A systematic review and meta-analysis of removable and fixed implant-supported prostheses in edentulous jaws: post-loading implant loss

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Key words: edentulous mandible, edentulous maxilla, implant-supported prosthesis, meta-analysis, systematic review

Abstract
Objectives: The aim of this systematic review was to analyze post-loading implant loss for implant-supported prostheses in edentulous jaws, regarding a potential impact of implant location (maxilla vs. mandible), implant number per patient, type of prosthesis (removable vs. fixed), and type of attachment system (screw-retained, ball vs. bar vs. telescopic crown).

Material and methods: A systematic literature search for randomized-controlled trials (RCTs) or prospective studies was conducted within PubMed, Cochrane Library, and Embase. Quality assessment of the included studies was carried out, and the review was structured according to PRISMA. Implant loss and corresponding 3- and 5-year survival rates were estimated by means of a Poisson regression model with total exposure time as offset.

Results: After title, abstract, and full-text screening, 54 studies were included for qualitative analyses. Estimated 5-year survival rates of implants were 97.9% [95% CI 97.4; 98.4] in the maxilla and 98.9% [95% CI 98.7; 99.1] in the mandible. Corresponding implant loss rates per 100 implant years were significantly higher in the maxilla (0.42 [95% CI 0.33; 0.53] vs. 0.22 [95% CI 0.17; 0.27]; P = 0.0001). Implant loss rates for fixed restorations were significantly lower compared to removable restorations (0.23 [95% CI 0.18; 0.29] vs. 0.35 [95% CI 0.28; 0.44]; P = 0.0148). Four implants and a fixed restoration in the mandible resulted in significantly higher implant loss rates compared to five or more implants with a fixed restoration. The analysis of one implant and a mandibular overdenture also revealed higher implant loss rates than an overdenture on two implants. The same (lower implant number = higher implant loss rate) applied when comparing 2 vs. 4 implants and a mandibular overdenture. Implant loss rates for maxillary overdentures on <4 implants were significantly higher than for four implants (7.22 [95% CI 5.41; 9.64] vs. 2.31 [1.56; 3.42]; P < 0.0001).

Conclusions: Implant location, type of restoration, and implant number do have an influence on the estimated implant loss rate. Consistent reporting of clinical studies is necessary and high-quality studies are needed to confirm the present results.

Introduction and rationale
Complete edentulism still is a common health problem. Although oral health studies illustrated a decrease of individuals suffering from an edentate status, in Germany still 22.6% of 65- to 70-year olds were completely edentulous in the year 2005 (Micheelis & Schiffner 2006).

A complete denture is the classic therapy of full edentulism. Nowadays, this kind of rehabilitation might not be considered as the standard therapy for the lower edentulous jaw any longer. The stabilization of the lower denture with at least two endosseous implants is applied for more than 20 years and was recommended by Feine and co-workers in the McGill consensus statement as standard therapy in 2002 already (Feine et al. 2002a,b,c).

The diversity of problems caused by complete dentures is not a modern issue. Patients do not only complain about insufficient chewing abilities and articulation problems, but also experience psychic strain and social impairment (Albaker 2013). On the contrary, clinical studies investigating the potential impact of implant-supported prostheses on...
the oral health-related quality of life were able to show clear improvement after implants had been inserted (Zitzmann & Marinello 2000a; Allen & McMillan 2003; Scala et al. 2012; Zembari & Wismeijer 2014). It is worth mentioning that clear evidence of benefits for the patient is merely available for the edentulous lower jaw with two interforaminal implants and an overdenture compared to a complete denture. The few studies concerning patient-centered outcome for implant-supported prostheses in the maxilla indicate advantages for the patient. However, considering daily practice, it has to be assumed that the majority of patients with a maxillary complete denture do not articulate major problems.

This systematic review is an update of our own (Schley & Wolfart 2011) and other previously published reviews on the edentulous jaw. As a result of clinical diversity reasons, usually, only a limited number of studies were included in these reviews. Moreover, probably due to a lack of high-quality studies, most of them also included retrospective studies (Lambert et al. 2009; Slot et al. 2009; Heydecke et al. 2012), which are known to have a lower level of evidence. Furthermore, they either included the edentulous maxilla (Slot et al. 2009) or mandible (Payne & Solomon 2000; Rocuzzo et al. 2012; Papaspynidas et al. 2013) or pooled the results for both jaws (Papaspynidas et al. 2012). Two very interesting systematic reviews with meta-analysis were recently published (Papaspynidas et al. 2012, 2013). They focused on biologic and technical complications of fixed implant restorations in edentulous mandibles and implant and prosthodontic survival rates of both jaws and reported an implant survival rate of 97.3% after 10 years.

There is still a large variety of opinions on the best rehabilitation of an edentulous patient. The patient’s wish and his or her individual circumstances, which also include financial capacities, have first priority in the decision-making. The anatomic situation and the dentist’s knowledge, that is his or her internal evidence, determine the further procedure. Nowadays, the insertion and/or restoration of dental implants in edentulous jaws can considered to be one of the basic treatment modalities in a dentist’s everyday practice. Therefore, it seems to be essential to define reproducible treatment protocols that support the individual’s expertise and help to establish clear concepts in the sense of an evidence-based dentistry.

The “optimal” number of implants for edentulous jaws still seems to be debatable. Different reviews tried to address this question (Lambert et al. 2009; Slot et al. 2009; Rocuzzo et al. 2012) and a recently published clinical guideline at least provided key recommendations concerning number of implants and type of implant prosthesis for the edentulous maxilla (Schley & Wolfart 2011; Schley et al. 2013).

To the authors’ best knowledge, the potential influence of several factors (not only implant number) on the outcome of dental implants in edentulous patients has not been systematically elaborated, statistically analyzed and compared for both fixed and removable restorations for maxilla and mandible in one review.

Thus, the aim of this systematic review was to address the following focused question:

Is there an impact of implant location (maxilla vs. mandible), implant number, type of prosthesis (fixed vs. removable) and/or different anchorage systems on the implant loss rate concerning the implant-prosthodontic rehabilitation of edentulous patients?

Material and methods

Protocol
Prior to the systematic literature search, a review protocol was determined with the software Review Manager, version 5.2.

Structure of the review
The systematic review was edited according to the “Preferred Reporting Items for Systematic Reviews and Meta-Analyses” (PRISMA) (Moher et al. 2009).

Eligibility criteria
The focused question was formulated according to the PICOS format, as suggested by the Center for Evidence-Based Medicine and served as a basis for the systematic literature search (Askig Focused Questions 2014):

Patients: edentulous patients (both jaws or either upper or lower jaw) with an implant-retained fixed or removable prosthesis;

Interventions: insertion of either machined or rough-surfaced endosseous titanium implants with a root-like or cylindrical form, irrespective of implant number, length, diameter, position, or angulation, into either local or augmented bone, prosthodontic rehabilitation with a fixed full-arch bridge, segmented reconstructions or a removable overdenture according to an immediate, early or conventional loading protocol.

Comparisons: comparison of different types of prostheses (fixed vs. removable) and/or anchorage systems (ball/locator, bar, telescopic crowns) or fixation mode (screw-retained/cemented) with different implant numbers, in one or between both jaws.

Outcomes: implant survival rate or number of implant losses after prosthetic loading after an observation period of at least 3 years.

Study design: randomized-controlled trials (RCTs) or prospective clinical studies as reported by the authors.

Definitions: A prosthesis not being detachable by the patient himself was defined as “fixed prosthesis,” that is, screw-retained or cemented fixed full-arch or segmented prostheses. An overdenture retained by different anchorage systems (bar, ball/locator or telescopic crown), and accordingly being removable by the patient, was defined as “removable prosthesis.” Regarding different implant surfaces merely a simple distinction between machined and so-called rough implant surfaces was made. A further differentiation of roughening methods or surface modifications, respectively, was not applicable. The loading protocols were defined according to Esposito et al. (2007), that is, an immediate loading was considered to be within 1 week after implant insertion, an early loading between 1 weeks and 2 months, and a conventional loading after a healing period of more than 2 months.

An implant being still in situ with a bony anchorage after the observation period was defined as “implant survival,” irrespective of hard or soft tissue condition around the implant. Prosthetic loading (immediate or after a conventional healing period) was defined as baseline, meaning, that so-called early losses, that is losses before prosthetic loading, were noted but not statistically evaluated.

Exclusion criteria: no clinical study, retrospective studies, observation period of <3 years, no mean observation period or detailed information on time of implant loss/dropout, no separate reporting of maxilla and mandible or fixed and removable prostheses, provisional implants, ceramic implants, or implants placed into the pterygomaxillary, zygomatic or palatal region, transmandibular implants, studies reporting on the same patient cohort more than once.
Information sources
The electronic databases of Medline (PubMed), Cochrane Library, and Embase were searched. A supplementary manual search in different German dental journals (Deutsche Zahnärztliche Zeitschrift, Implantologie, Quintessenz, Zeitschrift für Zahnärztliche Implantologie), reference lists of available publications, and private databases (End Note libraries) was conducted. Authors of available studies were contacted per mail in case of unclear data.

May 7, 2014 was the last date of search. (Table 1).

