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Interventions for replacing missing teeth: attachment systems for implant overdentures in edentulous jaws (Review)

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[Intervention Review]

Interventions for replacing missing teeth: attachment systems for implant overdentures in edentulous jaws

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ABSTRACT

Background

Implant overdentures are one of the most common treatment options used to rehabilitate edentulous patients. Attachment systems are used to anchor the overdentures to implants. The plethora of attachment systems available dictates a need for clinicians to understand their prosthodontic and patient-related outcomes.

Objectives

To compare different attachment systems for maxillary and mandibular implant overdentures by assessing prosthodontic success, prosthodontic maintenance, patient preference, patient satisfaction/quality of life and costs.

Search methods

Cochrane Oral Health's Information Specialist searched the following databases: Cochrane Oral Health's Trials Register (to 24 January 2018); Cochrane Central Register of Controlled Trials (CENTRAL; 2017, Issue 12) in the Cochrane Library (searched 24 January 2018); MEDLINE Ovid (1946 to 24 January 2018); and Embase Ovid (1980 to 24 January 2018). The US National Institutes of Health Trials Registry (ClinicalTrials.gov) and the World Health Organization International Clinical Trials Registry Platform were searched for ongoing trials on 24 January 2018. No restrictions were placed on the language or date of publication when searching the electronic databases.

Selection criteria

All randomised controlled trials (RCTs), including cross-over trials on maxillary or mandibular implant overdentures with different attachment systems with at least 1 year follow-up.

Data collection and analysis

Four review authors extracted data independently and assessed risk of bias for each included trial. Several corresponding authors were subsequently contacted to obtain missing information. Fixed-effect meta-analysis was used to combine the outcomes with risk ratios (RR) for dichotomous outcomes and mean differences (MD) for continuous outcomes, with 95% confidence intervals (95% CI). We used the GRADE approach to assess the quality of evidence and create 'Summary of findings' tables.

Main results

We identified six RCTs with a total of 294 mandibular overdentures (including one cross-over trial). No trials on maxillary overdentures were eligible. Due to the poor reporting of the outcomes across the included trials, only limited analyses between mandibular overdenture attachment systems were possible.

Comparing ball and bar attachments, upon pooling the data regarding short-term prosthodontic success, we identified substantial heterogeneity (I^2 = 97%) with inconsistency in the direction of effect, which was unexplained by clinical or methodological differences between the studies, and accordingly we did not perform meta-analyses for this outcome. Short-term re-treatment (repair of attachment system) was higher with ball attachments (RR 3.11, 95% CI 1.68 to 5.75; 130 participants; 2 studies; very low-quality evidence), and there was no difference between both attachment systems in short-term re-treatment (replacement of attachment system) (RR 1.18, 95% CI 0.38 to 3.71; 130 participants; 2 studies; very low-quality evidence). It is uncertain whether there is a difference in short-term prosthodontic success when ball attachments are compared with bar attachments.

Comparing ball and magnet attachments, there was no difference between them in medium-term prosthodontic success (RR 0.84, 95% CI 0.64 to 1.10; 69 participants; 1 study; very low-quality evidence), or in medium-term re-treatment (repair of attachment system) (RR 1.75, 95% CI 0.65 to 4.72; 69 participants; 1 study; very low-quality evidence). However, after 5 years, prosthodontic maintenance costs were higher when magnet attachments were used (MD -247.37 EUR, 95% CI -346.32 to -148.42; 69 participants; 1 study; very low-quality evidence). It is uncertain whether there is a difference in medium-term prosthodontic success when ball attachments are compared with magnet attachments.

One trial provided data for ball versus telescopic attachments and reported no difference in prosthodontic maintenance between the two systems in short-term patrix replacement (RR 6.00, 95% CI 0.86 to 41.96; 22 participants; 1 study; very low-quality evidence), matrix activation (RR 11.00, 95% CI 0.68 to 177.72; 22 participants; 1 study; very low-quality evidence), matrix replacement (RR 1.75, 95% CI 0.71 to 4.31; 22 participants; 1 study; very low-quality evidence), or in relining of the implant overdenture (RR 2.33, 95% CI 0.81 to 6.76; 22 participants; 1 study; very low-quality evidence). It is uncertain whether there is a difference in short-term prosthodontic maintenance when ball attachments are compared with telescopic attachments.

In the only cross-over trial included, patient preference between different attachment systems was assessed after only 3 months and not for the entire trial period of 10 years.

Authors' conclusions

For mandibular overdentures, there is insufficient evidence to determine the relative effectiveness of different attachment systems on prosthodontic success, prosthodontic maintenance, patient satisfaction, patient preference or costs. In the short term, there is some evidence that is insufficient to show a difference and where there was no evidence was reported. It was not possible to determine any preferred attachment system for mandibular overdentures.

For maxillary overdentures, there is no evidence (with no trials identified) to determine the relative effectiveness of different attachment systems on prosthodontic success, prosthodontic maintenance, patient satisfaction, patient preference or costs.

Further RCTs on edentulous cohorts must pay attention to trial design specifically using the same number of implants of the same implant system, but with different attachment systems clearly identified in control and test groups. Trials should also determine the longevity of different attachment systems and patient preferences. Trials on the current array of computer-aided designed/computer-assisted manufactured (CAD/CAM) bar attachment systems are encouraged.

PLAIN LANGUAGE SUMMARY

Attachments for implant dentures

Review question

The aim of this review was to assess different attachments used for upper or lower jaw implant dentures with respect to their success, wear and tear, patient satisfaction, patient preference and cost.

Background

For adults with complete tooth loss, the modern approach is implant dentures with attachment systems connecting the implants to the undersurface of the dentures. It is important to do the review as the choice of the number of implants and the design of the attachments influences prosthesis success, the amount of wear and tear, patient satisfaction, preference and costs.

Study characteristics

Authors from Cochrane Oral Health carried out this review and the evidence is up to date to 24 January 2018. A total of six trials on adults with complete tooth loss were included with a total of 294 lower jaw dentures (anchored by one or more implants). The review looked at

different attachment systems on the same implant systems. The six trials did not each evaluate the same attachment systems. There were no eligible trials with upper jaw implant dentures.

Key results

There is insufficient evidence to determine any significant differences between lower jaw implant denture attachment systems and an absence of evidence for upper jaw implant denture attachment systems. Further randomised controlled trials on people with complete tooth loss wearing dentures must pay specific attention to trial design using the same implant system and the same number of implants, but different attachment systems to determine their longevity and patient preferences.

Quality of the evidence

We judged the quality of the evidence to be very low. In all the included trials there were relatively few participants and few events, and there were serious limitations in the trial designs with data missing or not all outcomes reported.

Summary of findings for the main comparison. Ball compared to bar attachment systems for implant overdentures in edentulous jaws

Interventions for replacing missing teeth: attachment systems for implant overdentures in edentulous jaws						
Patient or population: edentulous adults receiving implant overdentures in one or both jaws to overcome problems with conventional complete dentures **Setting:** dental clinics (university clinics and/or private practice clinics) **Intervention:** ball attachment system of mandibular overdentures **Comparison:** bar attachment system of mandibular overdentures						
Outcomes	**Anticipated absolute effects* (95% CI)**		**Relative effect (95% CI)**	**Number of participants (studies)**	**Certainty of the evidence (GRADE)**	**Comments**
	Risk with bar attachment system	**Risk with ball attachment system**				
Success (short term) Follow-up: range 1 year to 3 years	Study population		-	130 (2 RCTs)	⊕⊖⊖⊖ VERY LOW[1]	Considerable heterogeneity (I^2 = 97%). Pooling of data was not done
	See comment	See comment				
Re-treatment (repair) (short term) Follow-up: range 1 year to 3 years	Study population		RR 3.11 (1.68 to 5.75)	130 (2 RCTs)	⊕⊖⊖⊖ VERY LOW[1]	
	141 per 1000	437 per 1000 (236 to 809)				
Re-treatment (replace) (short term) Follow-up: range 1 year to 3 years	Study population		RR 1.18 (0.38 to 3.71)	130 (2 RCTs)	⊕⊖⊖⊖ VERY LOW[1]	
	78 per 1000	92 per 1000 (30 to 290)				

*__The risk in the intervention group__ (and its 95% confidence interval) is based on the assumed risk in the comparison group and the **relative effect** of the intervention (and its 95% CI).

CI: confidence interval; **RCT:** randomised controlled trial; **RR:** risk ratio.

GRADE Working Group grades of evidence
High certainty: we are very confident that the true effect lies close to that of the estimate of the effect.
Moderate certainty: we are moderately confident in the effect estimate: the true effect is likely to be close to the estimate of the effect, but there is a possibility that it is substantially different.
Low certainty: our confidence in the effect estimate is limited: the true effect may be substantially different from the estimate of the effect.
Very low certainty: we have very little confidence in the effect estimate: the true effect is likely to be substantially different from the estimate of effect.

[1]Risk of bias (serious), inconsistency (very serious), imprecision (very serious); downgraded by 3 levels.

Summary of findings 2. Ball compared to telescopic attachment systems for implant overdentures in edentulous jaws

Interventions for replacing missing teeth: attachment systems for implant overdentures in edentulous jaws						
Patient or population: edentulous adults receiving implant overdentures in one or both jaws to overcome problems with conventional complete dentures **Setting:** dental clinics (university clinics and/or private practice clinics) **Intervention:** ball attachment system of mandibular overdentures **Comparison:** telescopic attachment system of mandibular overdentures						
Outcomes	**Anticipated absolute effects*** **(95% CI)**		**Relative effect (95% CI)**	**Number of participants (studies)**	**Certainty of the evidence (GRADE)**	**Comments**
	Risk with telescopic attachment system	**Risk with ball attachment system**				
Patrix replaced (short term) Follow-up: range 1 year to 3 years	Study population		RR 6.00 (0.86 to 41.96)	22 (1 RCT)	⊕⊖⊖⊖ VERY LOW[1]	
	91 per 1000	545 per 1000 (78 to 1000)				
Matrix activated (short term) Follow-up: range 1 year to 3 years	Study population		RR 11.00 (0.68 to 177.72)	22 (1 RCT)	⊕⊖⊖⊖ VERY LOW[1]	
	0 per 1000	0 per 1000 (0 to 0)				
Matrix replaced (short term) Follow-up: range 1 year to 3 years	Study population		RR 1.75 (0.71 to 4.31)	22 (1 RCT)	⊕⊖⊖⊖ VERY LOW[1]	
	364 per 1000	636 per 1000 (258 to 1000)				
Reline of implant overdenture (short term) Follow-up: range 1 year to 3 years	Study population		RR 2.33 (0.81 to 6.76)	22 (1 RCT)	⊕⊖⊖⊖ VERY LOW[1]	
	273 per 1000	635 per 1000 (221 to 1000)				

***The risk in the intervention group** (and its 95% confidence interval) is based on the assumed risk in the comparison group and the **relative effect** of the intervention (and its 95% CI).

CI: confidence interval; **RCT:** randomised controlled trial; **RR:** risk ratio.

GRADE Working Group grades of evidence
High certainty: we are very confident that the true effect lies close to that of the estimate of the effect.

Moderate certainty: we are moderately confident in the effect estimate: the true effect is likely to be close to the estimate of the effect, but there is a possibility that it is substantially different.
Low certainty: our confidence in the effect estimate is limited: the true effect may be substantially different from the estimate of the effect.
Very low certainty: we have very little confidence in the effect estimate: the true effect is likely to be substantially different from the estimate of effect.

[1]Risk of bias (serious), imprecision (very serious); downgraded by 3 levels.

Summary of findings 3. Ball compared to magnetic attachment systems for implant overdentures in edentulous jaws

Interventions for replacing missing teeth: attachment systems for implant overdentures in edentulous jaws

Patient or population: edentulous adults receiving implant overdentures in one or both jaws to overcome problems with conventional complete dentures
Setting: dental clinics (university clinics and/or private practice clinics)
Intervention: ball attachment system of mandibular overdentures
Comparison: magnetic attachment system of mandibular overdentures

Outcomes	Anticipated absolute effects* (95% CI)		Relative effect (95% CI)	Number of participants (studies)	Certainty of the evidence (GRADE)	Comments
	Risk with magnetic attachment system	Risk with ball attachment system				
Success (medium term) Follow-up: range 3 years to 5 years	Study population		RR 0.84 (0.64 to 1.10)	69 (1 RCT)	⊕⊖⊖⊖ VERY LOW[1]	
	826 per 1000	694 per 1000 (529 to 909)				
Re-treatment (repair) (medium term) Follow-up: range 3 years to 5 years	Study population		RR 1.75 (0.65 to 4.72)	69 (1 RCT)	⊕⊖⊖⊖ VERY LOW[1]	
	174 per 1000	304 per 1000 (113 to 821)				
Costs (medium term) Follow-up: range 3 years to 5 years	The mean costs (medium term) was EUR 2286.34	MD 247.37 EUR lower (346.32 lower to 148.42 lower)	-	69 (1 RCT)	⊕⊖⊖⊖ VERY LOW[1]	

*__The risk in the intervention group__ (and its 95% confidence interval) is based on the assumed risk in the comparison group and the **relative effect** of the intervention (and its 95% CI).

CI: confidence interval; **MD:** mean difference; **RCT:** randomised controlled trial; **RR:** risk ratio.

GRADE Working Group grades of evidence
High certainty: we are very confident that the true effect lies close to that of the estimate of the effect.

Moderate certainty: we are moderately confident in the effect estimate: the true effect is likely to be close to the estimate of the effect, but there is a possibility that it is substantially different.
Low certainty: our confidence in the effect estimate is limited: the true effect may be substantially different from the estimate of the effect.
Very low certainty: we have very little confidence in the effect estimate: the true effect is likely to be substantially different from the estimate of effect.

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[1]Risk of bias (serious), imprecision (very serious); downgraded by 3 levels.

BACKGROUND

Description of the condition

Edentulism according to the Glossary of Prosthodontic Terms (Ferro 2017; van Blarcom 2005) is defined as the state of being without any natural teeth. Complete tooth loss is an irreversible condition.

From an epidemiological perspective, there are numerous related risk factors leading to edentulism, with caries and periodontal disease seen as the main causes according to the World Health Organization (WHO) Global Oral Health databank (Brown 2009; Felton 2009; Petersen 2005a; Petersen 2005b). It is considered a disability by the WHO. Edentulism is also markedly affected by several factors including access to care, attitude towards dental hygiene, dentist/population ratios, oral health knowledge, education level, socioeconomic status, and lifestyle. Accordingly, its prevalence is known and varies considerably between countries and between different regions within the same country (Douglass 2002; Enami 2013; Mojon 2004; Petersen 2005a). It is higher in populations of lower income and educational levels, in rural areas, and in females; with the later being restricted to certain countries (Enami 2013; Felton 2009). Edentulism is always accompanied by reduction in the quality of life, due to it adversely affecting both oral and general health (Kapur 1964; Locker 1988; MacEntee 2003; Petersen 2005b). Tooth loss is associated with an increased risk of early mortality (Gupta 2018). Historically it has been identified to be a major oral disease entity (Atwood 1971).

From a prosthodontic perspective, the complete loss of either maxillary or mandibular teeth or both leads to adverse aesthetic and biomechanical sequelae including residual ridge resorption, degenerative changes, impaired masticatory function and loss of neuromuscular control (Hobkirk 2013; Zarb 2004).

Rehabilitation of edentulism improves quality of life and reduces morbidity. A recent systematic review on the rehabilitation of edentulism and mortality showed most of the included studies indicated a higher proportion of deceased edentulous patients not using dentures as compared to denture wearers (Gupta 2018).

Edentulism is managed through prosthodontic rehabilitation, either implant- or tissue-supported, with a fixed or removable prosthesis (Ferro 2017; Gupta 2018; van Blarcom 2005).

Description of the intervention

An overdenture is a removable dental prosthesis that covers and rests on one or more remaining natural teeth, the roots of natural teeth, and/or dental implants (Ferro 2017; van Blarcom 2005). Removable implant overdentures are one standard of care (Feine 2002; Fitzpatrick 2006) used to resolve the problems of edentulism and the limitations of conventional complete dentures (Zarb 2004). Removable overdentures are connected to the implants using different attachment systems (Payne 2013; Preiskel 1996). An attachment system is defined as a mechanical device for the fixation, retention and stabilization of an overdenture (Ferro 2017; van Blarcom 2005). All attachment systems are comprised of two parts: the matrix being the receptacle component, and the patrix which closely fits into the matrix either mechanically, magnetically or by friction fit (Ferro 2017; Laney 2007; van Blarcom 2005). One part of the attachment system is connected to the implants and the reciprocal part incorporated within the undersurface of the overdenture.

