	0.8	0.2	#
Pieri et al[35]	2009	28	1	0	4, bar	96.4	100	#	#	#	#
		75	2	0	5, bar	97.3	100	#	#	#	#
Raghoebar et al[34]	2006	56	0	0	6–8, bar	100	100	#	#	#	#
Raghoebar et al[33]	2005	30	1	0	6, bar	96.7	100	#	#	#	#
Payne et al[32]	2004	60	5	0	3, ball	92	#	#	#	#	#
		57	10	1	3, ball	82	#	#	#	#	#
Raghoebar et al[31]	2003	68	3	0	6–8, bar	95.6	100	0.3 (0.7)	0.5 (0.7)	0.7 (0.9)	3.4 (1.3)
Ferrigno et al[30]	2002	114	3	#	6, bar	92.2 (Milled bar)	94.7 (Milled bar)	#	#	#	#
		64	6	#	4, bar	86.9 (Dolder bar)	87.5 (Dolder bar)	#	#	#	#
Zitzmann and Marinello[28]	2000	#	#	0	6–8, bar	#	#	#	#	#	#
Zitzmann and Marinello[29]	2000	71	4	0	6–8, bar	94.4	100	0.92	54% (SD 26%)	#	#
Bergendal and Engquist[27]	1998	29	6	#	2–5, bar	79	90	1.25	#	#	#
		18	7	#	2–3, ball	61	88	1.0	#	#	#
Naert et al[26]	1998	53	6	6	4, bar	88.6	85	0.5	#	0.2 (0.7)	3.6 (0.9)
Watson et al[22]	1997	117	30	14	3–4, bar	72.4	77.9	#	#	#	#
Jemt et al[21]	1996	117	30	14	3–4, bar	72.4	77.9	0.8 (0.8)	#	#	#
Hutton et al[25]	1995	117	29	#	#, bar	72.4	72.4	#	#	#	#
Jemt et al[24]	1994	32	0	0	4–6, bar	100	100	Mesial side 0.30 (0.25) Distal side 0.34 (0.11)	#	#	#
Johns et al[23]	1992	117	21	5	#, bar	82.2	86.3	0.5	#	#	#

= no (detailed) information provided

Study name	Subgroup within study	Statistics for each study					Event rate and 95% CI	Weight (Random)				
		Event rate	Lower limit	Upper limit	Z value	*P* value		Relative weight	Relative weight	Std Residual	Std Residual	Std Residual
Slot et al[41]	≥ 6	0.020	0.006	0.060	-6.673	0.000		20.39		0.07		
Slot et al[41]	≥ 6	0.007	0.001	0.046	-4.987	0.000		9.28		-1.01		
Slot et al[43]	≥ 6	0.005	0.001	0.035	-5.270	0.000		9.29		-1.28		
Slot et al[42]	≥ 6	0.007	0.001	0.046	-4.987	0.000		9.28		-1.01		
Van Assche et al[39]	≥ 6	0.014	0.002	0.092	-4.233	0.000		9.23		-0.31		
Katsoulis et al[38]	≥ 6	0.071	0.004	0.577	-1.748	0.081		4.79		0.92		
Raghoebar et al[34]	≥ 6	0.009	0.001	0.125	-3.328	0.001		5.08		-0.54		
Raghoebar et al[33]	≥ 6	0.033	0.005	0.202	-3.311	0.001		9.08		0.54		
Zitzmann and Marinello[29]	≥ 6	0.056	0.021	0.141	-5.476	0.000		23.58		1.85		
		0.019	**0.010**	**0.036**	**-11.693**	**0.000**						

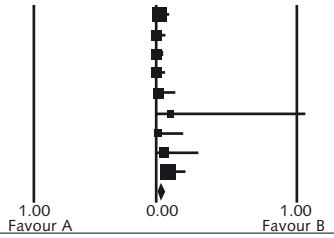

Fig 2 Meta-analysis of implant loss in case of ≥ 6 implants and a splinted superstructure. (When a study is mentioned twice, more than one implant system was analysed in that study. For details see Table 2.)