Search strategy
The search strategy is described in Table 1. The PubMed search complied with the PICOS question addressing Patients, Intervention, Comparison, Outcome and Study design.

Study selection
The resulting initial hits of the above-mentioned search were screened, and a first pre-screening by title was undertaken. Titles were sequentially excluded if they indicated a non-relevant content (e.g., no dental implants, animal or in vitro study). In case of any uncertainty, an additional abstract reading was performed. Abstracts of the selected titles were inspected for relevance resulting in a choice of possibly eligible full texts. If studies were published by the same author or institution several times, the according manuscripts were thoroughly read and compared to avoid the inclusion of duplicate data. After full-text selection and data extraction, it was decided whether the publication was adequate for the intended systematic review.

Study selection and data extraction were performed independently by two reviewers (JSK, TK), and any disagreement was solved by discussion. To assess consistency among the reviewers, the interviewer reliability using Cohen’s Kappa statistic was analyzed.

Data collection and data items
Extracted data were filled into pre-defined forms and included the following parameters: author, year, total number of patients/prostheses investigated, observation period, total number of implants, number and time of dropouts on implant level, number of implants per patient, type of implant prostheses, type of anchorage system, implant survival and implant losses before and after loading. Moreover, implant system, implant surface, loading protocol, and bone augmentation procedures were noted. All variables were pre-determined and no additional variables were added after the reviewing had started.

Risk of bias within and across studies
A potential risk of bias within the included studies was assessed using the methodology checklists provided by the Scottish Intercollegiate Guidelines Network (SIGN). These lists comprise the critical appraisal of the selection of subjects, the applied assessment, potential confounders, and the statistical analysis, and finally, the overall assessment of the methodological quality of the study:

- High quality: {++} Majority of criteria met. Little or no risk of bias. Results unlikely to be changed by further research.
- Acceptable quality: {+} Most criteria met. Some flaws in the study with an associated risk of bias. Conclusions may change in the light of further studies.
- Low quality: {−} Either most criteria not met, or significant flaws relating to key aspects of study design. Conclusions likely to change in the light of further studies.

Further explanations are shown as footnote of Table 2.
A special assessment of possible publication bias or selective reporting was not performed. There were no clues indicating that data within studies were missing. Several studies were industrially sponsored.

Summary measures and synthesis of results
In the majority of included studies, the investigated patients were subdivided into different groups, for example, to compare different loading protocols, anchorage systems, implant numbers or implant types. Whenever possible, data of these groups were recorded separately so that the statistical analysis incorporated more study populations than indicated by the number of included studies.

The primary outcome of the meta-analysis was the estimated implant loss rate per 100 implant years in the edentulous maxilla and mandible depending on type of prosthesis [fixed or removable], type of attachment [bar/ball/telescopic crowns, screw-retained/cemented], and implant number. This rate describes, for example, the risk of an implant loss regarding 100 implants over the course of 1 year or the risk of an implant loss regarding 10 implants over 10 years.

Based on these implant loss rates, 3- and 5-year implant survival rates were estimated.

For simplification, implant numbers were categorized for both jaws. For the mandible, these categories were as follows: one implant, two implants, four implants, and ≥5 implants. For the maxilla, a subdivision was chosen as follows: <4 implants, four implants, and ≥6 implants. Whenever information on the exact implant number per patient could not be extracted, further subcategories were chosen: 2–4 implants and 4–6 in the mandible, and 5–6 implants in the maxilla. Data of these overlapping categories were used to strengthen the overall analysis, but were not included for any comparisons. The same applies to missing or not extractable information of other categories [e.g., loading protocol or implant surface, declared as “not applicable”]. Tables 3 and 4 illustrate in detail which particular category was “not applicable”. The number of included study populations for each analysis is shown in the Tables, as well.

Ball and locator attachments were summarized in one category (“ball”). The category “bar” included all types of bars. The category “telescopic crowns” included all types of double crowns.

Additional subgroup analyses were carried out to calculate the estimated implant loss rates per 100 implant years with regard to loading protocol [immediate vs. conventional] and implant surface [rough vs. machined].

According to Pietrusson et al. [2007] implant loss rates were calculated by dividing the number of events [loss after loading] by the total exposure time of the implants. The total exposure time consisted of a) the exposure time of the implants being followed for the complete observation period, b) the exposure time of the implants until loss, and c) the exposure time until an implant dropout had occurred [withdrawal for different reasons, patient’s death/illness, patient missed recall or moved]. If the explicit information on an implant was not provided, that is time of dropout or loss, the total exposure time was calculated by multiplying the number of initially inserted implants [minus losses before loading] by the mean follow-up time. Implant loss rates were calculated for every study population by dividing the number of events [post-loading losses] by the total implant exposure time in years.

A Poisson regression models with a logarithmic link function and the logarithm of total exposure time as an offset variable were fitted to the data to obtain a cumulative estimate for the appropriate implant loss rate and a corresponding 95% confidence interval. 3- and 5-year implant survival rates and related 95% confidence limits were derived from the equation \( S(t) = e^{-\lambda t} \) where \( t \) denotes the time and \( \lambda \) the implant loss rate by assuming constant event rates over time. Comparison of loss rates in different subgroups were contrasted by descriptive \( P \)-values resulting from the correspondent Poisson regression model. Factors, which showed significant influence on implant loss in the univariate analysis, were simultaneously analyzed in a multivariate Poisson regression model. To explore possible effect modifiers, all two-way interactions between factors were evaluated within this model. The final Poisson regression model included all main effects and significant two-way interactions. \( P \)-values less than or equal to 0.05 were regarded as statistically meaningful. Due to the explorative nature of the study, no adjustment to the significance level was made. All statistical analyses were performed using the software SAS (SAS Institute Inc., Cary, NC, USA, Version 9.3).

Results

Literature search
The search strategy, as described in Figure 1 and Table 1, resulted in an initial number of 4317 titles. 3823 titles could be excluded after screening. The manual search revealed 80 further abstracts.

After filtering the abstracts and excluding the duplicates, the reviewers decided to conduct a full-text analysis of 210 publications. Fifty-six publications, describing 54 studies, could be considered for a quantitative analysis. The interreviewer agreement was found to be \( k = 0.9 \) [SD 0.098] concerning final study selection.

Study characteristics
The included clinical trials were published within an almost 20-year period (1996–2013). Ten of them investigated the edentulous maxilla, 36 the edentulous mandible, and eight investigated both jaws. Four studies were RCTs, and the rest were prospective clinical studies, sometimes described as “prospective, randomized” or “prospective, controlled” (Table 2).

In the majority of studies, observation periods between 3 and 10 years were stated, and in four studies, 11 or more years of follow-up were reported [Table 3]. Within the 54 included clinical trials, altogether 81 study populations have been investigated. Whenever subgroups were described in a study, this information is shown in Tables 4 and 5. In 30 study populations, patients were restored with fixed full-arch prostheses, and in the residual 51 study populations, patients received removable overdentures. All of the fixed, definitive prostheses had a metal framework [Au, CoCr, or Ti], veneered with acrylic resin or ceramic and were screw-retained. None of the studies reported on cemented or adhesively fixed prostheses. The removable prostheses were generally fabricated out of acrylic resin, reinforced with a metal framework or reinforcement [CoCr] and attached by different anchorage systems [ball, locator, telescopic crown as un-splitthed retention elements and different bars enabling a primary splinting].

Altogether 2368 patients received 9267 implants. Various implant types with different surface modifications were used (Table 3). All implants were titanium implants with different lengths and diameters. Implant numbers per patient varied between 1 and 6 implants in the mandible and 2 and 10 in the maxilla. The interferominal area was the preferred area for implant positioning in the mandible. If only one implant was inserted in the edentulous lower jaw, it was located in the midline symphysis, representing the absolute minimal treatment concept. In the maxilla, implant positions...
Table 2. Risk of bias within studies