Ball (stud-shaped), magnetic and telescopic attachment systems are most commonly extra-radicular (in which the male patrix element projects from the implant abutment) but also intra-radicular (where the male patrix element forms part of the denture base and engages a depression on the implant abutment). Bar attachment systems can be divided into two groups, those allowing rotational movement between the components (termed bar joints - where a spacer between the patrix and matrix is used) and comparatively rigid ones allowing no movement (termed bar units - where no spacer between the patrix and matrix is used) (Preiskel 1996). Overdenture bars have historically been soldered, cast with milled designs, made using spark-erosion or milled precision bars (Sadowsky 2007). Aligning with the path of insertion of the overdenture, the patrix and matrix can be made of metal alloys or plastic of various diameters and configurations and range from O-rings to pillar-shaped projections (telescopic attachment systems) with varying amount of retention (Laney 2007; Preiskel 1985; Preiskel 1996). All ball (or stud), magnetic, telescopic and bar attachment systems are adjustable or replaceable or both (Ferro 2017; Laney 2007; Preiskel 1996; van Blarcom 2005). Today, it is more common to see the use of computer-aided designed/computer-assisted manufactured (CAD/CAM) technology for both bar attachment systems alone or including additional ball (stud) attachments.

Mandibular overdentures (most commonly opposing complete maxillary dentures) are usually assisted by either one or two unsplinted implants with free-standing ball (stud-shaped), magnetic or telescopic attachment systems, or alternatively by two or as many as four splinted implants connected by bar joints or bar units (Alsabeeha 2009; Burns 2000; Carlsson 2003; Payne 2000a; Payne 2013).

Maxillary overdentures (most commonly opposing mandibular dentitions) have historically been assisted by at least four splinted implants using one of the bar attachment systems (Mericske-Stern 2003; Payne 2013; Sadowsky 2007), but today can be assisted by as few as unsplinted two implants with ball or stud attachment systems (Zembic 2014).

Implant overdentures depend on their attachment systems for prosthodontic treatment outcomes, but are independent of peri-implant marginal/crestal bone loss traditionally used in determining implant success or survival (Kim 2012; Klemetti 2008). Prosthodontic success is influenced by post-insertion maintenance or technical complications, adjustments/repairs or aftercare of the attachment systems (Andreiotelli 2010; Bragger 2015; Cehreli 2010a; Kim 2012). Terminology and methodology of reporting prosthodontic outcomes varies with attachment system design and implant systems (Payne 2001a). Patient preference, patient satisfaction (including quality of life) and costs may also be independent of the attachment system used (Kim 2012).

How the intervention might work

The intervention is by way of implants, the attachment system and the overdentures. The attachment systems provide anchorage, retention and stability for implant overdentures. This facilitates improved masticatory function (Geertman 1999; van Kampen

2004), bite forces (Fontijin-Tekamp 1998), food selection (Allen 2002) and quality of life (Awad 2003; Feine 1998).

There are four broad groups of attachment systems.

1. Ball/stud attachment systems: these are the simplest and the most widely used. They have a considerable stress-breaking/stress-relieving effect, provide adequate amount of retention and stability, are available in several vertical heights, and can be used with non-parallel implants. Although the size of ball/stud attachments currently used are small, the choice of historical larger ball/stud attachment systems is influenced by inter-arch space (Preiskel 1996) (Figure 1).
2. Bar attachment systems: these are made of single or multiple bars attached to and splinting the implants together, with the clips (riders) positioned in the undersurface of the overdenture. They offer high retentive capacities, reduce loading forces over the implants, and aid in correcting misaligned implants. However, the bulk of the attachments limits its application where there is limited inter-arch space and minimal residual ridge resorption. If used with tapered arches it may encroach on the tongue space and influence speech. Gingival hyperplasia or mucosal enlargement can develop under the bars (Payne 2001b), and the plaque control and hygiene measures are more complicated (Preiskel 1996) (Figure 2).
3. Magnet attachment systems: these offer the advantage of self-seating the prosthesis, which is especially suitable for elderly patients with limited manual dexterity or arthritis. Their fabrication procedures are relatively simple, can be used with maligned implants, and the amount of lateral loads transmitted by the retainer are less. Intraoral corrosion remains a main drawback, since it leads to rapid loss of retention and the replacement of the attachments becomes inevitable. Plaque tends to accumulate more around magnets, thus meticulous hygiene measures are required (Preiskel 1996) (Figure 3).
4. Telescopic attachment systems: these are composed of primary copings attached to implants and secondary telescopic crowns embedded in the overdenture. Hygiene measures are much easier and accessible in this system, and the secondary telescopic crowns add to the high retention and stability of the overdenture. Metal display of the primary crowns when the overdenture is removed can influence aesthetics (Langer 1980; Preiskel 1985) (Figure 3).

Figure 1. Ball stud attachment systems.
Copyright© 2018 Payne A, Zarb G. Implant overdentures. In: Zarb G, Hobkirk J, Eckert S, Jacob R, editor(s). Prosthodontic Treatment for Edentulous Patients: Complete Dentures and Implant-Supported Prostheses. 13th edition. St Louis, Missouri, USA: Mosby, 2013:330-9 (Payne 2013): reproduced with permission.

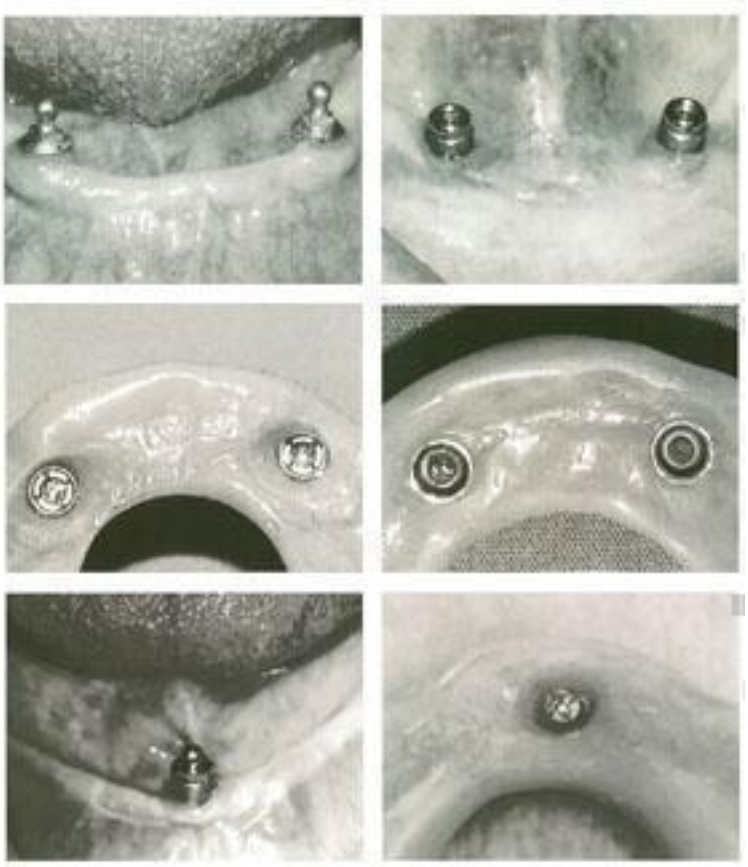

Figure 2. Bar attachment systems.
Copyright© 2018 Payne A, Zarb G. Implant overdentures. In: Zarb G, Hobkirk J, Eckert S, Jacob R, editor(s). Prosthodontic Treatment for Edentulous Patients: Complete Dentures and Implant-Supported Prostheses. 13th edition. St Louis, Missouri, USA: Mosby, 2013:330-9 (Payne 2013): reproduced with permission.

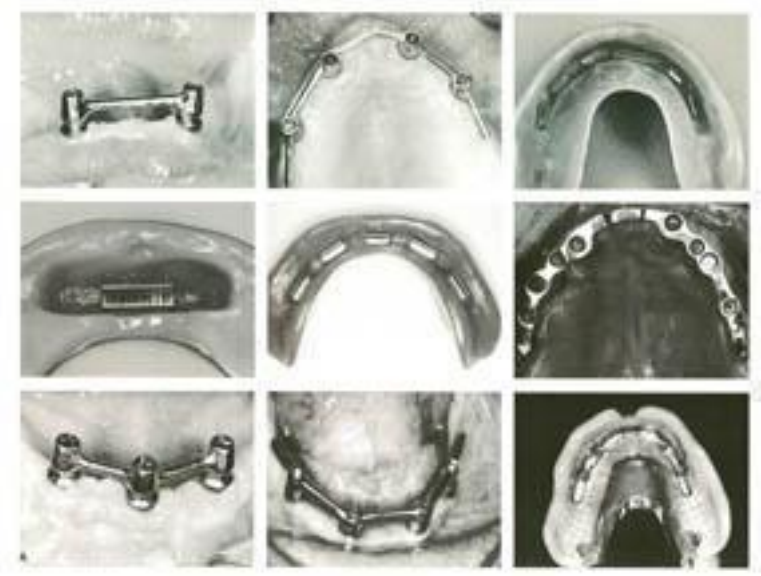

Figure 3. Magnet telescopic attachment systems.
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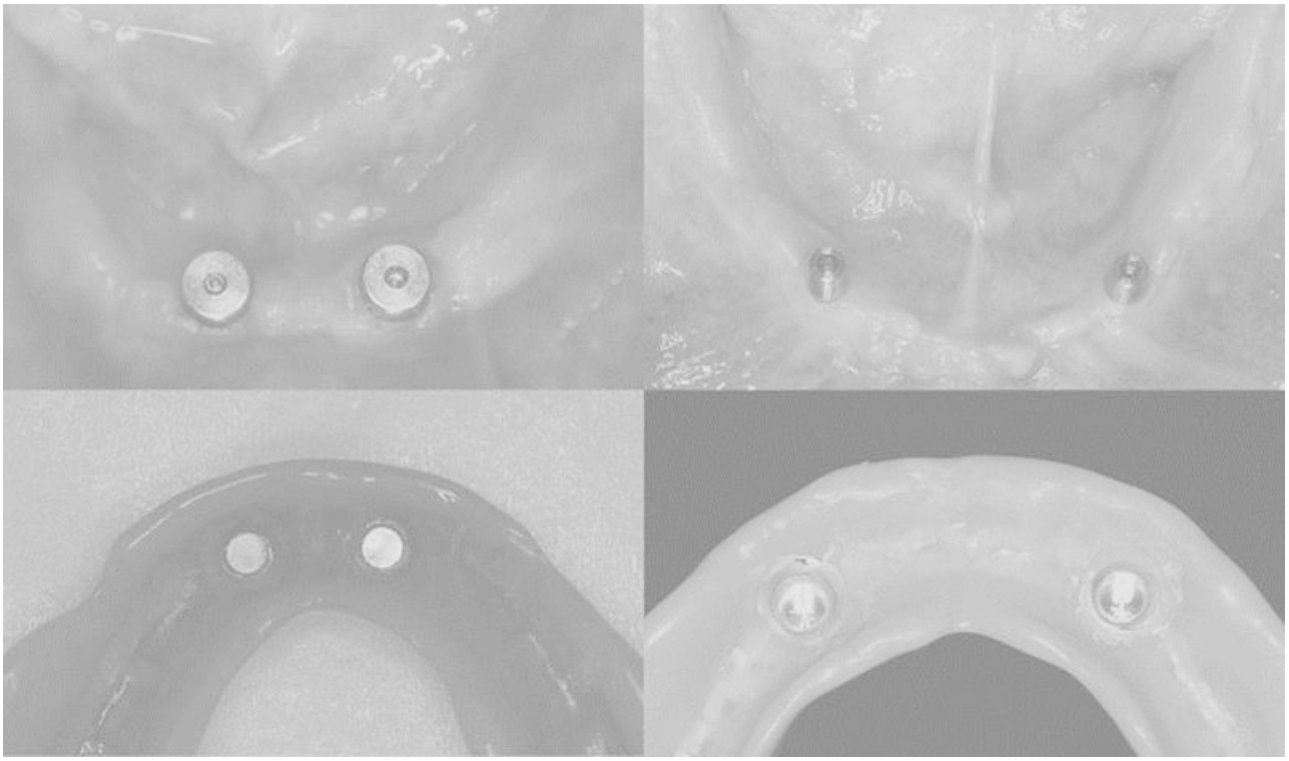


Why it is important to do this review

To determine whether any implant overdenture attachment system is more successful than others in terms of prosthodontic success, prosthodontic maintenance, patient preference, patient satisfaction and costs. Implant overdentures are used widely, but there are significant differences between some countries in their use related to healthcare systems which can favour or hinder

their choice as a treatment option by clinicians (Carlsson 2004). A recent global survey completed by 116 prosthodontists from 33 countries showed that implant overdenture treatment for their edentulous patients is common, but there was great variation regarding the number of implants and the attachment systems used (Kronstrom 2017). The majority (84%) reported using two implants, while 13% used four implants for overdenture retention. Only one respondent used a single implant for retention of the mandibular overdenture, and two reported using three implants. There were great variations in the use of attachment systems for mandibular implant overdentures with as many as 10 different types listed in terms of usage, with the most common being the Locator® attachments system (Zest Anchors LLC, Espandido, CA, USA).

Clinicians usually rely on their expertise, personal preferences, dental technician preferences or most commonly commercial influence in attachment system selection (Naert 2003). Attachment systems wear and deteriorate over time causing prosthodontic maintenance events for clinicians and additional costs to patients in terms of re-treatment. The constant evolution and changes in overdenture attachment systems principally driven by commercial implant companies, has resulted in some older designs being superseded by newer designs or alternatively subsequently withdrawn as problems develop with them in clinical practice (Walton 2006). In addition, there are pertinent aspects of sequential post-treatment costs related to the prosthodontic maintenance of overdenture attachment systems which is different to fixed implant bridges.

OBJECTIVES

To compare different attachment systems for maxillary and mandibular implant overdentures by assessing prosthodontic success, prosthodontic maintenance, patient preference, patient satisfaction/quality of life and costs.

METHODS

Criteria for considering studies for this review

Types of studies

Randomised controlled trials (RCTs) including cross-over trials with at least 1 year follow-up on attachment systems, and maxillary or mandibular overdentures or both, reporting prosthodontic and patient outcomes.

Types of participants

Edentulous adults receiving implant overdentures in one or both jaws to overcome problems with conventional complete dentures.

Types of interventions

- The same number of implants of the same implant system comparing different attachment systems (more than one).
- Ball/stud, magnetic, telescopic or bar attachment systems with mandibular 1-, 2-, 3-, or 4-implant overdentures using splinted or unsplinted prosthodontic designs.
- Ball/stud, magnetic, telescopic or bar attachment systems with maxillary 1-, 2-, 3-, 4-, 5-, or 6-implant overdentures using splinted or unsplinted prosthodontic designs.

Types of outcome measures

Primary outcomes

- Prosthodontic success by specific categorization (Appendix 1) and six-field protocol (Appendix 2).
- Prosthodontic maintenance by general categorization.

Secondary outcomes

- Patient preference in cross-over trials.
- Patient satisfaction or quality of life assessed by a validated measure.
- Cost (treatment time or material costs or both).

The outcomes would be assessed at the following time intervals:

- Short term: 1 to 3 years.
- Medium term: 3 to 5 years.
- Long term: 5 to 10 years.

Search methods for identification of studies

Electronic searches

Cochrane Oral Health's Information Specialist conducted systematic searches in the following databases for randomised controlled trials and controlled clinical trials without language or publication status restrictions:

- Cochrane Oral Health's Trials Register (searched 24 January 2018) (Appendix 3);
- Cochrane Central Register of Controlled Trials (CENTRAL; 2017, Issue 12) in the Cochrane Library (searched 24 January 2018) (Appendix 4);
- MEDLINE Ovid (1946 to 24 January 2018) (Appendix 5);
- Embase Ovid (1980 to 24 January 2018) (Appendix 6).

Subject strategies were modelled on the search strategy designed for MEDLINE Ovid. Where appropriate, they were combined with subject strategy adaptations of the highly sensitive search strategy designed by Cochrane for identifying randomised controlled trials and controlled clinical trials as described in the *Cochrane Handbook for Systematic Reviews of Interventions* Chapter 6 (Lefebvre 2011).

Searching other resources

The following trial registries were searched for ongoing studies:

- US National Institutes of Health Ongoing Trials Register ClinicalTrials.gov (clinicaltrials.gov; searched 24 January 2018) (Appendix 7);
- World Health Organization International Clinical Trials Registry Platform (apps.who.int/trialsearch; searched 24 January 2018) (Appendix 7).