Study name	Subgroup within study	Statistics for each study					Event rate and 95% CI	Weight (Random)				
		Event rate	Lower limit	Upper limit	Z value	*P* value		Relative weight	Relative weight	Std Residual	Std Residual	Std Residual
Zou et al[44]	≤ 4	0.012	0.001	0.167	-3.088	0.002		7.52		-0.47		
Slot et al[41]	≤ 4	0.004	0.000	0.057	-3.938	0.000		7.55		-1.07		
Slot et al[42]	≤ 4	0.005	0.000	0.074	-3.741	0.000		7.55		-0.93		
El-Ghareeb et al[40]	≤ 4	0.020	0.001	0.251	-2.724	0.006		7.49		-0.21		
Katsoulis et al[38]	≤ 4	0.011	0.002	0.076	-4.440	0.000		9.89		-0.59		
Mangano et al[37]	≤ 4	0.026	0.010	0.068	-7.126	0.000		12.92		-0.10		
Akça et al[36]	≤ 4	0.023	0.003	0.144	-3.718	0.000		9.85		-0.17		
Pieri et al[35]	≤ 4	0.036	0.005	0.214	-3.236	0.001		9.81		0.10		
Naert et al[26]	≤ 4	0.113	0.052	0.230	-4.748	0.000		13.29		0.98		
Watson et al[22]	≤ 4	0.256	0.185	0.343	-5.029	0.000		14.13		1.73		
		0.030	**0.010**	**0.086**	**-6.150**	**0.000**						

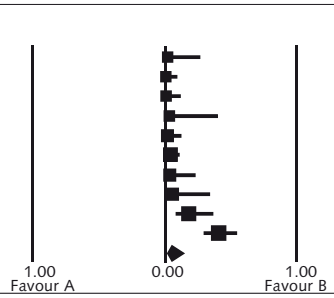

Fig 3 Meta-analysis of implant loss in case of ≤ 4 implants and a splinted superstructure.

Study name	Subgroup within study	Statistics for each study					Event rate and 95% CI	Weight (Random)				
		Event rate	Lower limit	Upper limit	Z value	*P* value		Relative weight	Relative weight	Std Residual	Std Residual	Std Residual
Zou et al[44]	≤ 4	0.012	0.001	0.167	-3.088	0.002		10.41		-1.40		
Zou et al[44]	≤ 4	0.012	0.001	0.167	-3.088	0.002		10.41		-1.40		
Payne et al[32]	≤ 4	0.175	0.097	0.296	-4.444	0.000		27.97		0.59		
Payne et al[32]	≤ 4	0.083	0.035	0.185	-5.134	0.000		25.76		-0.33		
Bergendal and Engquist[27]	≤ 4	0.389	0.198	0.621	-0.935	0.350		25.44		1.69		
		0.111	**0.040**	**0.273**	**-3.703**	**0.000**						

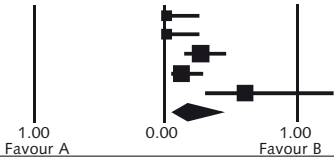

Fig 4 Meta-analysis of implant loss in case of ≤ 4 implants and a non-splinted superstructure. (When a study is mentioned twice more than one implant system was analysed in that study. For details see Table 2.)

anchorage was 0.019, which can be expressed as a survival rate of 98.1% per year (Fig 2). The event rate for implant loss in the case of ≤ 4 implants and a splinted anchorage was 0.030, which can be expressed as a survival rate of 97.0% per year (Fig 3). The event rate for implant loss in the case of ≤ 4 implants and a non-splinted anchorage was 0.111, which can be expressed as a survival rate of 88.9% per year (Fig 4).

Survival of maxillary overdentures

The survival of maxillary overdentures was defined as the percentage of overdentures initially placed that was still present at follow-up. Survival rates of the overdentures varied from 100% to 77.9% (Table 4). The weighted meta-analysis (for person-years and for study size) for overdenture loss, expressed as event rates, in case of ≥ 6 implants and a splinted anchorage was 0.005 (95% CI [0.002 – 0.012]), which can be expressed as a survival rate of 99.5% per year. The event rate for overdenture loss in the case of ≤ 4 implants and a splinted anchorage was 0.031 (95% CI [0.013 – 0.076]), which can be expressed as a survival rate of 96.9% per year. The event rate for overdenture loss in the case of ≤ 4 implants and a non-splinted anchorage was 0.012 (95% CI [0.002 – 0.086]), which can be expressed as a survival rate of 98.8% per year[27].