| Studies in alphabetical order | Study design      | Overall assessment of the study* | Level of evidence† | Sponsoring/support as reported by the authors                                                                 |
|-------------------------------|-------------------|----------------------------------|--------------------|---------------------------------------------------------------------------------------------------------------|
| Agliardi et al. (2012)        | Prospective       | +                                | 2+                 | n.r.                                                                                                          |
| Akca et al. (2010)            | Prospective       | +                                | 2+                 | Partly supported by State Planning Organization, Prime Ministry, Republic of Turkey                            |
| Akoglu et al. (2011)          | Prospective       | ++                               | 2+++               | n.r.                                                                                                          |
| Arvidson et al. (1998)        | Prospective       | +                                | 2+                 | Partly supported by Astra Tech, Sweden                                                                       |
| Arvidson et al. (2008)        | Prospective       | ++                               | 2+++               | Supported and sponsored by Institut Straumann AG, Basel, Switzerland                                         |
| Behneke et al. (2002)         | Prospective       | +                                | 2+                 | Financially supported by FRIADENT GmbH, Germany, provided kits for IL-1 composite genotype tests               |
| Bergendal & Engquist (1998)   | Prospective       | +                                | 2+                 | Study was self-funded by the authors and their institution                                                  |
| Cehreli et al. (2010)         | RCT               | +                                | 1+                 | Partly supported by the Prime Ministry, Republic of Turkey                                                  |
| Chiapasco & Gatti (2003)      | Prospective       | +                                | 2+                 | n.r.                                                                                                          |
| Collaert & De Bruyn (2008)    | Prospective       | +                                | 2+                 | n.r.                                                                                                          |
| Cooper et al. (2008)          | Prospective       | ++                               | 2+++               | n.r.                                                                                                          |
| Cordioli et al. (1997)        | Prospective       | +                                | 2+                 | Financially supported by FRIADENT GmbH, Germany, provided kits for IL-1 composite genotype tests               |
| Covani et al. (2012)          | Prospective       | +                                | 2+                 | n.r.                                                                                                          |
| Crespi et al. (2012)          | Prospective       | +                                | 2+                 | Financially supported by FRIADENT GmbH, Germany, provided kits for IL-1 composite genotype tests               |
| De Bruyn et al. (2008)        | Prospective       | +                                | 2+                 | n.r.                                                                                                          |
| De Santis et al. (2012)       | Prospective       | +                                | 2+                 | Financially supported by FRIADENT GmbH, Germany, provided kits for IL-1 composite genotype tests               |
| Degidi et al. (2010)          | Prospective       | +                                | 2+                 | Financially supported by FRIADENT GmbH, Germany, provided kits for IL-1 composite genotype tests               |
| Ekelund et al. (2003)/        | Prospective       | +                                | 2+                 | Financially supported by FRIADENT GmbH, Germany, provided kits for IL-1 composite genotype tests               |
| Lindquist et al. (1996)       | Prospective, randomized | +                       | 2+                 | Financially supported by FRIADENT GmbH, Germany, provided kits for IL-1 composite genotype tests               |
| Eliasson et al. (2010)        | Prospective, randomized | +                       | 2+                 | Financially supported by FRIADENT GmbH, Germany, provided kits for IL-1 composite genotype tests               |
| Gotfredsen & Holm (2000)      | Prospective, randomized | +                       | 2+                 | Financially supported by FRIADENT GmbH, Germany, provided kits for IL-1 composite genotype tests               |
| Harder et al. (2011)          | Prospective       | +                                | 2+                 | Financially supported by FRIADENT GmbH, Germany, provided kits for IL-1 composite genotype tests               |
| Heijdenrijk et al. (2006)     | Prospective, randomized | +                       | 2+                 | Financially supported by FRIADENT GmbH, Germany, provided kits for IL-1 composite genotype tests               |
| Heschl et al. (2013)          | Prospective       | +                                | 2+                 | Financially supported by FRIADENT GmbH, Germany, provided kits for IL-1 composite genotype tests               |
| Jemt et al. (1996)/           | Prospective       | +                                | 2+                 | Financially supported by FRIADENT GmbH, Germany, provided kits for IL-1 composite genotype tests               |
| Watson et al. (1997)          | RCT               | +                                | 1+                 | Financially supported by FRIADENT GmbH, Germany, provided kits for IL-1 composite genotype tests               |
| Krennmaier et al. (2008)      | Prospective, randomized | +                       | 2+                 | Study was self-funded by the authors and their institution                                                  |
| Krennmaier et al. (2011)      | Prospective, randomized | +                       | 2+                 | Study was self-funded by the authors and their institution                                                  |
| Krennmaier et al. (2012)      | Prospective, randomized | +                       | 2+                 | Study was self-funded by the authors and their institution                                                  |
| Leitner & Koenig (2011)       | Prospective       | +                                | 2+                 | Study was self-funded by the authors and their institution                                                  |
| Liddelomy & Henry (2010)      | Prospective       | +                                | 2+                 | Study was self-funded by the authors and their institution                                                  |
| Lorenzoni et al. (2013)       | Prospective       | +                                | 2+                 | Financially supported by FRIADENT GmbH, Germany, provided kits for IL-1 composite genotype tests               |
| Meijer et al. (2004)          | RCT               | +                                | 1+                 | Financially supported by FRIADENT GmbH, Germany, provided kits for IL-1 composite genotype tests               |
| Meijer et al. (2009a)         | Prospective       | +                                | 2+                 | Financially supported by FRIADENT GmbH, Germany, provided kits for IL-1 composite genotype tests               |
| Meijer et al. (2009b)         | Prospective       | +                                | 2+                 | Financially supported by FRIADENT GmbH, Germany, provided kits for IL-1 composite genotype tests               |
| Mertens et al. (2012)         | Prospective       | +                                | 2+                 | Financially supported by FRIADENT GmbH, Germany, provided kits for IL-1 composite genotype tests               |
| Murphy et al. (2002)          | Prospective       | +                                | 2+                 | Financially supported by FRIADENT GmbH, Germany, provided kits for IL-1 composite genotype tests               |
| Naert et al. (1998)           | Prospective       | +                                | 2+                 | Financially supported by FRIADENT GmbH, Germany, provided kits for IL-1 composite genotype tests               |
| Nyström et al. (2009a,b)      | Prospective       | +                                | 2+                 | Financially supported by FRIADENT GmbH, Germany, provided kits for IL-1 composite genotype tests               |
| Nyström et al. (2009a,b)      | Prospective       | +                                | 2+                 | Financially supported by FRIADENT GmbH, Germany, provided kits for IL-1 composite genotype tests               |
| Ortorp & Jent (2012)          | Prospective       | +                                | 2+                 | Financially supported by FRIADENT GmbH, Germany, provided kits for IL-1 composite genotype tests               |
| Rasmusson et al. (2005)       | Prospective       | +                                | 2+                 | Financially supported by FRIADENT GmbH, Germany, provided kits for IL-1 composite genotype tests               |
| Richter & Knapp (2010)        | Prospective       | +                                | 2+                 | Financially supported by FRIADENT GmbH, Germany, provided kits for IL-1 composite genotype tests               |
| Romero et al. (2004)          | Prospective       | +                                | 2+                 | Financially supported by FRIADENT GmbH, Germany, provided kits for IL-1 composite genotype tests               |
| Schwarz et al. (2010)         | Prospective       | +                                | 2+                 | Financially supported by FRIADENT GmbH, Germany, provided kits for IL-1 composite genotype tests               |
| Sjöstrom et al. (2007)        | Prospective       | +                                | 2+                 | Financially supported by FRIADENT GmbH, Germany, provided kits for IL-1 composite genotype tests               |
| Stoker et al. (2012)          | RCT               | +                                | 1+                 | Financially supported by FRIADENT GmbH, Germany, provided kits for IL-1 composite genotype tests               |
| Tertori et al. (2004)         | Prospective       | +                                | 2+                 | Financially supported by FRIADENT GmbH, Germany, provided kits for IL-1 composite genotype tests               |
| Van de Velde et al. (2007)    | Prospective       | +                                | 2+                 | Financially supported by FRIADENT GmbH, Germany, provided kits for IL-1 composite genotype tests               |
| Vroom et al. (2009)           | Prospective       | +                                | 2+                 | Financially supported by FRIADENT GmbH, Germany, provided kits for IL-1 composite genotype tests               |
| Weinlander et al. (2010)      | Prospective       | +                                | 2+                 | Financially supported by FRIADENT GmbH, Germany, provided kits for IL-1 composite genotype tests               |
| Zitzmann & Marinello (2000a,b)| Prospective       | +                                | 2+                 | Financially supported by FRIADENT GmbH, Germany, provided kits for IL-1 composite genotype tests               |
Table 2. (continued)

| Studies in alphabetical order | Study design | Overall assessment of the study* | Level of evidence† | Sponsoring/support as reported by the authors |
|-------------------------------|-------------|---------------------------------|-------------------|---------------------------------------------|
| Zou et al. (2013)             | Prospective | +                               | 2+                | Funded by Combined Engineering and Medical Project of Shanghai Jiao Tong University the National Natural Science Foundation of (YG2010M556), Science and Technology Commission of Shanghai Municipality (13ZR1424000), China (81100788, 31370983, 81371190), the Key Project of Chinese Ministry of Education (212080), Grants for Scientific Research of BSKY (XJ201109), and the Young Top-notch Talent Support Scheme from Anhui Medical University |

*How well was the study performed to minimize the risk of bias or confounding? (+) High quality (+) Acceptable (−) Low quality.
†Level of evidence according to SIGN: 1+ = well-conducted meta-analyses, systematic reviews, or RCTs with a low risk of bias; 2+ = high-quality systematic reviews of case-control or cohort studies, high-quality case-control or cohort studies with a very low risk of confounding or bias and a high probability that the relationship is causal. 2− = well-conducted case-control or cohort studies with a low risk of confounding or bias and a moderate probability that the relationship is causal; 3− = case-control or cohort studies with a high risk of confounding or bias and a significant risk that the relationship is not causal; 3 − Non-analytic studies, for example case reports, case series.

were often not described precisely. Only the following authors described the area of implant placement in more detail: Fischer & Stenberg (2012, 2013) located 5–6 implants from second premolar to second premolar. Agliardi et al. (2012) and Degidi et al. (2010) placed implants in the anterior area and (tilted) implants in the regions of the anterior and posterior sinus wall. De Santis et al. (2012) inserted 6–10 implants in the positions of former incisors, canines, premolars, and molars.