We wrote to authors of the identified RCTs, checked the bibliographies of all identified RCTs and used personal contacts in an attempt to identify unpublished or ongoing RCTs. We also contacted corresponding authors for further information to principally clarify aspects of the risk of bias tables, as well as unpublished data.

We did not perform a separate search for adverse effects of interventions used, we considered adverse effects described in included studies only.

Data collection and analysis

We used methods which were specified in the review protocol (Payne 2009) and updated where necessary to conform with the latest Methodological Expectations of Cochrane Intervention Reviews (MECIR) (MECIR 2016).

Selection of studies

Four review authors (Alan Payne (AP), Nabeel Alsabeeha (NA), Momen A Atieh (MAA), and Marwah Anas El-Wegoud (MAEW)) independently assessed studies for eligibility by initially screening titles, abstracts and keywords of every record retrieved through the electronic searches. The search was designed to be sensitive and include controlled clinical trials, these were filtered out early in the selection process if they were not randomised. We retrieved full-text articles for further assessment when studies met the inclusion criteria. In the presence of more than one publication of the same trial, we reviewed all the publications. We linked together studies with multiple publications under a single study ID. Any disagreements were resolved by discussion and consultation with a fifth author. Where resolution was not possible, a sixth review author was consulted. We excluded any studies that had insufficient data.

Data extraction and management

We initially designed a form to extract data. For eligible studies, four review authors (AP, MAEW, MAA, and NA) independently extracted the data using the agreed form. We resolved discrepancies through discussion or, if required, we consulted a fifth person. We entered the data into Review Manager software (Review Manager 2014) and checked them for accuracy. When information was unclear, we contacted authors of the original reports to provide further details. The review authors were not blinded to the study authors' names, institutional affiliations, or journal of publication.

Assessment of risk of bias in included studies

Three review authors (AP, MAEW, MAA) independently assessed risk of bias for each study using the criteria outlined in the *Cochrane Handbook for Systematic Reviews of Interventions* (Higgins 2011). There were no disagreements on the assessment of risk of bias in the included studies.

Random sequence generation (checking for possible selection bias)

We described for each included trial the method used to generate the allocation sequence in sufficient detail to allow an assessment of whether it should produce comparable groups.

We assessed the method as:

- low risk of bias (any truly random process, e.g. random number table; computer random number generator);
- high risk of bias (any non-random process, e.g. odd or even date of birth; hospital or clinic record number): these studies were excluded as per the pre-specified eligibility criteria; or
- unclear risk of bias.

Allocation concealment (checking for possible selection bias)

We described for each included trial the method used to conceal allocation to interventions prior to assignment and assess whether intervention allocation could have been foreseen in advance of, or during recruitment, or changed after assignment.

We assessed the methods as:

- low risk of bias (e.g. telephone or central randomisation; consecutively numbered sealed opaque envelopes);
- high risk of bias (open random allocation; unsealed or non-opaque envelopes);
- unclear risk of bias.

Blinding of participants and personnel (checking for possible performance bias)

We described for each included trial the methods used, if any, to blind study participants and personnel from knowledge of which intervention a participant received. We considered studies to be at low risk of bias if they were blinded, or if we judge that the lack of blinding would be unlikely to affect results. We assessed blinding separately for different outcomes or classes of outcomes.

We assessed the methods as:

- low, high or unclear risk of bias for participants and for personnel.

Blinding of outcome assessment (checking for possible detection bias)

We described for each included study the methods used, if any, to blind outcome assessors from knowledge of which intervention a participant received. We assessed blinding separately for different outcomes or classes of outcomes.

We assessed the methods used to blind outcome assessment as:

- low, high or unclear risk of bias.

Incomplete outcome data (checking for possible attrition bias due to the amount, nature and handling of incomplete outcome data)

We described for each included trial, and for each outcome or class of outcomes, the completeness of data including attrition and exclusions from the analysis. We stated whether attrition and exclusions were reported and the numbers included in the analysis at each stage (compared with the total randomised participants), reasons for attrition or exclusion where reported, and whether missing data were balanced across groups or were related to outcomes. Where sufficient information is reported, or was supplied by the trial authors, we re-included missing data in the analyses which we undertook.

We assessed methods as:

- low risk of bias (e.g. no missing outcome data; missing outcome data balanced across groups);
- high risk of bias (e.g. numbers or reasons for missing data imbalanced across groups; 'as treated' analysis done with substantial departure of intervention received from that assigned at randomisation);

- unclear risk of bias.

We categorized greater than 20% missing data as 'high' risk of bias.

Selective reporting (checking for reporting bias)

We described for each included trial how we investigated the possibility of selective outcome reporting bias and what we found.

We assessed the methods as:

- low risk of bias (where it is clear that all of the trial's pre-specified outcomes and all expected outcomes of interest to the review have been reported);
- high risk of bias (where not all the trial's pre-specified outcomes have been reported; one or more reported primary outcomes were not pre-specified; outcomes of interest are reported incompletely and so cannot be used; trial fails to include results of a key outcome that would have been expected to have been reported);
- unclear risk of bias.

Other bias

We described for each included trial any important concerns we have about other possible sources of bias.

We assessed whether each trial was free of other problems that could put it at risk of bias:

- low risk of other bias;
- high risk of other bias;
- unclear whether there is risk of other bias.

Overall risk of bias

We have made explicit judgements about whether studies were at high risk of bias, according to the criteria given in the *Cochrane Handbook for Systematic Reviews of Interventions* (Higgins 2011). With reference to all domains above, we assessed the likely magnitude and direction of bias and whether we considered it likely to impact on the findings.

We assessed the methods as:

- low risk of other bias (low risk of bias for all key domains);
- high risk of other bias (high risk of bias for one or more key domains); or
- unclear (unclear risk of bias for one or more key domains).

We planned to explore the impact of the level of bias through undertaking Sensitivity analysis.

Measures of treatment effect

We carried out statistical analysis using the Review Manager software (Review Manager 2014).

Dichotomous data

For dichotomous data, we presented results as summary risk ratio (RR) together with 95% confidence intervals (CIs).

Continuous data

For continuous data, we used the mean difference (MD) with 95% CI.

Unit of analysis issues

The statistical unit was the patient and the overdenture, not the number of implants, nor the type of implants used. In the analysis of cross-over trials, we included data, if any, from the first period, if the duration of the period was at least 1 year.

Dealing with missing data

For included trials, we noted levels of attrition. We planned to explore the impact of including trials with high levels of missing data in the overall assessment of treatment effect by using sensitivity analysis. For all outcomes, we carried out analyses, as far as possible, on an intention-to-treat basis, i.e. we attempted to include all participants randomised to each group in the analyses, and analyse all participants in the group to which they were allocated, regardless of whether or not they received the allocated intervention. The denominator for each outcome in each trial was the number randomised minus any participants whose outcomes were known to be missing.

Assessment of heterogeneity

We have assessed statistical heterogeneity in each meta-analysis using the Tau^2, I^2 and Chi^2 statistics. We regarded heterogeneity as substantial if I^2 was greater than 30% and either Tau^2 was greater than zero, or there was a low P value (less than 0.10) in the Chi^2 test for heterogeneity.

Assessment of reporting biases

In future updates of this review, if there are 10 or more trials in the meta-analysis we will investigate reporting biases (such as publication bias) using funnel plots. We will assess funnel plot asymmetry visually. If asymmetry is suggested by a visual assessment, we will perform exploratory analyses to investigate it.

Data synthesis

We carried out statistical analysis using the Review Manager software (Review Manager 2014). We have used fixed-effect meta-analysis for combining data where it is reasonable to assume that studies were estimating the same underlying treatment effect: i.e. where trials were examining the same intervention, and we judged the trials' populations and methods sufficiently similar. If there was clinical heterogeneity sufficient to expect that the underlying treatment effects differed between trials, or if we detected substantial statistical heterogeneity, we explored this by sensitivity analysis followed by random-effects if required.

Subgroup analysis and investigation of heterogeneity

Our planned subgroup analysis by the duration of follow-up was not conducted as there were no data.

Sensitivity analysis

Our planned sensitivity analysis to explore the effect of trial quality assessed by omitting trials rated as high risk of bias and unclear when considering allocation concealment and incomplete outcome data was not conducted because the meta-analysis of the primary outcomes included data from two trials only.

GRADE and 'Summary of findings' tables

We used the GRADE approach (Schünemann 2013) to create 'Summary of findings' tables (Summary of findings for the main comparison; Summary of findings 2; Summary of findings 3).

GRADEpro 2015 was used to import data from Review Manager (RevMan 2014) in order to create the 'Summary of finding' tables. A summary of the intervention effect and a measure of quality for each of the above outcomes was produced using the GRADE approach. The GRADE approach uses five considerations (trial limitations, consistency of effect, indirectness, imprecision, and publication bias) to assess the quality of the body of evidence for each outcome. The evidence was downgraded from 'high quality' by one level for serious (or by two levels for very serious) limitations in the five mentioned considerations.

RESULTS

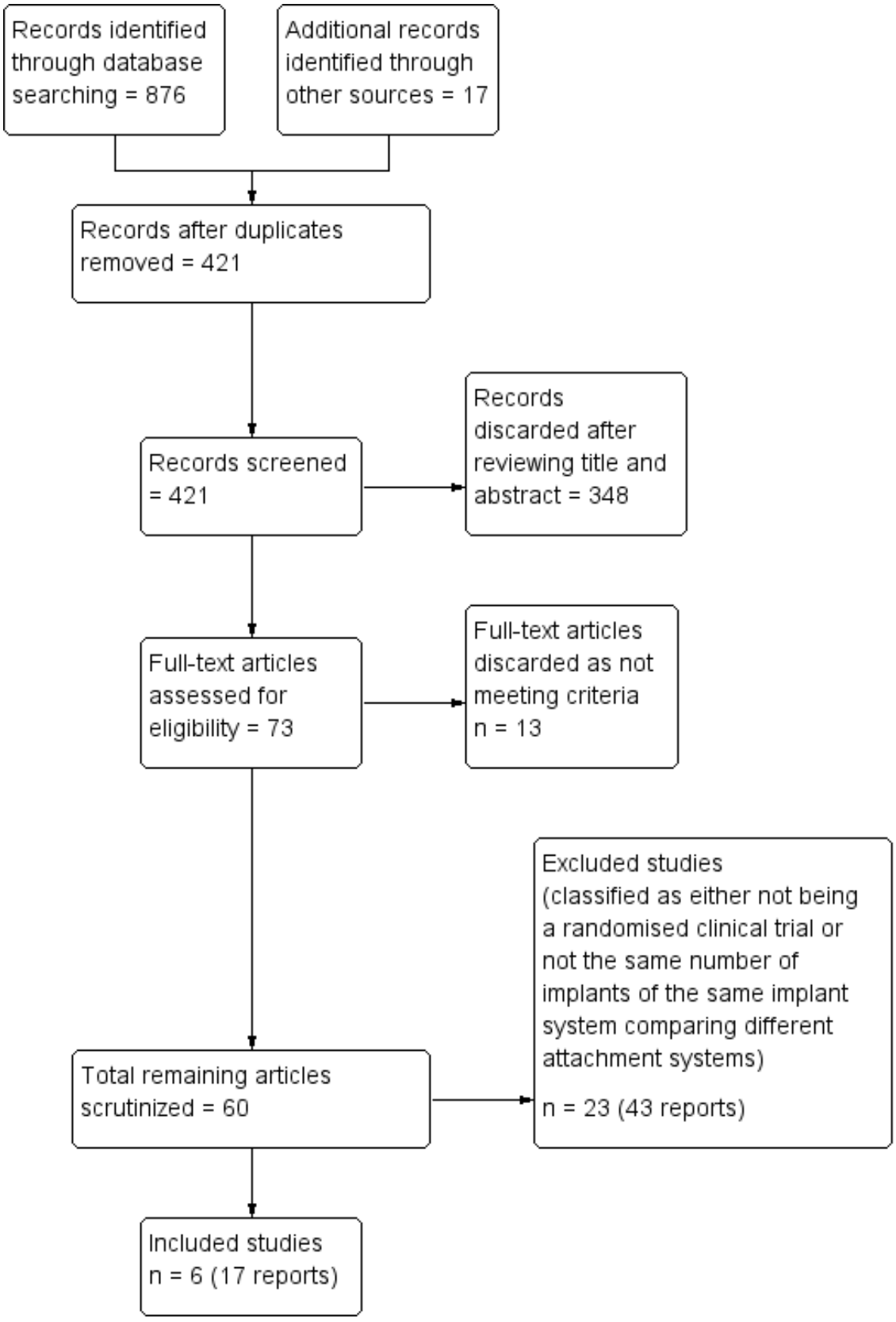
Description of studies

See: Characteristics of included studies; Characteristics of excluded studies.

Results of the search

Our electronic searches identified a total of 876 references, coupled with 17 references detected by manual searches or monitoring e-mail journal Table of Contents alerts. 421 references were assessed after duplicates were removed. Thereafter, 348 references were discarded after screening titles and abstracts leaving 73 references potentially eligible for inclusion. Assessment of full texts of these 73 references found a further 13 to be discarded as not meeting the criteria. The remaining 60 trials were scrutinized, leaving 23 (43 reports) being excluded studies, finally leaving six (17 reports) included studies (Figure 4).

Figure 4. Study flow diagram.



Authors of all six included studies were contacted for additional information and we received replies from five of them (Cristache 2014; Cune 2010; Kappel 2016; Naert 1999; Walton 2002).

Authors of 17 excluded studies were contacted for additional information and we received replies from 12 of them (Burns 2011; de Souza 2015; ELsyad 2012; Krennmair 2006; Krennmair 2008; Krennmair 2012; Krennmair 2012b; Kronstrom 2010; Slot 2013; Slot 2014; Walton 2009; Wismeijer 1997).

It is relevant that clinical experience suggests that prosthodontic maintenance of a mechanical nature usually take more than 1 year to manifest themselves.

Included studies

Six trials were eligible to be included (Cepa 2017; Cristache 2014; Cune 2010; Kappel 2016; Naert 1999; Walton 2002). All were on mandibular overdentures, with no trials on maxillary overdentures being eligible.

Characteristics of the trial settings and design

- Two trials were conducted in Germany (Cepa 2017; Kappel 2016), one conducted in the Netherlands (Cune 2010), one in Belguim (Naert 1999), one in Romania (Cristache 2014), and one in Canada (Walton 2002).
- Five trials had a parallel group study design (Cepa 2017; Cristache 2014; Kappel 2016; Naert 1999; Walton 2002).
- One trial had a cross-over study design (Cune 2010).
- Five trials declared industry support (Cepa 2017; Cristache 2014; Kappel 2016; Naert 1999; Walton 2002).
- All trials were conducted in university clinics or research centres.

Study duration ranged between 2 years (Kappel 2016) and 10 years (Cune 2010; Naert 1999).

Characteristics of the interventions

By prosthodontic design of mandibular or maxillary overdentures

- Ball/stud or bar attachment systems for mandibular 2-implant overdentures using splinted and unsplinted prosthodontic designs: two trials (Kappel 2016; Walton 2002).
- Ball/stud or telescopic attachment systems for mandibular 2-implant overdentures using an unsplinted prosthodontic design: one trial (Cepa 2017).
- Ball/stud, magnetic or bar attachment systems for mandibular 2-implant overdentures using splinted and unsplinted prosthodontic designs: three trials (Cristache 2014; Cune 2010; Naert 1999).
- No included trials for maxillary implant overdentures.

By attachment system of mandibular overdentures

- Locator® attachments (Zest Anchors, Escondido, CA, USA) or an egg-shaped bar (Dolder®, Sub-TecWirobond® MI bar abutment and Dolder bar; BEGO Implant GmbH & Co KG, Germany) (Kappel 2016).
- Branemark® 2.25 mm ball patrices and titanium alloy spring matrices; Branemark® 2 mm single round gold bar joint patrices and single clip matrices (Walton 2002).
- Ankylos® (Dentsply Implants, Mannheim, Germany) ball attachments or prefabricated conus (telescopic) attachments with connecting matrices were polymerized into spacers of the metal framework using a self-curing resin (Pattern Resin LS, GC Europe, Leuven, Belgium) (Cepa 2017).
- Straumann® 2.25 mm ball patrices and Dalla Bona type gold alloy matrices; titanium alloy spring matrices; Locator® (ZEST Anchors, Escondido, CA 92029 USA) stud matrices and plastic patrices; magnetic attachments (Titanmagnetics® Steco system-technick, Hamburg, Germany) (Cristache 2014).
- Frialit-2 (Friadent, Dentsply, Mannheim, Germany) 2.25 mm ball patrices and Dalla Bona type metallic matrices; single bar joint matrices and metal clips (Friadent); magnetic attachments (Dyna, Bergen, the Netherlands) (Cune 2010).
- Branemark® 3.25 mm ball patrices and O-ring matrices; Branemark® abutments with single egg-shaped Dolder bar joint patrices and clip matrices (Cendres et Metaux, Biel/Bienne, Switzerland); Branemark® abutments with open field magnetic attachments (Dyna, Bergen, the Netherlands) (Naert 1999).