Discussion

In contrast to the edentulous mandible, prospective studies with clinical and radiological baseline data reflecting the number of implants needed to support a maxillary overdenture, with an appropriate sampling frame, adequate sample size and sampling method are currently scarce. In addition, there is a shortage of RCTs to compare the outcome of specific questions related to the number of implants and design of the superstructure. In only two RCTs, the treatment outcome of 4 and 6 implants to support a maxillary denture was compared[42,43]. In these RCTs no difference was noted between these treatment concepts after 1-year follow-up. All the other included publications provided data from convenience samples. Notwithstanding this drawback, on the basis of the available data we conclude that an implant-supported maxillary denture on at least 4 implants and provided with a bar anchorage is a proper treatment option for the edentulous maxilla, mainly because implant loss is considerably higher when the implant-denture is supported by < 4 implants.

By contrast and as mentioned before, there is a large body of evidence on which treatment concept is most suitable for the edentulous mandible. A 2-implant supported mandibular overdenture should be the minimum offered to edentulous patients as a first choice of treatment. The implant survival rate of mandibular overdentures is high, regardless of the number of implants[15]. Furthermore, there is evidence from systematic reviews and a large number of RCTs applying patient-based outcome assessments such as patients' satisfaction, oral-health related quality of life and in-depth qualitative interviews with patients that implant-supported mandibular overdentures have considerable benefits over conventional complete dentures[14]. It has to be mentioned, however, that the aforementioned recommended 2-implant supported mandibular overdenture treatment was based mainly on the results of studies that described implants placed in edentulous mandibles with a mandibular height in the symphysis region of at least 12 mm, and not in extremely atrophied jaws (mandibular height <12 mm). For the extremely resorbed mandible, there might be a need to modify this treatment concept. A treatment proposal for these very atrophied mandibles based on the best evidence currently available in the literature is made[2]. According to this proposal, in the extremely resorbed mandible (bone height and width ≥ 6 mm), 4 short implants could be placed if the soft tissues are in a good condition. Only in cases with a bone height of <6 mm, or when the soft tissue not in a good-enough condition to support an implant-supported mandibular denture, a bone augmentation procedure is advised.

In contrast to the excellent long-term implant and prosthodontic survival and success rates for implant-supported mandibular overdentures[10,45,46], several studies have described a higher number of implant failures and prosthodontic complications for implant-supported maxillary overdentures[1,19,21,45]. Poor bone quality, low bone quantity, short implant length with reduced diameter and poor initial stability are problems observed in edentulous maxillae cases and may adhere to the higher risk of implant loss and loss of maxillary overdentures[21,47].

As reported, the 1-year implant survival rate in the case of ≥ 4 implants supplied with a bar anchorage is >95%, which is very promising and comparable to the concepts using 4 or 6 implants and a bar anchorage to support the maxillary denture[41-44]. Reliable long-term data are not yet available. When losing an implant as part of 6-implant concept, a new surgical treatment procedure is usually not needed, as the overdenture can be adjusted. This is often not the case for the 4-implant approach, as with many of these patients a new implant has to be placed and a new suprastructure has to be made before the overdenture can be adjusted.

Progressive marginal bone loss is a predictor for future implant loss. Therefore, it is very important to analyse marginal bone loss in a standardised and reliable way. However, most studies used panoramic radiographs on which small changes in marginal bone loss are often not easy or not possible to assess. In the few studies that used standardised intraoral radiographs, marginal bone loss was less than 1.3 mm after 1 year, which is promising[35,36,39,41-44]. Further studies are needed to truly rate the long-term marginal bone loss around maxillary implants.

Mucosa indices, bleeding indices and pocket probing depth provide insight into the health of the peri-implant soft tissues. In the studies covering this aspect, the soft tissues appeared relatively healthy,

although mucositis and gingival hyperplasia may occur around the implants and below the bar[21,22]. Mucositis and gingival hyperplasia are usually reserved to conditions where the space between the bar and the oral mucosa or the space between the implants is limited. These conditions make proper oral hygiene difficult.

Future research concerning implant treatment of the edentulous maxilla should focus on long-term prospective clinical trials with detailed follow-up, in which clinical and radiographic aspects are analysed, restoration of function is assessed and patient satisfaction is scored. The current RCTs still only report on the 1-year follow-up data. Besides trials with overdentures, long-term RCTs comparing maxillary implant overdentures and fixed implant prostheses (e.g. costs, success rate, patient preference, and patient quality of life) are needed. Such comparisons are currently lacking. Only when all these factors are properly assessed will an evidence-based treatment concept for implant-supported maxillary dentures be found, thereby contributing to a higher level of care in this field.

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