The results for fixed prostheses presented by Romeo et al. (2004) could not be considered, because only three patients had been provided with a fixed prosthesis. In another trial, the observation period was too short, and therefore, the “removable cases” had to be excluded (Zitzmann & Marinello 2000a, b). Covani et al. (2012) merely included six patients with an edentulous lower jaw, and hence, these cases were not regarded in this review. Some authors observed the same study population but reported on different clinical outcomes in different publications [surgical, periodontal, prosthetic] (Jemt et al. 1996; Watson et al. 1997; Fischer & Stenberg 2012, 2013). Their results were summarized.

Generally, criteria for the inclusion or exclusion of patients were pre-defined. For obvious reasons, these criteria were not consistent among the studies. Mostly, patients with severe diseases or uncontrolled diabetes, psychological problems, and heavy smokers were excluded. In general, the average age of the patients was between 50 and 60 years, although it is worth mentioning that mean ages were not always provided or sometimes not for all indications being investigated in one particular study (e.g., maxilla or mandible, edentulous or partially edentulous).

In the majority of studies, a 2-stage surgical procedure and a conventional loading protocol were carried out, but non-submerged healing (1-stage surgery) followed by immediate prosthetic loading was applied, as well (Table 3). Pre-implantological or simultaneous bone augmentation was reported in six studies and ranged from rather simple procedures (e.g., filling of post-extraction sites [Agliardi et al. 2012; Zou et al. 2013]) to complex reconstructions such as Le Fort I osteotomies with interpositional bone grafts (Nystrom et al. 2009b; De Santis et al. 2012) or onlay osteoplastics [Nystrom et al. 2009a; Sjostrom et al. 2007] either applied inlay, onlay, or interpositional grafting with free iliac grafts. Covani et al. (2012) partly carried out simultaneous sinus floor elevation with the osteotome technique. Richter & Knapp (2010) performed either bone splitting or bone spreading but no augmentation in case of heavy bone resorption. Three other studies (De Bruyn et al. 2008; Heschl et al. 2013; Lorenzoni et al. 2013) reported not to have applied augmentative or regenerative procedures. The rest of the studies cannot be commented as the authors did not make any statements about bone augmentation.

The examination of patients usually comprised the recording of several indices, that is, plaque indices, bleeding indices, and pocket depth. Implant stability was checked, sometimes by means of radio-frequency analysis or “damping capacity assessment” (Heschl et al. 2012). In the majority of the included studies, a radiographic examination was performed to measure marginal bone level changes. Several techniques were used for this, for example, standardized radiographic holders to achieve the highest possible reproducibility. In many cases, merely panoramic radiographs were compared.

**Overall implant survival and loss**

Results of individual patient groups

Estimated implant survival after 5 years ranged from 89.0% to 100% for fixed prostheses concerning both jaws (Tables 4 and 5). For removable prostheses, estimated survival rates of 24.9% up to 100% were calculated. The very low survival rate of 24.8%, with an associated annual implant loss rate of 27.8 per 100 implant years, is related to a very small patient group \(n = 7\) that was restored with merely 2 diameter-reduced implants and an overdenture in the edentulous maxilla (Richter & Knapp 2010).

**Synthesis of results**

Comparing the overall implant loss rate per 100 implant years for fixed vs. removable prostheses, a statistically significant difference could be assessed \(P < 0.0001\) if the category \(< 4\) implants [maxilla] was included (Tables 6 and 7). Excluding this latter category, there was also a significantly higher implant loss rate per 100 implant years comparing fixed and removable restorations \(0.23 [95\% \text{ CI 0.18; 0.29}] vs. 0.35 [95\% \text{ CI 0.28; 0.44}]\); \(P = 0.0148\).