By attachment system of maxillary overdentures

- No included trials for maxillary implant overdentures.

Characteristics of the outcome measures

- The primary outcome of prosthodontic success by specific categorization was recorded in two trials (Cristache 2014; Walton 2002). Unpublished data on this outcome was provided by email by authors of Kappel 2016.
- The primary outcome of prosthodontic maintenance by general categorization was recorded in six trials (Cepa 2017; Cristache 2014; Cune 2010; Kappel 2016; Naert 1999; Walton 2002).
- The secondary outcome of patient preference in cross-over trials, was not recorded in the only included cross-over trial (Cune 2010).
- The secondary outcome of patient satisfaction assessed by a validated measure was recorded in three trials (Cune 2010; Naert 1999; Walton 2002). However, we could not use any data from these studies. Quality of life as assessed by a validated measure was not recorded in any of the included trials.
- The secondary outcome of cost analysis (treatment time and/or material costs), was recorded in two trials (Cristache 2014; Walton 2002).

Participants

For more details, see the Characteristics of included studies table.

Inclusion criteria

For mandibular overdentures:

- healthy participants with adequate bone height; at least 1 year of experience wearing conventional complete dentures (Naert 1999; Walton 2002); persistent dissatisfaction/problems/complaints with their conventional dentures (Cepa 2017; Cune 2010; Naert 1999; Walton 2002); agreement for a follow-up period (Cristache 2014); willing to consent and commit to participation in the trial (Kappel 2016; Naert 1999; Walton 2002).

For maxillary overdentures:

- no included studies for maxillary implant overdentures.

Exclusion criteria

For mandibular overdentures:

- general contraindications for oral surgical procedures (Cepa 2017; Cristache 2014; Kappel 2016);
- insufficient bone volume to harbour two implants with a minimum length of 10 mm, unrealistic expectations of the prosthodontic treatment outcome, gag reflex, absence of maxillary complete denture, insufficient inter-arch space, patients in Class IV classification (McGarry 1999) or Angle Class II relationship (Cristache 2014; Naert 1999);
- participants were not enrolled in the trial after implant surgery because the prosthodontist found that the implants diverged more than 15 degrees from each other, or that the implants were located less than 20 mm or more than 35 mm apart, because of evidence that such an orientation and location of implants could disturb the stability and maintenance of the implant overdenture (Walton 2002).

For maxillary overdentures:

- no studies included for maxillary implant overdentures.

Sample size

The number of participants in the included studies ranged between 18 (Cune 2010) and 100 (Walton 2002).

Excluded studies

The reasons for exclusion of 23 trials were.

For mandibular overdentures:

- either not randomised controlled trials (Akca 2013; Karabuda 2008; Krennmair 2006; Krennmair 2012b; Mericske-Stern 2009; Payne 2000b);
- more than one implant system was used on one implant comparing different attachment systems (Alsabeeha 2011);
- one implant system, different numbers of implants were used (Burns 2011; Wismeijer 1997);
- the same number of implants used, two different implant systems were used each with different attachment systems (Cehreli 2010b);
- different implant systems were used, different numbers of implants were used with different attachment systems (de Souza 2015);
- two subtypes of bar attachment, and not between the main attachment system types (ball/stud, magnetic, telescopic or bar attachment systems) (ELsyad 2012);
- did not use the same number of implants in all included patients (Gotfredsen 2000);
- two subtypes of the ball attachment, and not between the main attachment system types (ball/stud, magnetic, telescopic or bar attachment systems) (Kleis 2010; Krennmair 2012);
- two subtypes of the bar attachment, and not between the main attachment system types (ball/stud, magnetic, telescopic or bar attachment systems) (Krennmair 2008);
- one implant system was used, different numbers of implants were used with only one attachment system (Kronstrom 2010; Walton 2009);
- it was on both maxillary and mandibular overdentures with one implant system, using the same number of implants, there were both titanium and zirconia implants used as well as only one attachment system used per jaw. Different attachment systems were not used in the maxilla and mandible for comparison (Osman 2014);
- more than one implant system was used on the same number of implants comparing different attachment systems (Watson 2002).

For maxillary overdentures:

- more than one implant system was used on the same number of implants comparing different attachment systems (Al-Zubeidi 2012a);
- on maxillary overdentures and one implant system was used, different numbers of implants were used with only one attachment system (Slot 2013; Slot 2014).

Further details for the reasons for their exclusion are in the Characteristics of excluded studies table.

Risk of bias in included studies

We have provided detailed descriptions of the risk of bias in the included trials in the 'Risk of bias' tables.
See Figure 5 and Figure 6 for a summary of 'Risk of bias' assessments.

Figure 5. Risk of bias graph: review authors' judgements about each risk of bias item presented as percentages across all included studies.

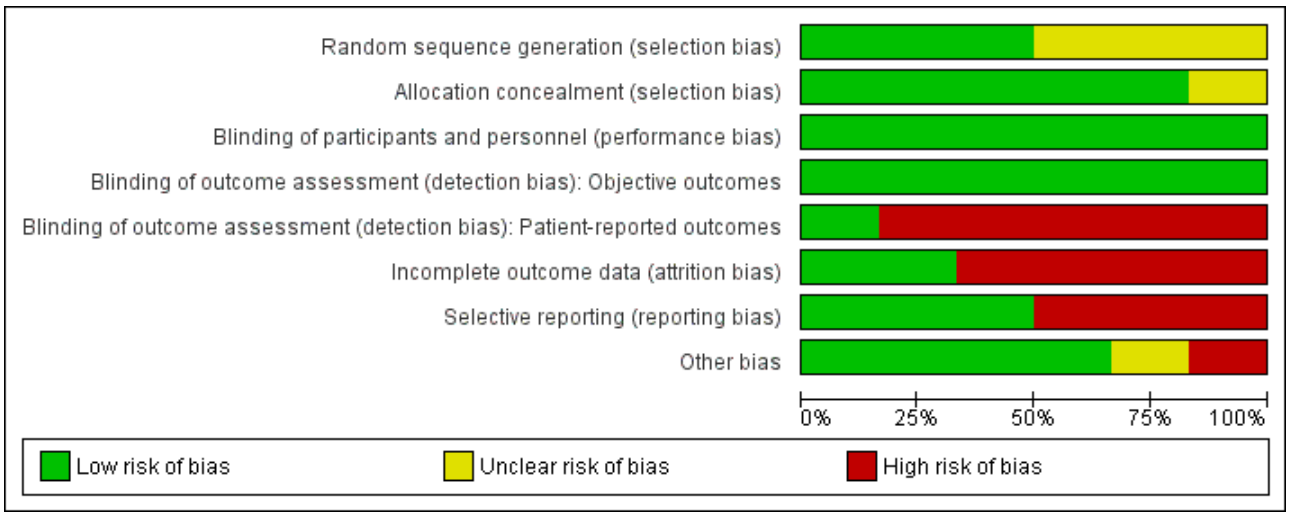
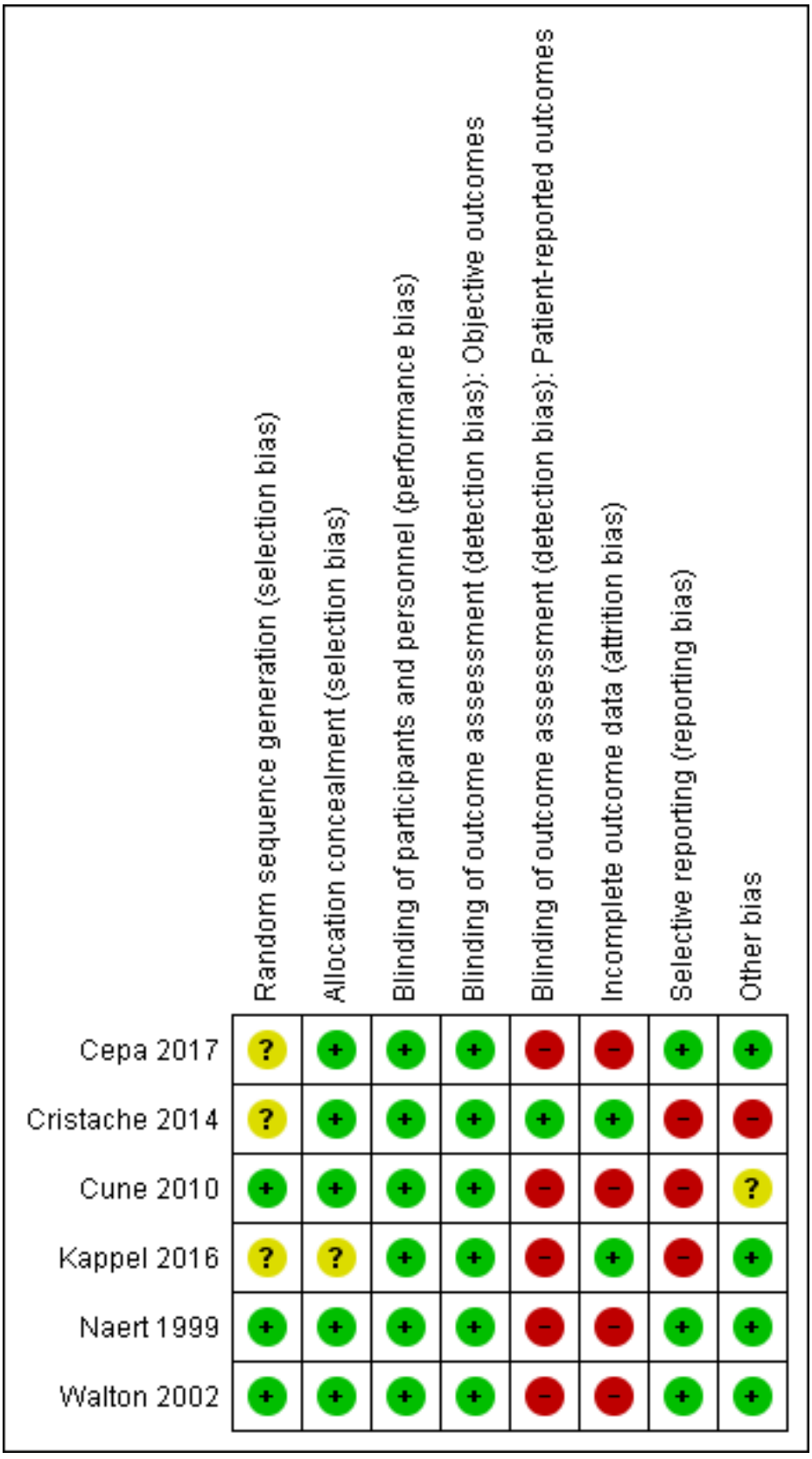


Figure 6. Risk of bias summary: review authors' judgements about each risk of bias item for each included study.



Allocation

Of the six included trials, only three noted adequate sequence generation (Cune 2010; Naert 1999; Walton 2002), while the other three trials did not provide any description of how the sequence was generated (Cepa 2017; Cristache 2014; Kappel 2016). All but one included trial (Kappel 2016 assessed as unclear) noted adequate allocation concealment and were at low risk of bias.

Blinding

Neither the participants nor the caregivers were blinded in the included trials due to the nature of the intervention, and since it is an operative procedure and the outcomes are not likely to be influenced by lack of blinding of participants and personnel, we considered the risk of performance bias to be low. Regarding detection bias, we assessed blinding separately for different classes of outcomes as described in the *Cochrane Handbook for Systematic Reviews of Interventions* (Higgins 2011), and assessed the risk as low in objective outcomes (e.g. prosthodontic maintenance) and high in patient-reported outcomes since lack of blinding can potentially introduce bias for this class of outcomes through multiple pathways (different expectations from the two groups and biased assessment of the effect).

Incomplete outcome data

For attrition bias, only two trials were at low risk (Cristache 2014; Kappel 2016), while the remaining four trials were at high risk due to reporting greater than 20% missing data (Cepa 2017; Cune 2010; Naert 1999), performing 'as treated' (Cune 2010) or 'per protocol' (Cepa 2017; Naert 1999) analyses, and presence of discrepancies between the reports of the same trial regarding the number of participants available for follow-up and the reasons for dropouts (Walton 2002).

Selective reporting

Three of the included trials were at low risk of selective reporting of outcomes (Cepa 2017; Naert 1999; Walton 2002). The other three were at high risk either due to failure to report all the outcomes pre-specified in their registered protocols (Cristache 2014; Kappel 2016), or due to failure to include results for key outcomes that would be expected to have been reported for such a study (Cune 2010).

Other potential sources of bias

The risk of other bias was low in four trials (Cepa 2017; Kappel 2016; Naert 1999; Walton 2002), and was high (Cristache 2014) and unclear (Cune 2010) in the other two trials.

Overall risk of bias

According to the criteria outlined in the *Cochrane Handbook for Systematic Reviews of Interventions* (Higgins 2011), overall risk of bias of all the included studies was high, due to being assessed at high risk of bias for one or more key domains.

Effects of interventions

See: **Summary of findings for the main comparison** Ball compared to bar attachment systems for implant overdentures in edentulous jaws; **Summary of findings 2** Ball compared to telescopic attachment systems for implant overdentures in edentulous jaws; **Summary of findings 3** Ball compared to magnetic attachment systems for implant overdentures in edentulous jaws

See Summary of findings for the main comparison; Summary of findings 2; Summary of findings 3.

The objectives of this review were to assess different attachment systems for maxillary and mandibular implant overdentures with respect to the outcomes measures of prosthodontic success, prosthodontic maintenance, patient preference, patient satisfaction (including quality of life), and costs.

By attachment system of maxillary overdentures

No maxillary overdenture trials were identified.

By attachment system of mandibular overdentures

Ball versus bar attachment systems

Two studies (Kappel 2016; Walton 2002) compared ball and bar attachments and reported results of 3 years of follow-up.

Prosthodontic success by specific categorization

(See Appendix 1 for categorization and Appendix 2 for six-field protocol.)

Kappel 2016 and Walton 2002 provided data that could be used and categorized into the six-field protocol. Upon pooling the data obtained from the two trials regarding the outcome prosthodontic success, we identified substantial heterogeneity (I^2 = 97%) with inconsistency in the direction of effect, which was unexplained by clinical or methodological differences between the studies, and accordingly we did not perform meta-analysis as this could produce misleading results (Analysis 1.1). However, re-treatment (repair) was higher in the ball attachment group (risk ratio (RR) 3.11, 95% confidence interval (CI) 1.68 to 5.75; 2 studies; 130 participants) (Analysis 1.2), and there was no difference between both systems in re-treatment (replace) (RR 1.18, 95% CI 0.38 to 3.71; 2 studies; 130 participants) (Analysis 1.3). It is uncertain whether there is a difference in short-term prosthodontic success when ball attachments are compared with bar attachments.

Prosthodontic maintenance by general categorization

Although this outcome was recorded by Kappel 2016 and Walton 2002, they did not provide usable data for inclusion in the review.

Patient satisfaction /quality of life assessed by a validated measure

Only Walton 2002 assessed patient satisfaction but reported narrative results and failed to provide any usable numbers. Quality of life as assessed by a validated measure was not recorded in any of the trials.

Cost (treatment time and/or material costs)

Walton 2002 reported costs but the data could not be used due to failure to report means and standard deviations and only providing the median of the costs.

Ball versus telescopic attachment systems

One trial compared ball and telescopic attachments (Cepa 2017).

Prosthodontic success by specific categorization

(See Appendix 1 for categorization and Appendix 2 for six-field protocol.)

Cepa 2017 did not assess this outcome.

Prosthodontic maintenance by general categorization

Among the six included studies, only Cepa 2017 provided usable data for this outcome. This trial compared ball and telescopic attachments, and after 3 years of follow-up reported no difference between both systems in patrix replacement (RR 6.00, 95% CI 0.86 to 41.96) (Analysis 2.1), matrix activation (RR 11.00, 95% CI 0.68 to 177.72) (Analysis 2.2), matrix replacement (RR 1.75, 95% CI 0.71 to 4.31) (Analysis 2.3), or in relining of the implant overdenture (RR 2.33, 95% CI 0.81 to 6.76) (Analysis 2.4). It is uncertain whether there is a difference in short-term prosthodontic maintenance when ball attachments are compared with telescopic attachments.