Regarding different attachment types for overdentures in both jaws, no significant differences could be detected for ball vs. bar anchorage. The estimated implant loss rate per 100 implant years was similar \(0.34 [95\% \text{ CI 0.16; 0.72}]\) to \(0.35 [95\% \text{ CI 0.27; 0.46}]\) per 100 implant years; \(P = 0.9607\). The comparison of bar vs. telescopic crown and ball vs. telescopic crown was not possible (no implant losses, merely three study populations included [not regarding the study of Richter & Knapp (2010), as it belonged to the group \(< 4\) implants, see below]).
| Study (Year of publication) | Study design | Jaw | Type of prosthesis | Type of anchorage | Implant system (as reported by the authors) | Loading protocol | Total number of implants | Total number of prostheses | Follow-up period (years) |
|-----------------------------|--------------|-----|--------------------|-------------------|---------------------------------------------|-----------------|-----------------------|--------------------------|--------------------------|
| Agliardi et al. (2012)      | Prospective  | Maxilla | Fixed              | Screw-retained    | Bränemark, Nobel Speedy (Nobel Biocare)     | Immediate       | 192                   | 32                       | 4.6                      |
| Colaert & De Bruyn (2008)   | Prospective  | Maxilla | Fixed              | Screw-retained    | TiOblast Astra Tech (Dentsply)              | Immediate       | 195                   | 25                       | 3                        |
| De Santis et al. (2012)     | Prospective  | Maxilla | Fixed              | Screw-retained    | Xive (Dentsply)                             | Conventional    | 154                   | 20                       | 4.3                      |
| Degidi et al. (2010)        | Prospective  | Maxilla | Fixed              | Screw-retained    | Esthetic Plus SLA (Straumann)               | Immediate/ conventional | 210                   | 30                       | 3                        |
| Fischer & Stenberg (2012)   | Prospective  | Maxilla | Fixed              | Screw-retained    | Astra Tech, Dentsply Bränemark (Nobel Biocare) | Conventional    | 142                   | 24                       | 10                       |
| Mertens et al. (2012)       | Prospective  | Maxilla | Fixed              | Screw-retained    | Conventional Bränemark (Nobel Biocare)      | Conventional    | 106                   | 17                       | 11.3                     |
| Naert et al. (1998)         | Prospective  | Maxilla | Fixed              | Screw-retained    | Conventional Bränemark (Nobel Biocare)      | Conventional    | 53                    | 13                       | 3                        |
| Nyström et al. (2009b)      | Prospective  | Maxilla | Fixed              | Screw-retained    | Bränemark (Nobel Biocare) Bränemark (Nobel Biocare) | Conventional    | 167                   | 26                       | 13                       |
| Nyström et al. (2009a)      | Prospective  | Maxilla | Fixed              | Screw-retained    | Bränemark (Nobel Biocare) Bränemark (Nobel Biocare) | Conventional    | 334                   | 44                       | 11                       |
| Richter & Knapp (2010)      | Prospective  | Maxilla | Removable          | Telescopic crown, locator Screw-retained    | Osseotite (Biomet 3i)                          | Conventional    | 44                    | 27                       | 5                        |
| Sjöström et al. (2007)      | Prospective  | Maxilla | Fixed              | Screw-retained    | Bränemark (Nobel Biocare) Bränemark (Nobel Biocare) | Conventional    | 222                   | 29                       | 3                        |
| Zitzmann & Marinello (2000b)| Prospective  | Maxilla | Fixed              | Screw-retained    | Bränemark (Nobel Biocare) Bränemark (Nobel Biocare) | Conventional    | 84                    | 10                       | 3.3                      |
| Zou et al. (2013)           | Prospective  | Maxilla | Removable          | Telescopic crown, bar, locator Ball          | ITI (Straumann)                                | Conventional    | 120                   | 30                       | 3                        |
| Akoglu et al. (2011)        | Prospective  | Mandible | Removable          | ITI (Straumann), Swiss Plus (Zimmer Dental), Astra Tech (Dentsply) | Conventional    | 72                    | 36                       | 5                        |
| Arvidson et al. (1998)      | Prospective  | Mandible | Fixed              | Screw-retained    | Astra Tech (Dentsply) ITI Monotype SLA (Straumann) | Conventional    | 618                   | 107                      | 5                        |
| Arvidson et al. (2008)      | Prospective, multicenter | Mandible | Fixed              | Screw-retained    | ITI Monotype SLA (Straumann)                | Early           | 250                   | 61                       | 3                        |
| Behneke et al. (2002)       | Prospective  | Mandible | Removable          | Bar              | ITI (Straumann)                             | Conventional    | 340                   | 100                      | 5.8                      |
| Study (Year of publication) | Study design | Jaw | Type of prosthesis | Type of anchorage | Implant system (as reported by the authors) | Loading protocol | Total number of implants | Total number of prostheses | Follow-up period (years) |
|----------------------------|--------------|-----|-------------------|------------------|---------------------------------------------|-----------------|------------------------|------------------------|--------------------------|
| Cehreli et al. (2010)      | RCT          | Mandible | Removable       | Ball             | SLA (Straumann), Branemark TiUnite (Nobel Biocare) | Early           | 56                     | 28                     | 5                        |
| Chiapasco & Gatti (2003)   | Prospective  | Mandible | Removable       | Bar              | Ha-Ti (Mathys Dental), ITI (Straumann), Branemark Conical (Nobel Biocare), Frialoc (Dentsply) | Immediate       | 328                    | 82                     | 5.2                      |
| Cooper et al. (2008)       | Prospective  | Mandible | Removable       | Ball             | Friatec (Dentsply) Biomet 3i | Conventional    | 118                    | 59                     | 5                        |
| Cordioli et al. (1997)     | Prospective  | Mandible | Removable       | Bar              | Standard Branemark (Nobel Biocare)           | Conventional    | 21                     | 21                     | 5                        |
| De Bruyn et al. (2008)     | Prospective  | Mandible | Fixed           | Screw-retained  | TiOBlast Astra Tech (Dentsply)              | Immediate       | 125                    | 25                     | 3                        |
| Ekelund et al. (2003)      | Prospective  | Mandible | Fixed           | Screw-retained  | Standard Branemark (Nobel Biocare)           | Conventional    | 273                    | 47                     | 21.5                     |
| Eliasson et al. (2010)     | Prospective, randomized | Mandible | Fixed           | Screw-retained  | Paragon TPS (Zimmer Dental)                | Conventional    | 168                    | 29                     | 5                        |
| Elsyad et al. (2012)       | RCT          | Mandible | Removable       | Ball             | Spectra System Screw Plant (Implant Direct LLC) Standard Branemark, Branemark conical 1-piece, Branemark MK II (Nobel Biocare) | Immediate/ conventional | 72                     | 36                     | 3                        |
| Engquist et al. (2005)     | Prospective, controlled | Mandible | Fixed           | Screw-retained  | Standard Branemark, Branemark conical 1-piece, Branemark MK II (Nobel Biocare) | Early/ conventional | 432                    | 108                    | 3                        |
| Gotfredsen & Holm (2000)   | Prospective, randomized | Mandible | Removable       | Bar, ball       | Astra Tech (Dentsply) Camlog Promote screw line (Camlog) | Conventional    | 52                     | 26                     | 5                        |
| Harder et al. (2011)       | Prospective  | Mandible | Removable       | Ball             | CAMLOG Promote Screw Line (Camlog)          | Conventional    | 11                     | 11                     | 3.6                      |
| Heijdenrijk et al. (2006)  | Prospective, randomized | Mandible | Removable       | Bar              | IMZ TPS, solid screw TPS (Straumann) Xive S plus (Dentsply) | Conventional    | 120                    | 60                     | 5                        |
| Heschl et al. (2013)       | Prospective  | Mandible | Removable       | Bar              | IMZ TPS, solid screw TPS (Straumann) Xive S plus (Dentsply) | Conventional    | 156                    | 39                     | 5                        |
| Study (Year of publication) | Study design | Jaw | Type of prosthesis | Type of anchorage | Implant system (as reported by the authors) | Loading protocol | Total number of implants | Total number of prostheses | Follow-up period (years) |
|-----------------------------|--------------|-----|--------------------|-------------------|---------------------------------------------|------------------|--------------------------|--------------------------|--------------------------|
| Krennmair et al. (2008)     | Prospective, randomized | Mandible | Removable | Bar | IMZ (Dentsply), Frialoc (Dentsply), Camlog root line (Camlog) | Conventional | 204 | 51 | 5 |
| Krennmair et al. (2011)     | Prospective, randomized | Mandible | Removable | Ball, telescopic crown | Camlog root line (Camlog) | Conventional | 50 | 25 | 5 |
| Krennmair et al. (2012)     | Prospective, randomized | Mandible | Removable | Bar, telescopic crown | Camlog root line (Camlog) | Conventional | 204 | 51 | 3 |
| Lethaus et al. (2011)       | Prospective | Mandible | Removable | Bar | SLA (Straumann) | Early | 70 | 14 | 5 |
| Liddelow & Henry (2010)     | Prospective | Mandible | Removable | Ball | Implant | Immediate | 32 | 32 | 3 |
| Lorenzoni et al. (2013)     | Prospective | Mandible | Removable | Bar | Xive S Plus (Dentsply) | Immediate/ conventional | 160 | 40 | 5 |
| Meijer et al. (2004)        | RCT          | Mandible | Removable | Bar | IMZ (Dentsply), Bränemark (Nobel Biocare) | Conventional | 122 | 61 | 10 |
| Meijer et al. (2009b)       | Prospective | Mandible | Removable | Bar | IMZ TPS (Dentsply), Bränemark (Nobel Biocare), ITI solid screw TPS (Straumann) | Conventional | 180 | 90 | 10 |
| Meijer et al. (2009a)       | Prospective | Mandible | Removable | Bar | IMZ TPS (Dentsply) | Conventional | 180 | 60 | 10 |
| Murphy et al. (2002)        | Prospective | Mandible | Fixed | Screw-retained | Astra Tech (Dentsply) | Conventional | 131 | 26 | 5 |
| Schwarz et al. (2010)       | Prospective | Mandible | Fixed | Screw-retained | Frialoc (Dentsply), Camlog root line (Camlog) | Early | 158 | 37 | 4.5 |
| Stoker et al. (2012)        | RCT          | Mandible | Removable | n.a. | 1-stage TPS Bonefit (Straumann) | Conventional | 296 | 110 | 8.3 |
| Testori et al. (2004)       | Prospective | Mandible | Fixed | Screw-retained | Osseotite, dual acid-etched, cylindrical, screw-shaped (3i) | Immediate | 116 | 19 | 3.2 |
| Study (Year of publication) | Study design | Jaw | Type of prosthesis | Type of anchorage | Implant system (as reported by the authors) | Loading protocol | Total number of implants | Total number of prostheses | Follow-up period (years) |
|---------------------------|-------------|-----|-------------------|------------------|--------------------------------------------|----------------|--------------------------|---------------------------|--------------------------|
| Van de Velde et al. (2007)| Prospective | Mandible | Fixed            | Screw-retained   | Branemark Mk II/Mk IV (Nobel Biocare)       | Immediate     | 91                       | 18                        | 3.8                      |
| Vroom et al. (2009)       | Prospective | Mandible | Removable        | Bar              | Astra Tech turned/tioblasted (Dentsply)     | Conventional  | 80                       | 20                        | 12                       |
| Weinländer et al. (2010)  | Prospective | Mandible | Removable        | Bar              | IMZ cylindrical, Frialloc (Dentply), Camlog screw line (Camlog) | Conventional  | 252                      | 76                        | 5                        |
| Akca et al. (2010)        | Prospective | Both jaws | Removable        | Bar              | ITI SLA/TPS (Straumann)                     | Conventional  | 124                      | 35                        | 4.9                      |
| Bergendal & Engquist (1998)| Prospective | Both jaws | Removable        | Bar, ball        | Branemark (Nobel Biocare)                   | Conventional  | 115                      | 50                        | 5.2                      |
| Covani et al. (2012)      | Prospective | Both jaws | Fixed            | Screw-retained   | Ossean (Intra Lock Int)                    | Immediate     | 128                      | 16                        | 3.6                      |
| Crespi et al. (2012)      | Prospective | Both jaws | Fixed            | Screw-retained   | PAD system (Sweden-Martina)                | Immediate     | 176                      | 44                        | 3                        |
| Jemt et al. (1996)/Watson et al. (1997) | Prospective | Both jaws | Removable        | Bar              | Branemark (Nobel Biocare)                   | Conventional  | 315                      | 133                       | 5                        |
| Ortorp & Jemt (2012)      | Prospective | Both jaws | Fixed            | Screw-retained   | Branemark (Nobel Biocare)                   | Conventional  | 728                      | 129                       | 10                       |
| Rasmusson et al. (2005)   | Prospective | Both jaws | Fixed            | Screw-retained   | TiOblast Astra Tech (Dentsply)             | Conventional  | 199                      | 36                        | 10                       |
| Romeo et al. (2004)       | Prospective | Both jaws | Removable        | n.a.             | ITI SLA/TPS (Straumann)                     | Conventional  | 126                      | 37                        | 3.9                      |
Table 4. Estimated implant loss rate and corresponding implant survival for edentulous maxillae with fixed and removable prostheses categorized by number of implants per patient