Patient satisfaction /quality of life assessed by a validated measure

Cepa 2017 assessed patient satisfaction but did not use validated measures and we could not use the data. Quality of life as assessed by a validated measure was not recorded.

Cost (treatment time and/or material costs)

Cepa 2017 did not assess this outcome.

Ball, bar or magnetic attachment systems

Three trials compared ball, bar and magnetic attachment systems (Cristache 2014; Cune 2010; Naert 1999). Cune 2010 was the only included trial with a cross-over design. We could not use Cune 2010 results because outcomes were reported only after 3 months which is not the time frame of interest to the review, and at 10 years which were results of "as treated analysis", and accordingly could not be used.

Prosthodontic success by specific categorization

(See Appendix 1 for categorization and Appendix 2 for six-field protocol.)

Only Cristache 2014 provided data that could be used and categorized into the six-field protocol. Cristache 2014 compared ball and magnetic attachments and reported no difference between both systems in success (RR 0.84, 95% CI 0.64 to 1.10; 1 study; 69 participants) (Analysis 3.1) or re-treatment (repair) (RR 1.75, 95% CI 0.65 to 4.72; 1 study; 69 participants) (Analysis 3.2) after a follow-up of 5 years. It is uncertain whether there is a difference in medium-term prosthodontic success when ball attachments are compared with magnet attachments.

Prosthodontic maintenance by general categorization

Although this outcome was recorded by Cristache 2014; Cune 2010; Naert 1999, they did not provide usable data for inclusion in the review.

Patient preference in cross-over trials

Among the six included trials, only one had a cross-over design (Cune 2010). It did not assess patient preference between the attachments used during the trial's observation period.

Patient satisfaction /quality of life assessed by a validated measure

Two trials (Cune 2010; Naert 1999) reported patient satisfaction. However, we could not use any data from these studies. Quality of life as assessed by a validated measure was not recorded in any of the trials.

Cost (treatment time and/or material costs)

Cristache 2014 compared between total aftercare and costs of prosthodontic maintenance after 5 years with ball and magnet attachments, and reported higher costs when magnets were used (mean difference (MD) -247.37 EUR, 95% CI -346.32 to -148.42; 1 study; 69 participants) (Analysis 3.3).

DISCUSSION

Summary of main results

For mandibular overdentures, there is insufficient evidence to determine the relative effectiveness of different attachment systems on prosthodontic success, prosthodontic maintenance, patient satisfaction, patient preference or costs. In the short term, there is some evidence that is insufficient to show a difference and where there was no evidence was reported. It was not possible to determine any preferred attachment system for mandibular overdentures.

For maxillary overdentures, there is no evidence (with no trials identified) to determine the relative effectiveness of different attachment systems on prosthodontic success, prosthodontic maintenance, patient satisfaction, patient preference or costs.

There were six randomised controlled trials (RCTs) on mandibular overdentures (all opposing conventional complete maxillary dentures) included in this review evaluating ball/stud, magnetic, telescopic or bar attachment systems (Cepa 2017; Cristache 2014; Cune 2010; Kappel 2016; Naert 1999; Walton 2002). Two of the trials were over 2 years, one of 3 years, one over 5 years, and two over 10 years. There were no eligible trials on maxillary overdentures. Methodology of reporting the primary and secondary outcomes varied widely, but possibly less so in two trials (Cristache 2014; Walton 2002).

With regard to reporting the primary outcome of prosthodontic success by specific categorization (Appendix 1; Appendix 2), there is some evidence that there is no difference between ball and magnetic attachments and specifically re-treatment (repair) up to 5 years. However, after 5 years, prosthodontic maintenance costs were higher when magnet attachments were used (Cristache 2014). In addition, with ball and bar attachments up to 3 years there appears to be no difference between both systems in re-treatment (replace), however when looking at re-treatment (repair) there is evidence that this is higher in the ball attachment group, which resulted in bar attachments having a higher prosthodontic success (Kappel 2016; Walton 2002). It is uncertain whether there is a difference in short-term prosthodontic success when ball attachments are compared with bar attachments as well as when ball attachments are compared with magnet attachments.

Although prosthodontic maintenance by general categorization was evaluated in all six trials, there was also considerable variation in the way in which the prosthodontic maintenance or technical complications, adjustments/repairs or aftercare of the attachment systems were documented. Related to this

prosthodontic maintenance by general categorization, there is some evidence that there is no difference between ball and telescopic attachments (Cepa 2017). It is uncertain whether there is a difference in short-term prosthodontic maintenance when ball attachments are compared with telescopic attachments.

Related to patient preference between attachment systems in cross-over trials, as well as patient satisfaction and quality of life using a validated measure, there is limited evidence from the single cross-over trial (Cune 2010), with no possibility of performing any data analysis on different sets of data. This could have been possible if there had been more than one cross-over trial.

Patient satisfaction measured in three of the six trials was with different validated measures (Cune 2010; Naert 1999; Walton 2002) and cost analysis (treatment time and/or material costs), measured in two trials (Cristache 2014; Walton 2002) was done in different manners. Although improved patient satisfaction is undoubtedly predictable regardless of the attachment system used for mandibular overdentures, a preferred attachment system related to prosthodontic success, prosthodontic maintenance, patient preference and costs could not be identified.

Related to cost (treatment time and/or material costs), there is some evidence that there are higher costs when using magnetic attachments, as opposed to ball attachments (Cristache 2014).

Overall completeness and applicability of evidence

The trials identified are not sufficient to address the review question. Although the participants and interventions investigated were of direct relevance to our review question, the pooled included trials did not provide a sufficient number of participants and did not report on the attachment systems with maxillary overdentures. In addition, the studies did not report on long-term outcomes, and failed to include results for important key outcomes in usable numerical form to allow for meta-analysis. Therefore, there can be no consensus on the attachment system to be used with maxillary or mandibular implant overdentures based on this review findings.

There are distinct difficulties in conducting randomised clinical trials in prosthodontics and especially determining true economic aspects of hardware maintenance longitudinally. This is of utmost relevance in older studies given the attachment systems included in those studies are no longer commercially available, except in some instances by custom fabrication by the commercial companies at a high cost to the clinician. In addition, although some of the older studies have a relevance, they could not be included as they were conducted not in a randomised clinical trial format, but rather in a prospective study format which was the usual study design at that time.

Quality of the evidence

The body of evidence identified do not allow for a robust conclusion regarding the objectives of the review. The evidence was of very low quality for all pre-specified outcomes (Summary of findings for the main comparison; Summary of findings 2; Summary of findings 3). In all the included trials there were relatively few participants and few events, and most of the reported outcomes had wide confidence interval (CI) around the estimate of the effect that overlaps no effect and includes both appreciable benefit and appreciable harm. In addition, there were serious limitations in the trial design regarding incomplete outcome data and selective reporting of the outcomes. We evaluated the quality of evidence by using the GRADE approach. The evidence was of very low quality, we have very little confidence in the effect estimate: the true effect is likely to be substantially different from the estimate of effect (Schünemann 2013).

Potential biases in the review process

The review authors followed the guidelines for conducting this systematic review under the strictest of conditions (Higgins 2011). We performed comprehensive searches to identify eligible trials, all abstracts were independently dual screened, and all references were assessed and had the risk of bias assessment carried out by at least two independent authors. All trials were subsequently reviewed and agreed by three of the review authors. Some corresponding authors did not reply to our requests of random sequence generation, allocation concealment, blinding of outcome assessment (detection bias), or additional primary outcome data on their trials and were therefore excluded from the analysis.

As the clinicians provided the evaluations related to the outcomes in the studies, there was a possibility of reporting bias and under-reporting.

Agreements and disagreements with other studies or reviews

The present review included all the RCTs available to date. There have been five other related systematic reviews (Anas El-Wegoud 2018; Assaf 2017; Cehreli 2010a; Kim 2012; Leão 2018).

Two of these were just on prosthodontic maintenance and complications of implant overdentures (Andreiotelli 2010; Cehreli 2010a) and both of these also included prospective studies as well as RCTs with a variation of 18 to 49 selected studies between them. Therefore direct comparisons with our findings could be misleading and difficult to interpret in these reviews. In addition, Kim 2012 also included prospective studies as well as RCTs up to August 2010, with duplication of the same studies at different time points in the 24 included studies. Implant survival was inaccurately attempted to be assessed simultaneously and lead to ambiguity. There were conflicting findings on prosthodontic maintenance between ball (stud) and bar attachments, and patient satisfaction was stated as "appearing" to be independent of attachment system. No meta-analysis was performed.

The systematic review by Leão 2018 attempted to determine the influence of splinted and unsplinted overdenture attachment systems on prosthodontic maintenance and marginal bone loss and implant survival rate. Nine studies were included in the qualitative and quantitative analyses. A total of 984 implants were placed in 380 patients (mean age: 62.8 years). Splinted and unsplinted overdenture attachment systems achieved similar results with regard to prosthodontic maintenance. The meta-analysis demonstrated no statistically significant differences between splinted and unsplinted attachment systems with regard to marginal bone loss (P = 0.39; mean difference (MD) -0.11, 95% confidence interval (CI) -0.37 to 0.14), complications (P = 0.31; risk ratio (RR) 1.26, 95% CI 0.80 to 1.99), and implant survival rate (P = 0.14; RR 0.37, 95% CI 0.10 to 1.36).

Similarly, Assaf 2017 from a total of 130 articles, found 33 studies that met the specified inclusion criteria for the review

(14 RCTs, eight prospective clinical trials, three retrospective studies, and four systematic reviews). It was deduced that these articles provided evidence that a mean complication rate of prosthodontic maintenance was impossible to determine because of the multiplicity of contributing factors. No clear identification of the causes of prosthodontic maintenance were found, nor was there any clear evidence of superiority of any implant system or attachment design over another or both. It was concluded that prosthodontic maintenance with implant overdentures is inevitable. Further clinical studies were encouraged to achieve a constructive meta-analysis that accounts for different parameters such as opposite arch, attachment functional variety, connection method, and prosthesis quality.

A more robust review was published recently by Anas El-Wegoud 2018 who concluded that there was insufficient evidence to support bar or ball attachments being used with implant overdentures in edentulous patients to improve patient satisfaction and prosthesis retention. They included 10 trials (465 participants). After 5 years, one trial reported higher patient satisfaction when bar attachment was used (MD 1.30, 95% CI 0.20 to 2.40), and reported no difference between both systems in overdenture retention (MD -0.90, 95% CI -1.90 to 0.10). Two trials in Anas El-Wegoud 2018 reported no implant failures after 1 and 5 years in both attachments and one of these (Naert 1999) was amongst the six included trials for this Cochrane Review. Downgrading of evidence was based on the unclear risk of bias of included studies and the wide confidence interval crossing the line of no effect.

AUTHORS' CONCLUSIONS

Implications for practice

For mandibular overdentures, there is insufficient evidence to determine the relative effectiveness of different attachment systems on prosthodontic success, prosthodontic maintenance, patient satisfaction, preference or costs. It was not possible to determine any preferred attachment system for mandibular overdentures.

For maxillary overdentures, there is no evidence (with no trials identified) to determine the relative effectiveness of different attachment systems on prosthodontic success, prosthodontic maintenance, patient satisfaction, patient preference or costs.

Implications for research

There is a profound need for further randomised controlled trials (especially on maxillary overdentures) with specific attention to trial design with the same number of implants of the same implant system, with different attachment systems (including those made with computer-aided designed/computer-assisted manufactured (CAD/CAM) technology clearly identified with control and test groups.

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* Indicates the major publication for the study

CHARACTERISTICS OF STUDIES

Characteristics of included studies *[ordered by study ID]*

Cepa 2017

Methods	Trial design: 3-year follow-up, randomised parallel group trial Parallel group randomised clinical trial in which the individuals were randomly assigned to the 2 trial groups consisting of ball and telescopic attachments. Randomisation was carried out by a statistician not involved in the trial using sealed envelopes. The envelope containing information on the abutments to be used was opened by a dental nurse
Participants	Inclusion criteria: participants recruited for the trial were dissatisfied with their conventional mandibular overdenture Exclusion criteria: general contraindications for oral surgical procedures such as infectious or metabolic diseases, cardiovascular disease and pregnancy; local contraindications (e.g. tumours, ulcers); alcohol abuse or smoking; psychological disease; non-compliance and intolerance of pre- or post-operative medication in the presence of chronic disease Age at baseline (years): mean 65.2

Cepa 2017 *(Continued)*

	Gender (M/F): not specified Number of mandibular overdentures randomised: 25 (mandibular 2-implant overdentures: 12 ball; 13 telescopic attachment) Number of mandibular overdentures evaluated at 1 year: 23 (12 ball; 11 telescopic attachment) Number of mandibular overdentures evaluated at 2 years: 21 (11 ball; 10 telescopic attachment) Number of mandibular overdentures evaluated at 3 years: 16 (11 ball; 5 telescopic attachment)
Interventions	Mandibular 2-implant overdentures - unsplinted prosthodontic design Test group 1 (n = 12): Ankylos® (Dentsply Implants, Mannheim, Germany) ball attachments with connecting matrices were polymerized into spacers of the metal framework using a self-curing resin (Pattern Resin LS, GC Europe, Leuven, Belgium) Test group 2 (n = 13): prefabricated telescopic (conus) attachments with connecting matrices were polymerized into spacers of the metal framework using a self-curing resin (Pattern Resin LS, GC Europe, Leuven, Belgium)
Outcomes	Prosthodontic maintenance by general categorization Patient satisfaction (trial did not use validated criteria for this outcome) Data collection was performed on the day of overdenture delivery and after 1, 2 and 3 years
Notes	Location: Germany Funding source: this investigation was supported by a grant from Dentsply Implants, Mannheim, Germany Patient satisfaction data presented did not use validated criteria Authors contacted by email (7 February 2017): requested full prosthodontic maintenance categorization to facilitate data analysis - no reply received Details of ethical approval: Freiburg Regional Council and the Ethics Committee of the Medical-Center, Freiburg, Germany (Votum number: 105/04)

Risk of bias

Bias	Authors' judgement	Support for judgement
Random sequence generation (selection bias)	Unclear risk	Quote: "The patients were randomly assigned to the two trial groups consisting of ball and telescopic attachments" Comment: the trial does not include any description of how the sequence was generated
Allocation concealment (selection bias)	Low risk	Quote: "Randomization was carried out by a statistician not involved in the study using sealed envelopes. The envelope containing information on the abutments to be used was opened by a dental nurse"
Blinding of participants and personnel (performance bias) All outcomes	Low risk	Quote: "As the prosthetic reconstruction was visible, blinding of the investigators was not possible" Comment: although participants and personnel were not blinded, we judge the risk of bias as low since it is an operative procedure and the outcomes are not likely to be influenced by lack of blinding of participants and personnel
Blinding of outcome assessment (detection bias)	Low risk	The trial did not report blinding, however blinding is not possible due to the nature of the intervention, but we judge the risk of bias as low regarding

Cepa 2017 *(Continued)*

Objective outcomes		prosthodontic maintenance due to being objective and is not likely to be influenced by lack of blinding
Blinding of outcome assessment (detection bias) Patient-reported outcomes	High risk	The trial did not report blinding, however blinding is not possible due to the nature of the intervention, but we judge the risk of bias as high regarding patient satisfaction due to being subjective and is likely to be influenced by lack of blinding
Incomplete outcome data (attrition bias) All outcomes	High risk	Total losses: 9/25 (36%) Ball group losses: 1/12 Telescopic group losses: 8/13 • Ball attachment group: 12 participants received IODs. 12 participants were followed up after 1 year, whereas 11 participants were followed up after 2 and 3 years. 1 participant was deceased within the second year of observation • Prefabricated telescopic group: 13 participants received IODs. 11 participants were followed up after 1 year. 1 participant deceased, and 1 refused to further participate in the investigation. 10 participants were followed up after 2 years, as another participant refused to further participate in the investigation. Only 5 participants were followed up after 3 years of observation because further 5 dropouts occurred. Another participant deceased, and 4 more participants refused to further participate in the follow-up appointments. 4 dropouts of the telescopic group were changed to ball attachments during their ongoing aftercare appointments in the department In addition, 'per protocol' analysis was performed when analysing the patient satisfaction outcome
Selective reporting (reporting bias)	Low risk	The trial protocol is not available, but we judge the risk of bias as low due to reporting key outcomes that are expected to be reported for such a trial
Other bias	Low risk	None noted

Cristache 2014

Methods	Trial design: 5-year follow-up, randomised parallel group trial Parallel group randomised trial. A dental assistant, not involved in this research project randomly assigned the participants to 1 of the 3 main groups. The random assigning was done using 69 sequentially numbered opaque sealed envelopes (SNOSE)
Participants	Inclusion criteria: complaints about the stability of the existing mandibular denture, Class I to III (McGarry 1999), acceptance of a mandibular overdenture retained by 2 implants; agreement for a 5-year follow-up period Exclusion criteria: insufficient bone volume (height and width) for inserting of at least a 10 mm implant (diameter 4.1), patients in Class IV classification (McGarry 1999), Angle Class II relationship, physical condition that will affect the minimal invasive surgical procedure or constitute a hindrance for a 5-year follow-up (e.g. immunosuppressive therapy, elderly patients in poor physical condition), history of radio-/chemotherapy in the head and neck region, history of pre-prosthetic surgery (including bone graft procedures) or previous implants Age at baseline (years): 42 to 84 Gender (M/F): not specified Number of mandibular overdentures randomised: 69 (mandibular 2-implant overdentures)

Cristache 2014 *(Continued)*

	Number of mandibular overdentures evaluated at 5 years: 69
Interventions	Mandibular 2-implant overdentures - unsplinted prosthodontic design Test group B1 (n = 12): Straumann® 2.25 mm ball patrices and Dalla Bona type gold alloy matrices Test group B2 (n = 11): Straumann® 2.25 mm ball patrices and titanium alloy spring matrices Test group M (n = 23): Titanmagnetics® magnetic attachments (patrices/matrices) Test group L (n = 23): Locator® stud matrices and plastic patrices
Outcomes	Prosthodontic success by specific categorization (Appendix 1) and 6-field protocol (Appendix 2) Prosthodontic maintenance by general categorization Cost (treatment time and/or material costs) Data collection was performed at baseline assessment (1 week after insertion of the implant overdenture) (T0), 6 months (T) and annually thereafter for 5 years (T1–T5)
Notes	Location: Romania Funding source: supported by Grant Number 316/03 and Grant 507-207 from the ITI Foundation for the Promotion of Oral Implantology, Switzerland Insufficient details on method of random sequence generation, allocation concealment, participant allocation, blinding of outcome assessment (detection bias) Authors contacted by email (23 August 2015): reply received 28 August 2015. Unpublished information supplied for risk of bias table Details of ethical approval: the use of human subjects in this trial was reviewed and approved by the Romanian Ministry of Health and written informed consent was obtained from all participants ClinicalTrials. gov Identifier: NCT01034930

Risk of bias

Bias	Authors' judgement	Support for judgement
Random sequence generation (selection bias)	Unclear risk	Quote: "A dental assistant, not involved in this research project randomly assigned the participants to one of the three main groups" Comment: the trial does not include any description of how the sequence was generated
Allocation concealment (selection bias)	Low risk	Quote: "The random assigning was done using 69 sequentially numbered opaque sealed envelopes (SNOSE)"
Blinding of participants and personnel (performance bias) All outcomes	Low risk	The trial did not report blinding, but we judge the risk of bias as low since it is an operative procedure and the outcomes are not likely to be influenced by lack of blinding of participants and personnel
Blinding of outcome assessment (detection bias) Objective outcomes	Low risk	The trial did not report blinding, however blinding is not possible due to the nature of the intervention, but we judge the risk of bias as low due to the outcomes being objective and are not likely to be influenced by lack of blinding
Blinding of outcome assessment (detection bias) Patient-reported outcomes	Low risk	Not applicable

Cristache 2014 *(Continued)*

Incomplete outcome data (attrition bias) All outcomes	Low risk	No attrition and exclusion reported
Selective reporting (reporting bias)	High risk	The trial protocol is available, and not all of the trial's pre-specified primary outcomes have been reported (ClinicalTrials.gov Identifier: NCT01034930)
Other bias	High risk	Inconsistencies between the protocol and the trial report regarding recruitment and randomisation procedures Protocol: "Participants will be randomly assigned to one of two main groups balls and magnets, and these two groups will then be compared with 23 participants receiving Locator system abutments not originally included in the randomisation procedure" Trial: the participants were randomly assigned to 1 of the 3 main groups Accordingly, the Locator attachment system results were not included in any analysis

Cune 2010

Methods	Trial design: 10-year follow-up, randomised, cross-over trial Cross-over randomised trial where the sequence in which the 3 attachments were applied was randomised
Participants	Inclusion criteria: healthy and fit participants, bone height in the inter-foraminal > 15 mm Exclusion criteria: not reported Age at baseline (years): 33 to 56 Gender (M/F): 17/1 Number of mandibular overdentures randomised: 18 (mandibular 2-implant overdentures) Number of mandibular overdentures evaluated at 10 years: 14
Interventions	Mandibular 2-implant overdentures - unsplinted prosthodontic design (cross-over study) 3 different attachment systems used; the attachment type was changed after 3 and 6 months respectively in random order and at the end of the trial at 1 year, the participants selected their attachment system. Of the 14 participants with complete data sets, evenly distributed between ball-socket and bar-clip groups Test group 1 (n = 7): Frialit-2 2.25 mm ball abutment patrices and Dalla Bona type metallic matrices Test group 2 (n = 7): Frialit- single bar-clip attachment system (round 2 mm bar) in conjunction with a metal omega-shaped IMZ clip, Friadent Test group 3 (n = 0): magnetic attachment system (Dyna magnet ES, type extra strong; Dyna Dental Engineering, Bergen, the Netherlands)
Outcomes	Prosthodontic maintenance by general categorization Patient satisfaction assessed by a validated measure (4-point scale and VAS scale) Patient preference (cross-over trial)
Notes	Location: the Netherlands

Cune 2010 *(Continued)*

Funding source: this trial was supported in part by the University Medical Center Utrecht, Military Hospital Utrecht, The Netherlands Institute for Dental Sciences and Friadent, Friedrichfeld, Germany. The laboratory procedures were performed by the Dental Laboratory of the University Clinic of Utrecht and the Zeister Tandtechnisch Laboraratorium, Zeist, the Netherlands

Insufficient details on method of random sequence generation, allocation concealment, participant allocation, blinding of outcome assessment (detection bias)

Authors contacted by email (23 August 2015): reply received 29 August 2015. Unpublished information supplied for risk of bias table

Details of ethical approval: not mentioned

Risk of bias

Bias	Authors' judgement	Support for judgement
Random sequence generation (selection bias)	Low risk	Clarification from trial authors: "The sequence was generated before the start of the trial by means of a randomisation protocol in SPSS, using the seed of the computer, ensuring that the different possible orders were equally distributed among the participants"
Allocation concealment (selection bias)	Low risk	Clarification from trial authors: "Consecutive participants fitting the inclusion and exclusion criteria who were willing to participate were enrolled in the trial. Cune was the supervising researcher. Whenever a new participant entered the trial, Cune communicated the order in which the attachment systems were to be provided to the treating surgeon (van Kampen)"
Blinding of participants and personnel (performance bias) All outcomes	Low risk	Clarification from trial authors: "Neither participants or examiners were blinded" Comment: we judge the risk of bias as low since it is an operative procedure and the outcomes are not likely to be influenced by lack of blinding of participants and personnel
Blinding of outcome assessment (detection bias) Objective outcomes	Low risk	The trial did not report blinding of outcome assessor, however blinding is not possible due to the nature of the intervention, but we judge the risk of bias as low regarding prosthodontic maintenance due to being objective and is not likely to be influenced by lack of blinding
Blinding of outcome assessment (detection bias) Patient-reported outcomes	High risk	The trial did not report blinding of outcome assessor, however blinding is not possible due to the nature of the intervention, but we judge the risk of bias as high regarding patient satisfaction due to being subjective and is likely to be influenced by lack of blinding
Incomplete outcome data (attrition bias) All outcomes	High risk	Total losses: 4/18 (22%) (after 10 years, 4 of the initial 18 participants were lost to follow-up. No measures were made to follow the non-respondents) In addition, 'as treated' analysis was performed in the 10 years reports (at the end of the initial trial, the dentures were fitted with the attachment type of the participant's choice, and the outcomes at 10 years were measured for the attachment of participant's preference)
Selective reporting (reporting bias)	High risk	The trial report failed to include results for key outcomes that would be expected to have been reported for such a trial
Other bias	Unclear risk	Insufficient duration of follow-up to provide clinically meaningful data (3 months)

Kappel 2016

Methods	Trial design: 2-year follow-up, randomised parallel group trial Parallel group randomised trial in which participants were randomly assigned to 1 of 2 attachment systems and special sealed sequentially numbered envelopes containing the randomised allocation were prepared at the beginning of the trial by an external source
Participants	Inclusion criteria: edentulous mandibles, adequate dimensions of the vertical and horizontal bone of the inter-foramina regions (vertically and horizontally at least 1 mm of bone around each implant), and informed consent to participation Exclusion criteria: drug or alcohol abuse, inadequate vertical or horizontal bone dimensions or quality, less than 35 Ncm insertion torque, pregnant at the time of implant placement, and administration of intravenous bisphosphonates in the last 10 years Age at baseline (years): mean 69.4 Gender (M/F): 34:12 (73.9% male) Number of mandibular overdentures randomised: 46 (mandibular 2-implant overdentures) Number of mandibular overdentures evaluated at 1 year: not specified Number of mandibular overdentures evaluated at 2 years: 43
Interventions	Mandibular 2-implant overdentures - unsplinted prosthodontic design Test group 1 (n = 23): Locator® attachments (Zest Anchors LLC, Espandido, CA, USA) Test group 2 (n = 23): egg-shaped bar (Dolder®, Sub-TecWirobond® MI bar abutment and Dolder bar joint (BEGO Implant GmbH & Co KG, Bremen, Germany)
Outcomes	Prosthodontic maintenance by general categorization Patient satisfaction (trial did not use validated criteria for this outcome) Follow-up examinations were performed after 3, 6, 12, and 24 months Unpublished data conforming to Appendix 1; Appendix 2 by authors via email
Notes	Location: Germany Funding source: BEGO Implant Systems GmbH & Co KG, Bremen, Germany: financial and material support Dr Stefanie Kappel was supported by the Olympia-Morata programme of the Medical Faculty of the University of Heidelberg, Germany Patient satisfaction data presented did not use validated criteria ("Patients were asked whether they would recommend the treatment knowing what it entailed") Kappel 2016 is the primary trial since first report of Kappel 2015 was for less than 1 year of duration Authors contacted by email (07 February 2017): replies received (15 and 20 February 2017) providing participant numbers in test groups at year 2 plus full prosthodontic maintenance categorization from author (unpublished data) confirming to Appendix 1; Appendix 2 Details of ethical approval: the ethics committee of the Medical Faculty of the University of Heidelberg (S-208/2010) approved the trial. Registered in the German Registry for Clinical Studies (DRKS 00004245)

Risk of bias

Bias	Authors' judgement	Support for judgement

Kappel 2016 *(Continued)*

Random sequence generation (selection bias)	Unclear risk	Quote: "Participants were allocated to a treatment group on the basis of the content of the next envelope in the sequence" Comment: the trial does not include any description of how the sequence was generated
Allocation concealment (selection bias)	Unclear risk	Quote: "Sealed, sequentially numbered envelopes containing the randomised allocation were prepared by an external source before the trial began" Comment: it is not clear whether the envelopes were opaque or opened by an independent source not involved in the study
Blinding of participants and personnel (performance bias) All outcomes	Low risk	The trial did not report blinding, but we judge the risk of bias as low since it is an operative procedure and the outcomes are not likely to be influenced by lack of blinding of participants and personnel
Blinding of outcome assessment (detection bias) Objective outcomes	Low risk	The trial did not report blinding, however blinding is not possible due to the nature of the intervention, but we judge the risk of bias as low due to the outcomes being objective and are not likely to be influenced by lack of blinding
Blinding of outcome assessment (detection bias) Patient-reported outcomes	High risk	The trial did not report blinding, however blinding is not possible due to the nature of the intervention, but we judge the risk of bias as high regarding patient satisfaction due to being subjective and is likely to be influenced by lack of blinding
Incomplete outcome data (attrition bias) All outcomes	Low risk	Total losses: 3/46 (6.5%) 3 participants were lost to follow-up because of death or serious illness
Selective reporting (reporting bias)	High risk	The trial protocol is available, and not all of the trial's pre-specified outcomes have been reported (ISRCTN: DRKS00004245)
Other bias	Low risk	None noted

Naert 1999

Methods	Trial design: 10-year follow-up randomised, parallel group trial Parallel group randomised trial. A randomised procedure, based on a lottery without replacement of the tags, allocated the patients into 3 groups of equal size
Participants	Inclusion criteria: all participants edentulous for at least more than 1 year and all complained about their existing mandibular dentures Exclusion criteria: insufficient bone volume to harbour 2 implants with a minimum length of 10 mm, Angle Class II jaw relationship, psychological problems with acceptance of a removable denture, gag reflex, absence of maxillary complete denture, administrative or physical considerations that would seriously affect the surgical procedure or longitudinal follow-up Age at baseline (years): mean 63.7 (range 36 to 85) Gender (M/F): 17/19 Number of mandibular overdentures randomised: 36 (mandibular 2-implant overdentures) Number of mandibular overdentures evaluated at 5 years: 31 Number of mandibular overdentures evaluated at 10 years: 26

Naert 1999 *(Continued)*

	Note: some patients shifted from 1 group to another after allocation, hence the "intention-to-treat" principle was applied to prevent selection bias. Only those patients who maintained the same attachment system from the baseline ("pure group") were considered. 2 methods were applied, referring to the intention-to-treat group or the pure group
Interventions	Mandibular 2-implant overdentures - splinted and unsplinted prosthodontic design Baseline: • Bar group (n = 12): Branemark® abutments with single egg-shaped Dolder bar joint patrices and clip matrices • Ball group (n = 12): Branemark® 3.25 mm ball patrices and O-ring matrices • Magnet group (n = 12): Branemark® abutments with open field magnetic attachments At 5 years: • Bar group (n = 9) • Ball group (n = 11) • Magnet group (n = 11) At 10 years: • Bar group (n = 7) • Ball group (n =9) • Magnet group (n = 10)
Outcomes	Prosthodontic maintenance by general categorization (recorded at 4, 6, 24, 36, 48, 60, and 120 months after abutment connection) Patient satisfaction assessed by a validated measure (questionnaire) (recorded at 12, 60, and 120 months)
Notes	Location: Belgium Funding source: NobelBiocare, Göteborg, Sweden, provided the ball attachments, Dyna Engineering, and Bergen of Zoom, the Netherlands, provided the magnet attachments Authors contacted by email (30 August 2015 and 20 September 2015): reply received 22 September 2015. Unpublished information supplied for risk of bias table Naert 1999 is 5-year report which is same trial as Naert 2004 which is 10-year report Details of ethical approval: not mentioned

Risk of bias

Bias	Authors' judgement	Support for judgement
Random sequence generation (selection bias)	Low risk	Quote: "A randomised procedure, based on a lottery without replacement of the tags, allocated the patients into three groups of equal size"
Allocation concealment (selection bias)	Low risk	Quote: "A randomised procedure, based on a lottery without replacement of the tags, allocated the patients into three groups of equal size"
Blinding of participants and personnel (performance bias) All outcomes	Low risk	The trial did not report blinding, but we judge the risk of bias as low since it is an operative procedure and the outcomes are not likely to be influenced by lack of blinding of participants and personnel
Blinding of outcome assessment (detection bias) Objective outcomes	Low risk	The trial did not report blinding, however blinding is not possible due to the nature of the intervention, but we judge the risk of bias as low regarding

Naert 1999 *(Continued)*

		prosthodontic maintenance due to being objective and is not likely to be influenced by lack of blinding
Blinding of outcome assessment (detection bias) Patient-reported outcomes	High risk	The trial did not report blinding, however blinding is not possible due to the nature of the intervention, but we judge the risk of bias as high regarding patient satisfaction due to being subjective and is likely to be influenced by lack of blinding
Incomplete outcome data (attrition bias) All outcomes	High risk	Total losses: 10/36 (28%) (9 participants died, and 1 was unable to complete 10 years of follow-up because of severe illness (5, 2, and 3 participants had dropped out from the bar, magnet, and ball groups respectively)) Additionally, 'per protocol' analysis was performed for some of the outcomes (to evaluate clinical aspects, only those patients who maintained the same attachment system from the baseline, referred to as the "pure group" were considered)
Selective reporting (reporting bias)	Low risk	The trial protocol is not available, but we judge the risk of bias as low due to reporting key outcomes that are expected to be reported for such a trial
Other bias	Low risk	None noted