| Study | Subgroups within study | Number of implants per patient | Total number of implants | Type of prosthesis and anchorage | Number of post-loading implant losses | Total implant exposure time (implant years) | Estimated implant loss (per 100 implant years) | Estimated implant survival after 5 years (%) |
|-------|------------------------|--------------------------------|--------------------------|-----------------------------------|--------------------------------------|------------------------------------------|----------------------------------------------|---------------------------------------------|
| Richter & Knapp | Locator | <4* | 14 | Removable, BL | 12 | 43.1 | 27.8 | 24.6 |
| | Telocpic crowns | 4* | 30 | Removable, TC | 18 | 119.5 | 15.1 | 47.1 |
| Bergendal & Engquist | Bar | <4* | 29 | Removable, BR | 6 | 140.3 | 4.3 | 80.7 |
| | Ball | <4* | 18 | Removable, BL | 7 | 88.0 | 8.0 | 67.2 |
| Romeo et al. | n.a. | <4* | 42 | Removable | 4 | 246.0 | 1.2 | 94.1 |
| Naert et al. | n.a. | 4 | 53 | Removable, BR | 3 | 135.9 | 2.21 | 89.4 |
| Akka et al. | n.a. | 4 | 44 | Removable, BR | 1 | 210.7 | 0.5 | 97.6 |
| Crespe et al. | n.a. | 4 | 96 | Fixed, SR | 1 | 285.3 | 0.35 | 98.3 |
| Jent/Watson et al. | n.a. | 4 | 117 | Removable, BR | 21 | 375.5 | 5.6 | 75.0 |
| Zou et al. | Telescopic crowns | 4 | 40 | Removable, TC | 0 | 120.0 | 0 | 100 |
| Agliardi et al. | n.a. | ≥6 | 192 | Fixed, SC | 0 | 120.0 | 0 | 100 |
| Fischer & Stenberg | n.a. | 5–6 | 142 | Fixed, SC | 0 | 120.0 | 0 | 100 |
| Rasmusson et al. | n.a. | 5–6 | 91 | Fixed, SC | 4 | 1095.0 | 0.4 | 98.2 |
| Collaert & De Bruyn | n.a. | 5–6 | 195 | Fixed, SC | 0 | 787.0 | 0 | 100 |
| De Santis et al. | n.a. | 5–6 | 154 | Fixed, SC | 0 | 780.0 | 0 | 100 |
| Degidi et al. | n.a. | 5–6 | 210 | Fixed, SC | 1 | 630.1 | 0.2 | 99.1 |
| Mertens et al. | n.a. | 5–6 | 90 | Fixed, SC | 2 | 1050.9 | 0.2 | 99.1 |
| Nytröm et al. | n.a. | 5–6 | 157 | Fixed, SC | 5 | 2132.0 | 0.2 | 98.8 |
| Nyström et al. | n.a. | 5–6 | 334 | Fixed, SC | 4 | 3674.0 | 0.1 | 99.5 |
| Sjöström et al. | n.a. | 5–6 | 222 | Fixed, SC | 4 | 1975.5 | 0.1 | 98.3 |
| Zitzmann & Marinello | n.a. | 5–6 | 84 | Fixed, SC | 0 | 820.0 | 0 | 100 |
| Covani et al. | n.a. | 5–6 | 128 | Fixed, SC | 0 | 460.8 | 0 | 100 |
| Ortolani et al. | n.a. | 5–6 | 355 | Fixed, SC | 17 | 2042.5 | 0.8 | 95.9 |

BL, ball; BR, bar; TC, telescopic crown; SC, screw-retained; n.a., not applicable.

*This category was excluded from further statistical analysis.

Results of individual patient groups

Concerning the estimated implant survival rates of both fixed and removable implant-supported prostheses, a significantly higher implant loss rate was estimated for fixed prostheses compared to removable prostheses. This resulted in a higher estimated implant loss rate for fixed prostheses (3.9% ± 0.15) compared to removable prostheses (3.1% ± 0.12). The difference was statistically significant (P < 0.0001).

Implant survival and loss in the maxilla

The estimated implant loss rates were higher for fixed prostheses (4.0% ± 0.15) compared to removable prostheses (2.7% ± 0.12). The difference was statistically significant (P < 0.0001).

Implant survival and loss in the mandible

The estimated implant loss rates were higher for fixed prostheses (3.6% ± 0.15) compared to removable prostheses (2.3% ± 0.12). The difference was statistically significant (P < 0.0001).

Synthesis of results and subgroup analyses

The estimated implant loss rates were higher for fixed prostheses (4.0% ± 0.15) compared to removable prostheses (2.7% ± 0.12). The difference was statistically significant (P < 0.0001).
Eligibility

The study being judged with "2 prostheses, same patient cohort at earlier stage, case report, no survival rate nor implant loss, different emphasis, not edentulous, retrospective/study design unclear, no separate reporting of edentulous jaws/removable or fixed region, no clinical examination/no regular follow-up, observation higher (fixed restoration resulted in a significantly 0.14; 0.28; 0.34 [95% CI 0.16; 0.72] vs. 0.20 [95% CI 0.16; 0.27]). No statistically significant differences were shown comparing machined vs. rough (P = 0.1745) and between mandible and maxilla in the immediate loading protocol (P = 0.0986) showed no significant differences (Table 13).

Multivariate analysis

To explore the independent effects and inter-relation between factors influencing the estimated implant loss rate, a multivariate Poisson regression model was fitted to the data of univariate meaningful factors. The first model included the location of implants, the type of prosthesis, the surface of implants, the loading protocol, and the number of implants per patient and all two-way interaction terms. Due to the sparse distribution of number of implants across the remaining factors, the Poisson regression model did not converge. Thus, the final model was reduced to the location of implants, the type of prosthesis, the surface of implants, and the loading protocol as main effects. Additionally, the significant two-way interaction between location and loading protocol remained in the model. Within this model, type of prosthesis (P < 0.0001 fixed vs. removable), surface of implants (P = 0.0001 machined vs. rough), and the interaction term between jaw and loading protocol (P = 0.0006) demonstrated significant influence on the estimated implant loss rate. From the significant interaction between jaw and loading protocol, a significant difference between conventional and immediate loading in the mandible (P < 0.0001) and between mandible and maxilla in the conventional loading protocol (P < 0.0001) followed. The comparisons between conventional and immediate loading in the maxilla (P = 0.1745) and between mandible and maxilla in the immediate loading protocol (P = 0.0986) showed no significant differences (Table 13).

Bone augmentation

The analysis of a potential impact of bone augmentation on implant loss or survival was not a part of the focused question and serves as additional information.

Studies reporting on complex augmentative procedures (e.g., Le Fort I, onlay osteoplastic with iliac graft) were already described. Bone augmentation was reported for the maxilla, exclusively. Assuming that complex procedures would have been reported if executed, a comparison of post-loading implant loss per 100 implant years revealed a significantly higher rate for non-augmented (0.93 [95% CI 0.76; 1.14; 22 study populations]) vs. augmented (0.25 [95% CI 0.16; 0.40]; 4 study populations) edentulous maxillae (P < 0.0001). Corresponding 5-year implant survival estimations were 95.45% [95% CI 94.47; 96.26] for non-augmented and 98.75% [95% CI 98.00; 99.22] for augmented.
Table 5. Estimated implant loss rate and corresponding implant survival for edentulous mandible with fixed and removable prostheses categorized by number of implants per patient

| Study                        | Number of implants per patient | Number of implants* | Type of prosthesis and anchorage | Number of post-loading implant losses | Total implant exposure time (implant years) | Estimated implant loss (per 100 implant years) | Estimated implant survival after 5 years (%) |
|------------------------------|--------------------------------|---------------------|----------------------------------|--------------------------------------|---------------------------------------------|-----------------------------------------------|-----------------------------------------------|
| Cordioli et al.              | n.a.                           | 1                   | Removable, BL                     | 0                                    | 95.0                                        | 0                                             | 100                                           |
| Harder et al.                | n.a.                           | 1                   | Removable, BL                     | 0                                    | 38.9                                        | 0                                             | 100                                           |
| Liddelow et al.              | Machined                       | 1                   | Removable, BL                     | 0                                    | 24.2                                        | 25.1                                          |                                               |
| Akoglu et al.                | Rough                          | 2                   | Removable, BL                     | 0                                    | 36.5                                        | 100                                          |                                               |
| Cehrel et al.                | n.a.                           | 2                   | Removable, BL                     | 0                                    | 360.0                                       | 0                                             | 100                                           |
| Cooper et al.                | n.a.                           | 2                   | Removable, BL                     | 0                                    | 230.0                                       | 0                                             | 100                                           |
| Elsyad et al.                | Immed. load.                   | 2                   | Removable, BL                     | 0                                    | 557.0                                       | 0                                             | 100                                           |
| Gottfredsen & Holm           | Bar                            | 2                   | Removable, BL                     | 0                                    | 92.3                                        | 4.3                                           |                                               |
| Heijlenrijk et al.           | 1-stage                        | 2                   | Removable, BL                     | 0                                    | 108.0                                       | 0                                             | 100                                           |
| Krennmair et al.             | Ball                           | 2                   | Removable, BL                     | 0                                    | 122.0                                       | 0                                             | 100                                           |
| Akoglu et al.                | IMZ                            | 2                   | Removable, BR                     | 0                                    | 536.0                                       | 0.7                                           |                                               |
| Cehrel et al.                | IMZ                            | 2                   | Removable, BR                     | 1                                    | 356.0                                       | 0.7                                           |                                               |
| Cooper et al.                | IMZ                            | 2                   | Removable, BR                     | 4                                    | 96.0                                        | 0                                             | 100                                           |
| Eskiad et al.                | IMZ                            | 2                   | Removable, BR                     | 0                                    | 94.9                                        | 0                                             |                                               |
| Gotfredsen & Holm            | Br                             | 2                   | Removable, BR                     | 0                                    | 100                                         | 0                                             |                                               |
| Meijer et al.                | IMZ                            | 2                   | Removable, BR                     | 3                                    | 560.0                                       | 0.2                                           |                                               |
| Bergendal & Engquist        | Bar                            | 2                   | Removable, BR                     | 0                                    | 108.0                                       | 0                                             | 100                                           |
| Meier et al.                 | IMZ                            | 2                   | Removable, BR                     | 1                                    | 560.0                                       | 0.2                                           |                                               |
| Meier et al.                 | IMZ                            | 2                   | Removable, BR                     | 4                                    | 96.3                                        | 0.7                                           |                                               |
| Stoker et al.                | IMZ                            | 2                   | Removable, BR                     | 0                                    | 97.9                                        | 0                                             |                                               |
| Romeo et al.                 | IMZ                            | 2                   | Removable, BR                     | 9                                    | 97.9                                        | 0                                             |                                               |
| Chiacos et al.               | IMZ                            | 2                   | Removable, BR                     | 0                                    | 97.9                                        | 0                                             |                                               |
| Engquist et al.              | 1-stage Bra/Str                | 4                   | Fixed, SC                         | 3                                    | 331.0                                       | 0.9                                           |                                               |
| 2-stage Bra/Str              | 4                               | 120                 | Fixed, SC                         | 1                                    | 243.0                                       | 0.4                                           |                                               |
| 1-stage Bra 1-piece          | 4                               | 88                  | Fixed, SC                         | 7                                    | 299.0                                       | 2.3                                           |                                               |
| 1-stage Bra Mk II            | 4                               | 104                 | Fixed, SC                         | 0                                    | 237.6                                       | 0.7                                           |                                               |
| Lorenzoni et al.             | Convent. load.                 | 4                   | Fixed, SC                         | 2                                    | 745.0                                       | 0.1                                           |                                               |
| Lorenzoni et al.             | Immed. load.                   | 4                   | Fixed, SC                         | 7                                    | 745.0                                       | 0.1                                           |                                               |
| Meier et al.                 | IMZ                            | 2                   | Removable, BR                     | 0                                    | 852.0                                       | 0.4                                           |                                               |
| Meier et al.                 | IMZ                            | 2                   | Removable, BR                     | 0                                    | 94.0                                        | 0                                             |                                               |
| Tromb et al.                 | IMZ                            | 2                   | Removable, BR                     | 0                                    | 756.0                                       | 0                                             |                                               |
| Meier et al.                 | IMZ                            | 2                   | Removable, BR                     | 0                                    | 286.0                                       | 0                                             |                                               |
| Murphy et al.                | IMZ                            | 2                   | Removable, BR                     | 0                                    | 635.0                                       | 0                                             |                                               |
| Schwarz et al.               | IMZ                            | 2                   | Removable, BR                     | 0                                    | 693.3                                       | 1.0                                           |                                               |
| Testorl et al.               | IMZ                            | 2                   | Removable, BR                     | 3                                    | 745.0                                       | 0.1                                           |                                               |
| Van de Velde et al.          | IMZ                            | 2                   | Removable, BR                     | 0                                    | 94.9                                        | 0.7                                           |                                               |
maxillae. Both groups were pooled for further analyses.

Risk of bias within and across studies

Table 2 shows the risk of bias for each study as identified by the respective SIGN check-list. According to the terms of SIGN, most of the included clinical cohort studies or RCTs were of an acceptable or high quality, meaning “some flaws in the study with an associated risk of bias” or little to no risk of bias. Selective reporting or publication bias cannot be completely ruled out, especially as some of the studies were sponsored by dental companies or a foundation being associated with a dental company.

Discussion

Summary of evidence

The objective of this systematic review and meta-analysis was to address the following question: Is there an impact of implant location (maxilla vs. mandible), implant number, type of prosthesis (fixed vs. removable) and/or different anchorage systems on the implant loss rate concerning the implant-prosthodontic rehabilitation of edentulous jaws. In summary, the data situation in each of these subgroups was comparable and did not allow for statistical analysis.

Table 5. (continued)

| Study                  | Subgroups within study | Number of implants per patient | Total number of implants | Type of prosthesis and anchorage | Number of post-loading implant losses | Total implant exposure time (implant years) | Estimated implant loss (per 100 implant years) | Estimated implant survival after 5 years (%) |
|------------------------|------------------------|-------------------------------|--------------------------|----------------------------------|---------------------------------------|---------------------------------------------|-----------------------------------------------|-----------------------------------------------|
| Ortorp et al.          | n.a.                   | ≤5                            | 373                      | Fixed, SC                        | 0                                    | 2200.0                                      | 0                                             | 100                                           |
| Rasmussen et al.       | n.a.                   | ≥5                            | 108                      | Fixed, SC                        | 0                                    | 1054.0                                      | 0                                             | 100                                           |

BL, ball; BR, bar; TC, telescopic crown; SC, screw-retained; n.a., not applicable.

Table 6. Overall comparison

| Number of study populations | Number of patients | Number of implants | Total number of post-loading implant losses | Total exposure time (implant years) | Estimated loss rate per 100 implant years [95% CI] | Estimated 3-year implant survival (%) [95% CI] | Estimated 5-year implant survival (%) [95% CI] | P-value |
|-----------------------------|--------------------|-------------------|--------------------------------------------|------------------------------------|-------------------------------------------------|-----------------------------------------------|-----------------------------------------------|---------|
| Maxilla vs. mandible        |                    |                  |                                            |                                    |                                                 |                                              |                                               |         |
| Maxilla                     | 25*                | 496               | 2850                                       | 113                                | 0.67 [0.55; 0.80]                               | 97.99 [97.60; 98.33]                           | 96.68 [96.03; 97.24]                           | -0.0001 |
| Mandible                    | 56                 | 1872              | 6417                                       | 77                                 | 0.42 [0.33; 0.53]                               | 98.76 [98.43; 99.02]                           | 97.95 [97.40; 98.38]                           | 0.0001  |
| Fixed vs. removable prostheses |               |                  |                                            |                                    |                                                 |                                              |                                               |         |
| removable                  | 51*                | 1383              | 3901                                       | 118                                | 0.55 [0.46; 0.66]                               | 98.35 [98.03; 98.62]                           | 97.27 [96.73; 97.71]                           | 0.0148  |
| removable                  | 46†                | 1354              | 3768                                       | 72                                 | 0.35 [0.28; 0.44]                               | 98.96 [98.69; 99.17]                           | 98.27 [97.82; 98.63]                           | 0.0148  |
| fixed                      | 30                 | 955               | 5306                                       | 72                                 | 0.23 [0.18; 0.29]                               | 99.31 [99.13; 99.45]                           | 98.84 [98.55; 99.08]                           | -0.0001 |

*Category ≤4 implants (maxilla) included.
†Category <4 implants (maxilla) excluded.

Risk of bias within and across studies

Table 2 shows the risk of bias for each study as identified by the respective SIGN check-list. According to the terms of SIGN, most of the included clinical cohort studies or RCTs were of an acceptable or high quality, meaning “some flaws in the study with an associated risk of bias” or little to no risk of bias. Selective reporting or publication bias cannot be completely ruled out, especially as some of the studies were sponsored by dental companies or a foundation being associated with a dental company.
for the completely edentulous maxilla (Schley & Wolfart 2011), the authors decided to perform a statistical analysis. Analyzing non-randomized, non-controlled studies raises a complex of problems and does not allow for a classical analysis in form of a forest plot that always intends to compare different intervention groups, that is, randomized-controlled trials. Furthermore, the inconsistent reporting of results among the studies complicates a meaningful analysis. The absence of exact information on implant/prosthesis loss or dropout and/or the absence of a mean observation period led to the exclusion of several articles. Hence, the authors adopted a frequently applied statistical method, suggested by Pjetursson et al. (2007) and Sailer et al. (2007) using the “total exposure time” of the investigated objects and estimating failure (or loss) and survival rates by Poisson regression. Recently, Pjetursson et al. (2014) applied the same method to describe the implant failure and the survival in a systematic review. Also, the present calculation of the “implant loss rate per 100 implant years” is based on the assumption of a constant event rate over time. The resulting “data distortion” is mainly caused by those studies with a very long or short observation period leading to an extrapolation or adaption of the available data, respectively. From a clinical point of view, this assumption is debatable; however, in the authors’ opinion, currently, it is the best method to compare the results of the different clinical studies with each other. To provide full information, the actual implant losses and observation periods are given in Tables 3–5.