Walton 2002

Methods	Trial design: 3-year follow-up, randomised parallel group trial Factorial design randomised trial where participants were randomly allocated to 1 of 4 treatment groups using balanced randomisation (retained by a ball or by a bar and clips, with or without a metal framework). The treatments were assigned randomly in blocks of 4 participants (via random permutations, generated in an Excel spreadsheet), using distinct randomisation within each of the 4 strata based jointly on gender and on ridge resorption
Participants	Inclusion criteria: edentulous participants with at least 1 year of experience wearing conventional complete dentures, medically and psychologically suited for implant surgery, able to complete the trial forms and to communicate orally in English, willing to commit to 2 years of participation in the trial after receiving new dentures (Walton 2002 and MacEntee 2005) but Walton 2003 states "be available for the duration of the trial" Exclusion criteria: received treatment previously with implants, need for additional pre-prosthetic surgery, insufficient bone height for at least an 8.5 mm mandibular implant, or a history of systemic or neurologic disease or head and neck radiation, participants were not enrolled in the trial after implant surgery because the prosthodontist found that the implants diverged more than 15 degrees from each other, or that the implants were located less than 20 mm or more than 35 mm apart, because of evidence that such an orientation and location of implants could disturb the stability and maintenance of the implant overdenture Age at baseline (years): bar-clip group: 61, ball-spring: 63 (from MacEntee 2005); but Walton 2003 says 41 to 89 years (mean 65 years); and Walton 2002 says "ranged in age from 41.4 to 88.9 years, with a mean age of 64.4 years" Gender (M/F): bar-clip group: 12/22, ball-spring: 13/21 (from MacEntee 2005); Walton 2002 says "female participants (n = 41) outnumbered male participants (n = 23) by a ratio of almost 2:1" Number of mandibular overdentures randomised: 100 (mandibular 2-implant overdentures) Number of mandibular overdentures evaluated at 1 year: 67 Number of mandibular overdentures evaluated at 2.98 years: 87

Walton 2002 *(Continued)*

	Note: number evaluated (participants): Walton 2002 says "of the 100 participants enrolled, 67 had their overdenture for a minimum of 1 year prior to the present analysis". 3 of these 67 were lost to follow-up (1 died, 1 delayed treatment because of financial problems, and 1 was lost to follow-up after implant placement surgery), leaving 64 continuing participants who had a mandibular overdenture for at least 1 year Note: MacEntee 2005 says 68/136; 87 participants had their overdentures for 2 to 4 years (mean 2.98)
Interventions	Mandibular 2-implant overdentures - splinted and unsplinted prosthodontic design Test group 1 (n = 34 at 1 year): Branemark® 2 mm single round gold bar joint patrices and single clip matrices Test group 2 (n = 34 at 1 year): Branemark® 2.25 mm ball patrices and titanium alloy spring matrices
Outcomes	Data were collected prior to implant surgery, and at 1 month, 1 year, 2 years, and 3 years after prosthesis placement, except for patient satisfaction which was not evaluated at year 3 Prosthodontic success by specific categorization Appendix 1 and 6-field protocol Appendix 2 Prosthodontic maintenance by general categorization Patient satisfaction/quality of life assessed by a validated measure (VAS 100 mm scale after de Grandmont 1994) Cost (treatment time and/or material costs) measured in US dollars
Notes	Location: Canada Funding source: supported by Health Canada, National Health and Research Development Program (project number 6610-2061-403) and Nobel Biocare Canada Authors contacted by email (30 August 2015): reply received 14 September 2015. Unpublished information supplied for risk of bias table MacEntee 2005, Walton 2002, Walton 2003: all reports of same trial (Walton 2002) Details of ethical approval: not mentioned

Risk of bias

Bias	Authors' judgement	Support for judgement
Random sequence generation (selection bias)	Low risk	Quote: "The treatments were assigned randomly in blocks of 4 participants (via random permutations, generated in an Excel spreadsheet)"
Allocation concealment (selection bias)	Low risk	Clarification from trial authors: "Statistician (Dr Ned Glick) completed the stratification and randomisation protocols, and provided sealed envelopes for participant allocation. The outer envelopes were each labelled with a stratum name (e.g. female, severe ridge resorption) and contained additional sealed envelopes specifying either number of implants or type of attachment system. Once a trial clinician had determined, according to pre-defined criteria, the stratum to which the participant belonged, the trial dental assistant was instructed to confirm the stratum and then draw and open, in the presence of the clinician, an allocation envelope from that stratum. The assignment was then recorded on trial forms for that participant"
Blinding of participants and personnel (performance bias) All outcomes	Low risk	The trial did not report blinding, but we judge the risk of bias as low since it is an operative procedure and the outcomes are not likely to be influenced by lack of blinding of participants and personnel
Blinding of outcome assessment (detection bias)	Low risk	The trial did not report blinding, however blinding is not possible due to the nature of the intervention, but we judge the risk of bias as low regarding the

Walton 2002 *(Continued)*

Objective outcomes		following outcomes due to being objective and are not likely to be influenced by lack of blinding: 1. prosthodontic maintenance 2. time or costs
Blinding of outcome assessment (detection bias) Patient-reported outcomes	High risk	The trial did not report blinding, however blinding is not possible due to the nature of the intervention, but we judge the risk of bias as high regarding patient satisfaction due to being subjective and is likely to be influenced by lack of blinding
Incomplete outcome data (attrition bias) All outcomes	High risk	Discrepancies exist between the 3 trial reports regarding the number of participants available for follow-up at 3 years and the reasons for dropouts MacEntee 2005: • "The results reported here are for the first 68 participants for whom data were available for 3 years" • "2 died, 5 withdrew, 6 were otherwise lost to follow-up, and 19 participants had less than 3 years in the trial since receiving new dentures" Walton 2003: • "87 participants were available for follow-up after 3 years" • "Of the 13 participants who dropped out of the trial, 2 did so before overdenture placement (1 died and 1 was lost to follow-up after stage-one implant surgery). 1 participant in the bar-clip group died after overdenture delivery. The remaining 10 (3 in the ball attachment group and 7 in the bar-clip group) left the trial at the end of their 2 year commitment"
Selective reporting (reporting bias)	Low risk	The trial protocol is not available, but we judge the risk of bias as low due to the reporting of key outcomes that are expected to be reported for such a trial
Other bias	Low risk	None noted

F = female; IODs = implant-retained overdentures; M = male; n = number; VAS = visual analogue scale.

Characteristics of excluded studies *[ordered by study ID]*

Study	Reason for exclusion
Akca 2013	Not an RCT - no specific details on method of allocation concealment, participant allocation, blinding of outcome assessment (detection bias)
Al-Zubeidi 2012a	Although this was an RCT on maxillary overdentures, more than 1 implant system was used on the same number of implants comparing different attachment systems
Alsabeeha 2011	Although this was an RCT, more than 1 implant system was used on the same number of implants (1 implant only) comparing different attachment systems
Burns 2011	Although this was an RCT using 1 implant system, different numbers of implants were used
Cehreli 2010b	Although this was termed as an RCT, and the same number of implants was used, 2 different implant systems were used each with different attachment systems Note: authors advised that this was a retrospective study as see excluded from Esposito 2014

Study	Reason for exclusion
de Souza 2015	Although this was an RCT, different implant systems were used, different numbers of implants were used with different attachment systems
ELsyad 2012	The RCT compares between 2 subtypes of bar attachment, and not between the main attachment system types (ball/stud, magnetic, telescopic or bar attachment systems) listed under Types of interventions
Gotfredsen 2000	The study did not use the same number of implants in all included participants. Study classified as an RCT, and even though termed a randomised prospective study, no details on method of random sequence generation, allocation concealment, participant allocation, or blinding of outcome assessment (detection bias) are included
Karabuda 2008	Not an RCT. The study also used different implant systems and different number of implants Note: see also excluded from Esposito 2014
Kleis 2010	The study compares between 2 subtypes of the ball attachment, and not between the main attachment system types (ball/stud, magnetic, telescopic or bar attachment systems) listed under Types of interventions. Study classified as not an RCT although termed as a randomised, clinical prospective study
Krennmair 2012	The study compares between 2 subtypes of the ball attachment, and not between the main attachment system types (ball/stud, magnetic, telescopic or bar attachment systems) listed under Types of interventions. Study classified as not a cross-over RCT with consecutive participants admitted to the study
Krennmair 2006	Not an RCT - participants were randomised according to their clinician treating preference
Krennmair 2008	The study compares between 2 subtypes of the bar attachment, and not between the main attachment system types (ball/stud, magnetic, telescopic or bar attachment systems) listed under Types of interventions
Krennmair 2012b	Not an RCT - participants were randomly assigned according to clinician preference
Kronstrom 2010	Although this was an RCT and 1 implant system was used, different numbers of implants were used with only 1 attachment system
Mericske-Stern 2009	Study classified as not a cross-over RCT. The study compares between 2 subtypes of the bar attachment, and not between the main attachment system types (ball/stud, magnetic, telescopic or bar attachment systems) listed under Types of interventions
Osman 2014	Although this was an RCT - it was on maxillary and mandibular overdentures with 1 implant system, using the same number of implants, there were titanium and zirconia implants used as well as only 1 attachment system used per jaw. Different attachment systems were not used in the maxilla and mandible for comparison
Payne 2000b	Study not an RCT - confirmed by author correspondence
Slot 2013	Although this was an RCT on maxillary overdentures and 1 implant system was used, different numbers of implants were used with only 1 attachment system
Slot 2014	Although this was an RCT on maxillary overdentures and 1 implant system was used, different numbers of implants were used with only 1 attachment system
Walton 2009	Although this was an RCT and 1 implant system was used, different numbers of implants were used with only 1 attachment system

Study	Reason for exclusion
Watson 2002	Although this was an RCT more than 1 implant system was used on the same number of implants comparing different attachment systems
Wismeijer 1997	Although this was an RCT using 1 implant system, different numbers of implants were used

RCT = randomised controlled trial.

DATA AND ANALYSES

Comparison 1. Ball versus bar attachment systems

Outcome or subgroup title	No. of studies	No. of participants	Statistical method	Effect size
1 Success (short term; 1 to 3 years)	2		Risk Ratio (M-H, Fixed, 95% CI)	Subtotals only
2 Re-treatment (repair) (short term; 1 to 3 years)	2	130	Risk Ratio (M-H, Fixed, 95% CI)	3.11 [1.68, 5.75]
3 Re-treatment (replace) (short term; 1 to 3 years)	2	130	Risk Ratio (M-H, Fixed, 95% CI)	1.18 [0.38, 3.71]

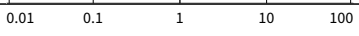
Analysis 1.1. Comparison 1 Ball versus bar attachment systems, Outcome 1 Success (short term; 1 to 3 years).

Study or subgroup	Ball n/N	Bar n/N	Risk Ratio M-H, Fixed, 95% CI	Weight	Risk Ratio M-H, Fixed, 95% CI
Kappel 2016	20/21	18/22		0%	1.16[0.94,1.45]
Walton 2002	11/45	31/42		0%	0.33[0.19,0.57]

Favours [Bar] Favours [Ball]

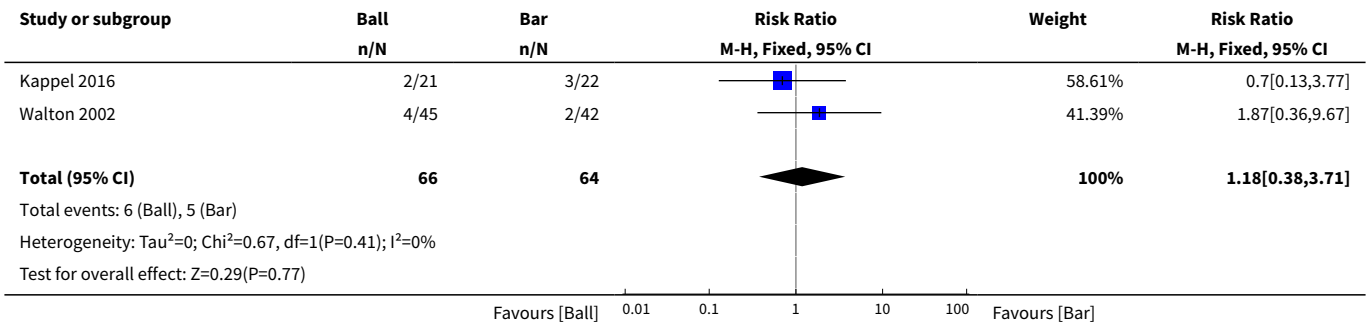
Analysis 1.2. Comparison 1 Ball versus bar attachment systems, Outcome 2 Re-treatment (repair) (short term; 1 to 3 years).

Study or subgroup	Ball n/N	Bar n/N	Risk Ratio M-H, Fixed, 95% CI	Weight	Risk Ratio M-H, Fixed, 95% CI
Kappel 2016	0/21	0/22			Not estimable
Walton 2002	30/45	9/42		100%	3.11[1.68,5.75]
Total (95% CI)	**66**	**64**		**100%**	**3.11[1.68,5.75]**
Total events: 30 (Ball), 9 (Bar)					
Heterogeneity: Not applicable					
Test for overall effect: Z=3.62(P=0)					



Favours [Ball] Favours [Bar]

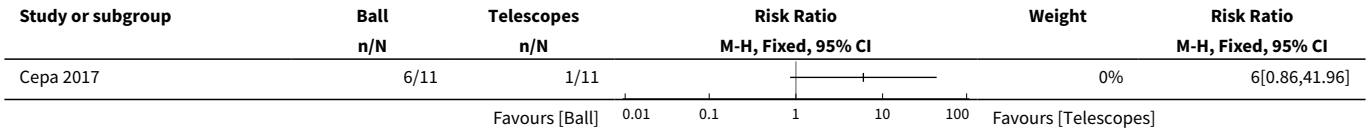
Analysis 1.3. Comparison 1 Ball versus bar attachment systems, Outcome 3 Re-treatment (replace) (short term; 1 to 3 years).



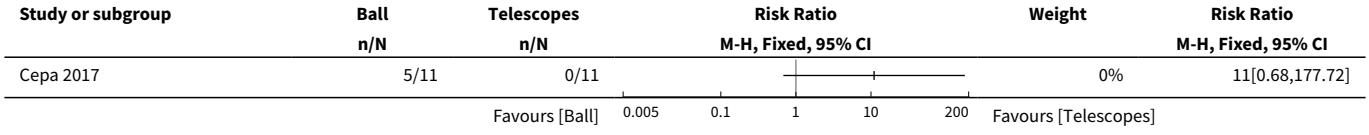
Comparison 2. Ball versus telescopic attachment systems

Outcome or subgroup title	No. of studies	No. of participants	Statistical method	Effect size
1 Patrix replaced (short term; 1 to 3 years)	1		Risk Ratio (M-H, Fixed, 95% CI)	Subtotals only
2 Matrix activated (short term; 1 to 3 years)	1		Risk Ratio (M-H, Fixed, 95% CI)	Subtotals only
3 Matrix replaced (short term; 1 to 3 years)	1		Risk Ratio (M-H, Fixed, 95% CI)	Subtotals only
4 Reline of implant overdenture (short term; 1 to 3 years)	1		Risk Ratio (M-H, Fixed, 95% CI)	Subtotals only

Analysis 2.1. Comparison 2 Ball versus telescopic attachment systems, Outcome 1 Patrix replaced (short term; 1 to 3 years).



Analysis 2.2. Comparison 2 Ball versus telescopic attachment systems, Outcome 2 Matrix activated (short term; 1 to 3 years).



Analysis 2.3. Comparison 2 Ball versus telescopic attachment systems, Outcome 3 Matrix replaced (short term; 1 to 3 years).

Study or subgroup	Ball n/N	Telescopes n/N	Risk Ratio M-H, Fixed, 95% CI	Weight	Risk Ratio M-H, Fixed, 95% CI
Cepa 2017	7/11	4/11		0%	1.75[0.71,4.31]

Analysis 2.4. Comparison 2 Ball versus telescopic attachment systems, Outcome 4 Reline of implant overdenture (short term; 1 to 3 years).

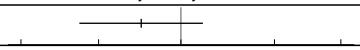
Study or subgroup	Ball n/N	Telescopes n/N	Risk Ratio M-H, Fixed, 95% CI	Weight	Risk Ratio M-H, Fixed, 95% CI
Cepa 2017	7/11	3/11		0%	2.33[0.81,6.76]

Comparison 3. Ball versus magnetic attachment systems

Outcome or subgroup title	No. of studies	No. of participants	Statistical method	Effect size
1 Success (medium term; 3 to 5 years)	1		Risk Ratio (M-H, Fixed, 95% CI)	Subtotals only
2 Re-treatment (repair) (medium term; 3 to 5 years)	1		Risk Ratio (M-H, Fixed, 95% CI)	Subtotals only
3 Costs (medium term; 3 to 5 years)	1		Mean Difference (IV, Fixed, 95% CI)	Subtotals only

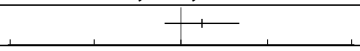
Analysis 3.1. Comparison 3 Ball versus magnetic attachment systems, Outcome 1 Success (medium term; 3 to 5 years).

Study or subgroup	Ball n/N	Magnets n/N	Risk Ratio M-H, Fixed, 95% CI	Weight	Risk Ratio M-H, Fixed, 95% CI
Cristache 2014	32/46	19/23		0%	0.84[0.64,1.1]



Analysis 3.2. Comparison 3 Ball versus magnetic attachment systems, Outcome 2 Re-treatment (repair) (medium term; 3 to 5 years).

Study or subgroup	Ball n/N	Magnets n/N	Risk Ratio M-H, Fixed, 95% CI	Weight	Risk Ratio M-H, Fixed, 95% CI
Cristache 2014	14/46	4/23		0%	1.75[0.65,4.72]



Analysis 3.3. Comparison 3 Ball versus magnetic attachment systems, Outcome 3 Costs (medium term; 3 to 5 years).

Study or subgroup	Ball		Magnets		Mean Difference	Weight	Mean Difference
	N	Mean(SD)	N	Mean(SD)	Fixed, 95% CI		Fixed, 95% CI
Cristache 2014	46	2039 (129.5)	23	2286.3 (224.1)		0%	-247.37[-346.32,-148.42]

Favours [Ball] -1000 -500 0 500 1000 Favours [Magnets]

APPENDICES

Appendix 1. Specific categories of prosthodontic maintenance for prosthodontic success

According to Payne 2001a.

1. Patrix loose. (Patrix here pertains to the patrix (ball abutment, retentive anchor, stud attachment, magnetic keeper) and/or its component screws as well as the patrix component screws of any related gold cylinders and all inter-abutment and cantilever bars/superstructures (round, ovoid, U shaped, milled, spark eroded).)
2. Patrix activated (number of occasions).
3. Patrix replaced (number of occasions unilaterally or bilaterally).
4. Patrix fractured.
5. Dislodged, worn, or loose matrix or its respective housing. (Matrix here pertains to the matrix components (O ring, resilient cap, titanium spring, gold cap attachment, magnets) as well as all types of metal alloy or plastic retention clips (single sleeve or multiple sleeve) or permanent resilient lining material, connecting to inter-abutment or cantilevered bars/superstructures.)
6. Matrix activated (number of occasions).
7. Matrix replaced (number of occasions unilaterally or bilaterally).
8. Matrix fractured.
9. Fractured implant overdenture, puncture fracture of acrylic resin over patrix, or fractured denture teeth.
10. Reline of implant overdenture.
11. New implant overdenture constructed.
12. Peri-implant or inter-abutment mucosal enlargement.

Appendix 2. 6-field protocol for prosthodontic success for implant overdentures

Field	Definition	Category (Appendix 1)
Success	Review of patient records during the study period reveals no evidence of re-treatment except 1–8, 10, 12 for accepted maintenance.[a] Number of implants,[b] support differentiation,[c] and status of the opposing arch[d] are identified	1–8, 10, 12
Survival	Patient cannot be examined directly, but the patient or another clinician confirms no evidence 1–8, 10, 12 of re-treatment except that described for a successful outcome. Number of implants,[b] support differentiation,[c] and status of the opposing arch[d] are identified	1–8, 10, 12

(Continued)

Unknown	Patient cannot be traced; surviving or successful implant overdenture removed to allow (lost to provision of a new overdenture, e.g. conversion to another overdenture design with additional follow-up) implants or a fixed implant prosthesis using the same or additional implants	-
Dead	Patient died during the study period regardless of whether successful or surviving criteria were experienced before death	-
Re-treatment (repair)	Treatment of implant overdenture and/or mucosa where marginal integrity and associated patrices/1–10, 12 (repair) matrices are maintained irrespective of modifications as long as it continues as an implant overdenture. More than 2 replacements of either patrix or matrix in the first year or more than 5 replacements in the first 5 years. Includes replacement of worn or fractured overdenture teeth/fractured overdentures, relining of overdenture more than once in 5 years, or excision of patrix associated mucosal enlargement as a result of infringement on the shoulder/undersurface of the patrix. Number of implants,[b] support differentiation,[c] and status of the opposing arch[d] are identified	1–10, 12
Re-treatment (replace)	Part or all of implant overdenture is no longer serviceable because of either loss of implants or 11 (replace) irreparable mechanical breakdown. A replacement prosthesis is indicated. Number of implants,[b] support differentiation,[c] and status of the opposing arch[d] are identified	11

[a] Includes patrix activation/repair/replacement, matrix activation/repair/replacement, and asymptomatic peri-implant/interabutment mucosal enlargement not requiring excision. There is a limit of 2 replacements of either patrix or matrix in the first year and 5 replacements in 5 years, and 1 reline of the overdenture base in 5 years.
[b] Designated as 1, 2, 3, 4, 5, or more than 5. Horseshoe designs for maxillary overdentures are identified.
[c] Designated as implant only or implant and mucosa.
[d] Designated as dentate, removable partial denture, complete denture, fixed implant prosthesis of any form, or implant overdenture. A combination of these designations is possible.

According to Payne 2001a.

Appendix 3. Cochrane Oral Health's Trials Register search strategy

#1 ((denture* and attachment*):ti,ab) AND (INREGISTER)
#2 (((denture* or implant or attach*) and (ball* or bar* or magnet* or splint* or telescopic or "double crown*")):ti,ab) AND (INREGISTER)
#3 ((attachment* and (prosthodontic* or prosthetic* or prosthes*)):ti,ab) AND (INREGISTER)
#4 (#1 or #2 or #3) AND (INREGISTER)
#5 ((dental and implant*)) AND (INREGISTER)
#6 (("mandibular implant*" or "oral implant*"):ti,ab) AND (INREGISTER)
#7 (#5 or #6) AND (INREGISTER)
#8 ((overdenture* or "over denture*" or over-denture*):ti,ab) AND (INREGISTER)
#9 (("complete denture*" or "full-upper denture*" or "full-lower denture*" or "full lower denture*" or "full upper denture*" or "full denture*"):ti,ab) AND (INREGISTER)
#10 (#8 or #9) AND (INREGISTER)
#11 (#4 and #7 and #10) AND (INREGISTER)

Appendix 4. Cochrane Central Register of Controlled Trials (CENTRAL) search strategy

#1 (denture* near/4 attachment*)
#2 ((denture* or implant* or attach*) and (ball* or bar* or magnet* or splint* or telescopic or "double crown*"))
#3 (attachment* and (prosthodontic* or prosthetic* or prothes*))
#4 #1 or #2 or #3
#5 [mh ^"Dental prosthesis, implant supported"]
#6 [mh "Dental implantation"]
#7 [mh "Dental implants"]
#8 [mh ^"Mandibular prosthesis implantation"]

#9 ((dental* and implant*) or "mandibular implant*" or "oral implant*")
#10 #5 or #6 or #7 or #8 or #9
#11 [mh "Denture complete"]
#12 (overdenture* or "over denture*" or over-denture*)
#13 ("complete denture*" or "full-upper denture*" or "full-lower denture*" or "full lower denture*" or "full upper denture*" or "full denture*")
#14 #11 or #12 or #13
#15 #4 and #10 and #14

Appendix 5. MEDLINE Ovid search strategy

1. (denture$ adj4 attachment$).mp.
2. ((denture$ or implant$ or attach$) and (ball$ or bar$ or magnet$ or splint$ or telescopic or "double crown$")).mp.
3. (attachment$ and (prosthodontic$ or prosthetic$ or prosthes$)).mp.
4. or/1-3
5. Dental prosthesis, implant-supported/
6. exp Dental implantation/
7. exp Dental implants/
8. Mandibular prosthesis implantation/
9. ((dental$ and implant$) or "mandibular implant$" or "oral implant$").mp
10. or/5-9
11. exp Denture complete/
12. (overdenture$ or "over denture$" or over-denture$).mp.
13. ("complete denture$" or "full-upper denture$" or "full-lower denture" or "full lower denture$" or "full upper denture$" or "full denture $").mp.
14. or/11-13
15. 4 and 10 and 14

This subject search was linked to the Cochrane Highly Sensitive Search Strategy (CHSSS) for identifying randomised trials in MEDLINE: sensitivity- maximising version (2008 revision) as referenced in Chapter 6.4.11.1 and detailed in box 6.4.c of the*Cochrane Handbook for Systematic Reviews of Interventions* Version 5.1.0 (updated March 2011) (Lefebvre 2011).

1. randomized controlled trial.pt.
2. controlled clinical trial.pt.
3. randomized.ab.
4. placebo.ab.
5. drug therapy.fs.
6. randomly.ab.
7. trial.ab.
8. groups.ab.
9. or/1-8
10. exp animals/ not humans.sh.
11. 9 not 10

Appendix 6. Embase Ovid search strategy

1. (denture$ adj4 attachment$).mp
2. ((denture$ or implant$ or attach$) and (ball$ or bar$ or magnet$ or splint$ or telescopic or "double crown$")).mp.
3. (attachment$ and (prosthodontic$ or prosthetic$ or prosthes$)).mp.
4. or/1-3
5. Tooth implantation/
6. Tooth implant/
7. ((dental$ and implant$) or "mandibular implant$" or "oral implant$").mp.
8. or/5-7
9. Complete denture/
10. (overdenture$ or "over denture$" or over-denture$).mp.
11. ("complete denture$" or "full-upper denture$" or "full-lower denture" or "full lower denture$" or "full upper denture$" or "full denture $").mp.
12. or/9-11
13. 4 and 8 and 12

This subject search was linked to an adapted version of the Cochrane Centralised Search Project filter for identifying RCTs in Embase Ovid (see www.cochranelibrary.com/help/central-creation-details.html for information):

1. Randomized controlled trial/
2. Controlled clinical study/
3. Random$.ti,ab.
4. randomisation/
5. intermethod comparison/
6. placebo.ti,ab.
7. (compare or compared or comparison).ti.
8. ((evaluated or evaluate or evaluating or assessed or assess) and (compare or compared or comparing or comparison)).ab.
9. (open adj label).ti,ab.
10. ((double or single or doubly or singly) adj (blind or blinded or blindly)).ti,ab.
11. double blind procedure/
12. parallel group$1.ti,ab.
13. (crossover or cross over).ti,ab.
14. ((assign$ or match or matched or allocation) adj5 (alternate or group$1 or intervention$1 or patient$1 or subject$1 or participant $1)).ti,ab.
15. (assigned or allocated).ti,ab.
16. (controlled adj7 (study or design or trial)).ti,ab.
17. (volunteer or volunteers).ti,ab.
18. trial.ti.
19. or/1-18
20. (exp animal/ or animal.hw. or nonhuman/) not (exp human/ or human cell/ or (human or humans).ti.)
21. 19 not 20

Appendix 7. US National Institutes of Health Ongoing Trials Register (ClinicalTrials.gov) and World Health Organization International Clinical Trials Registry Platform search strategy

implant AND attachment AND overdenture

CONTRIBUTIONS OF AUTHORS

The specific tasks specified for the review authors are as follows.

Task	Who has agreed to undertake the task?
Draft the protocol	Alan GT Payne, Joanne Walton, Nabeel HM Alsabeeha, Marco Esposito, Helen Worthington
Develop a search strategy	Alan GT Payne, Anne Littlewood
Search for trials	Alan GT Payne, Nabeel HM Alsabeeha, Momen A Atieh, Sunyoung Ma
Obtain copies of trials	Alan GT Payne, Nabeel HM Alsabeeha
Select which trials to include	Alan GT Payne, Nabeel HM Alsabeeha, Momen A Atieh, Marwah Anas El-Wegoud
Extract data from trials	Alan GT Payne, Marwah Anas El-Wegoud, Momen A Atieh, Nabeel HM Alsabeeha
Enter data into Review Manager	Marwah Anas El-Wegoud
Carry out the analysis	Marwah Anas El-Wegoud
Create GRADE 'Summary of findings' table	Marwah Anas El-Wegoud
Interpret the analysis	Alan GT Payne, Marwah Anas El-Wegoud, Momen A Atieh
Draft the final review	Alan GT Payne, Marwah Anas El-Wegoud, Nabeel HM Alsabeeha, Momen A Atieh, Sunyoung Ma, Marco Esposito
Update the review	Alan GT Payne, Nabeel HM Alsabeeha, Marwah Anas El-Wegoud

DECLARATIONS OF INTEREST

Alan GT Payne: none known.

Nabeel HM Alsabeeha: none known.

Momen A Atieh: none known.

Marco Esposito: from April 2011 Marco Esposito became a full-time freelance consultant in dentistry specialising in implantology. Therefore he receives funding for conducting clinical trials and presenting the results of trials/Cochrane Reviews at international dental meetings. This funding comes from universities, companies (in alphabetical order: Apollonia e Fama Implant, Biomax, Biomet 3i, Bioteck, Bone System, Branemark Integration, CMS Dental, Dentsply-Friadent, Geistlich Pharma, Geass, Keystone Dental, MegaGen Implant, Mozo-Grau, Nano Bridging molecules, Nobel Biocare, Ricerfarma, Saint Jude Medical, Southern Implants, Supercharched production, Techoss Dental Thommen Medical, Tutogen Medical, Zimmer Dental, Z-Systems), scientific societies, publishing companies, and private dentists. This list of companies was provided by Marco on Friday 4 November 2011 and the funders will change all the time. This is to certify that: a) Marco does not own stock in companies that produce products included in the reviews of which he is an author; b) he does not have patents on any of the products included in the reviews; c) his salary will not be affected by company sales of any of the products included in the reviews. Marco's authorship has been authorised by The Cochrane Collaboration Funding Arbiter (reference 071111/057: Cochrane Oral Health).

Sunyoung Ma: none known.

Marwah Anas El-Wegoud: none known.

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DIFFERENCES BETWEEN PROTOCOL AND REVIEW

- The objective has been changed to "To compare different attachment systems for maxillary and mandibular implant overdentures by assessing the prosthodontic success, prosthodontic maintenance, patient preference, patient satisfaction/quality of life and costs." It was previously "To test the null hypothesis that there is no difference in the relative effectiveness of various attachment systems for mandibular or maxillary implant overdentures or both with respect to prosthesis (overdenture) success, prosthodontic maintenance, patient satisfaction, patient preference, implant success and costs." The justification is related to being more specific about what was assessed.
- Under Types of interventions, we have specified the attachment systems of interest.
- The sequence of primary and secondary outcomes has been changed, as well as additional secondary outcomes being added. The justifications were all to be more specific. The first primary outcome has been modified to "Prosthodontic success by specific categorization (Appendix 1) and six-field protocol (Appendix 2)." It was only "prosthesis (overdenture) success" in the protocol. The second primary outcome has been modified to "Prosthodontic maintenance by general categorization." It was "Prosthodontic maintenance/technical complications/adjustments and repairs/aftercare" in the protocol. "Patient preference in cross-over trials" is now the first secondary outcome. "Patient satisfaction or quality of life assessed by a validated measure" is now the second secondary

outcome. The third secondary outcome has been changed to "cost (treatment time and/or material costs)". It was "costs" in the protocol. The protocol included "implant success" as the first secondary outcome and this has now been removed. The reason is that attachment systems are independent of the type of implants used and their peri-implant marginal/crestal bone loss. We have now also specified the time intervals for outcome assessment (short term: 1 year to 3 years; medium term: 3 years to 5 years; and long term: 5 years to 10 years).

- We have used fixed-effect meta-analysis for combining data in the review and not random-effects as indicated in the protocol.

INDEX TERMS

Medical Subject Headings (MeSH)

*Denture, Overlay; Dental Implantation [*methods]; Jaw, Edentulous [*rehabilitation]; Randomized Controlled Trials as Topic; Tooth Preparation, Prosthodontic; Treatment Outcome

MeSH check words

Humans