Considering the focused question, it can be stated that all of the mentioned factors (jaw, implant number, type of prosthesis, and anchorage system) seem to have an impact on implant survival and implant loss. Generally, estimated implant survival was satisfactory for both, fixed and removable rehabilitation concepts. The risk for implant loss per 100 implant years in the edentulous mandible is significantly lower than in the maxilla [0.22 [95% CI 0.17; 0.27] vs. 0.41 [95% CI 0.32; 0.52]; P = 0.0001]. Regarding the direct comparisons of implant numbers in the mandible, higher numbers showed a clear tendency of resulting in lower implant loss rates. The therapeutic concept of one implant inserted into the midline symphysis in the edentulous lower jaw is an ongoing and intensively discussed topic. The present data of this concept are based on merely three studies and revealed a 5-year survival estimation of 92.1%, which is

**Table 7. Overall comparison bar vs. ball vs. telescopic crown (category <4 implants excluded)**

| Number of study populations | Number of implants | Number of post-loading implant losses | Total exposure time (implant years) | Estimated loss rate per 100 implant years [95% CI] | Estimated 3-year implant survival (%) [95% CI] | Estimated 5-year implant survival (%) [95% CI] | P-value |
|-----------------------------|-------------------|--------------------------------------|------------------------------------|-----------------------------------------------|-----------------------------------------------|-----------------------------------------------|---------|
| Ball                         | 28                | 507                                  | 2048.23                            | 0.34 [0.16; 0.72]                              | 98.31 [96.46; 99.20]                            | 98.20 [96.46; 99.20]                            | 0.9607  |
| Bar                          | 28                | 727                                  | 15494.73                           | 0.35 [0.27; 0.46]                              | 98.98 [97.87; 99.51]                            | 98.96 [97.73; 98.66]                            | 0.9607  |
| Telescopic crown            | 3                 | 169                                  | 15494.73                           | 0.35 [0.27; 0.46]                              | 98.96 [97.87; 99.51]                            | 98.96 [97.73; 98.66]                            | 0.9607  |
| Ball                         | 28                | 507                                  | 2048.23                            | 0.34 [0.16; 0.72]                              | 98.31 [96.46; 99.20]                            | 98.20 [96.46; 99.20]                            | 0.9607  |
| Bar                          | 28                | 727                                  | 15494.73                           | 0.35 [0.27; 0.46]                              | 98.98 [97.87; 99.51]                            | 98.96 [97.73; 98.66]                            | 0.9607  |

**Table 8. Comparison in the maxilla**

| Number of study populations | Number of patients | Number of implants | Number of post-loading implant losses | Total exposure time (implant years) | Estimated loss rate per 100 implant years [95% CI] | Estimated 3-year implant survival (%) [95% CI] | Estimated 5-year implant survival (%) [95% CI] | P-value |
|-----------------------------|--------------------|--------------------|--------------------------------------|------------------------------------|-----------------------------------------------|-----------------------------------------------|-----------------------------------------------|---------|
| Fixed vs. removable prostheses (category <4 implants excluded) | 14                 | 363                | 25                                  | 19500.26                            | 0.28 [0.20; 0.39]                              | 99.16 [98.84; 99.39]                            | 99.09 [98.74; 99.35]                            | <0.0001 |
| Removable: <4 implants vs. 4 implants | 6                  | 283                | 25                                  | 1082.10                            | 2.31 [1.56; 3.42]                              | 93.30 [98.91; 99.41]                            | 93.30 [98.87; 99.38]                            | <0.0001 |
| Fixed: ≥6 (no comparison feasible) | 13                 | 928                | 28                                  | 15060.08                           | 0.28 [0.20; 0.39]                              | 98.52 [97.48; 99.56]                            | 99.09 [98.74; 99.35]                            | 0.2476  |

**Table 9. Overall comparison bar vs. ball vs. telescopic crown (category <4 implants excluded)**

| Number of study populations | Number of implants | Number of post-loading implant losses | Total exposure time (implant years) | Estimated loss rate per 100 implant years [95% CI] | Estimated 3-year implant survival (%) [95% CI] | Estimated 5-year implant survival (%) [95% CI] | P-value |
|-----------------------------|--------------------|--------------------------------------|------------------------------------|-----------------------------------------------|-----------------------------------------------|-----------------------------------------------|---------|
| Ball                         | 13                 | 507                                  | 2048.73                            | 0.34 [0.16; 0.72]                              | 98.31 [96.46; 99.20]                            | 98.20 [96.46; 99.20]                            | 0.9607  |
| Bar                          | 28                | 727                                  | 15494.73                           | 0.35 [0.27; 0.46]                              | 98.98 [97.87; 99.51]                            | 98.96 [97.73; 98.66]                            | 0.9607  |
| Telescopic crown            | 3                 | 169                                  | 15494.73                           | 0.35 [0.27; 0.46]                              | 98.96 [97.87; 99.51]                            | 98.96 [97.73; 98.66]                            | 0.9607  |
| Ball                         | 28                | 507                                  | 2048.73                            | 0.34 [0.16; 0.72]                              | 98.31 [96.46; 99.20]                            | 98.20 [96.46; 99.20]                            | 0.9607  |
| Bar                          | 28                | 727                                  | 15494.73                           | 0.35 [0.27; 0.46]                              | 98.98 [97.87; 99.51]                            | 98.96 [97.73; 98.66]                            | 0.9607  |
| Telescopic crown            | 3                 | 169                                  | 15494.73                           | 0.35 [0.27; 0.46]                              | 98.96 [97.87; 99.51]                            | 98.96 [97.73; 98.66]                            | 0.9607  |
| Ball                         | 28                | 507                                  | 2048.73                            | 0.34 [0.16; 0.72]                              | 98.31 [96.46; 99.20]                            | 98.20 [96.46; 99.20]                            | 0.9607  |
Table 9. Comparison in the mandible

| Study Type          | Number of Patients | Number of Implants | Number of Study Populations | Total Number of Implants | Total Exposure Time (Implant Years) | Estimated 3-Year Implant Survival (%) [95% CI] | Estimated 5-Year Implant Survival (%) [95% CI] | P-value |
|---------------------|--------------------|--------------------|-----------------------------|--------------------------|-----------------------------------|-----------------------------------------------|-----------------------------------------------|---------|
| Fixed vs. removable prostheses | Fixed: 4 implants vs. 5 implants | 4 6 | 189 762 | 16 200 | 4.85 | 0.80 [0.49; 1.30] | 97.63 [96.17; 98.54] | 96.10 [93.69; 97.59] | 0.0001 |
|                     | Removable: 1 implant vs. 2 implants | 1 4 | 66 66 | 3 182 | 2.81 | 1.64 [0.53; 5.09] | 95.20 [85.94; 98.42] | 92.17 [77.63; 97.38] | 0.0001 |
|                     | Removable: 2 implants vs. 4 implants | 2 19 | 557 1134 | 24 724.90 | 0.33 [0.22; 0.49] | 99.36 [98.53; 99.34] | 98.30 [97.38; 99.31] | 0.0007 |
| Fixed: 4 implants vs. removable prostheses | Fixed: 4 implants vs. removable prostheses | 10 365 | 1366 | 8 697 | 1.25 | 0.11 [0.06; 0.23] | 99.66 [99.31; 99.82] | 99.42 [98.86; 99.70] | 0.0001 |
|                     | Removable: 2 implants vs. removable prostheses | 4 10 | 365 1366 | 8 697 | 1.25 | 0.11 [0.06; 0.23] | 99.66 [99.31; 99.82] | 99.42 [98.86; 99.70] | 0.0001 |

Table 10. Comparison bar vs. ball vs. telescopic crown for mandible

| Study Type          | Number of Patients | Number of Implants | Number of Study Populations | Total Number of Implants | Total Exposure Time (Implant Years) | Estimated 3-Year Implant Survival (%) [95% CI] | Estimated 5-Year Implant Survival (%) [95% CI] | P-value |
|---------------------|--------------------|--------------------|-----------------------------|--------------------------|-----------------------------------|-----------------------------------------------|-----------------------------------------------|---------|
| Ball                | 13                 | 257                | 64                          | 2533                     | 14526.73                          | 98.98 [97.87; 99.51] | 98.41 [97.95; 99.59] | 0.1499 |
| Bar                 | 24                 | 864                | 37                          | 2533                     | 14526.73                          | 98.98 [97.87; 99.51] | 98.41 [97.95; 99.59] | 0.1499 |
| Telescopic crown    | 24                 | 864                | 37                          | 2533                     | 14526.73                          | 98.98 [97.87; 99.51] | 98.41 [97.95; 99.59] | 0.1499 |
| Ball                | 13                 | 257                | 64                          | 2533                     | 14526.73                          | 98.98 [97.87; 99.51] | 98.41 [97.95; 99.59] | 0.1499 |
| Bar                 | 24                 | 864                | 37                          | 2533                     | 14526.73                          | 98.98 [97.87; 99.51] | 98.41 [97.95; 99.59] | 0.1499 |
| Telescopic crown    | 24                 | 864                | 37                          | 2533                     | 14526.73                          | 98.98 [97.87; 99.51] | 98.41 [97.95; 99.59] | 0.1499 |

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satisfactory. Nevertheless, implant loss rates for two and four implants with an overdenture were significantly lower, and data were predicated on 19 and 10 patient groups, respectively. The “gold-standard concept” of two implants with an overdenture seems to be consolidated by the analyses of this systematic review, regarding post-loading implant survival, exclusively. Only 21 studies could be included regarding the edentulous upper jaw, rendering extensive statistical comparisons difficult. However, the present analyses clearly indicate that at least four implants are needed in the edentulous maxilla, irrespective of the type of restoration. Less than four implants have been suggested not to be feasible for the edentulous maxilla in an experts’ consensus conference and is not recommendable at the time being (Schley et al. 2013). This fact was proven by the present analysis that revealed unacceptable survival estimations after 5 years (69.7% [95% CI 61.75; 76.30]) and significantly higher implant loss rates per 100 implant years when compared to implant numbers of four and more [7.22 [95% CI 5.41; 9.64] vs. 2.31 [95% CI 1.56; 3.42]; P < 0.0001). Therefore, it was decided to merely include this group for an overall survival analysis, but to exclude it from further statistical evaluations and comparisons. No statistically significant differences for post-loading implant loss could be assessed when comparing bar or ball anchorage. Estimated implant survival was very high for both attachment types (ball: 98.31% [95% CI 96.46; 99.20]; bar: 98.27 [95% CI 97.73; 98.66]). Telescopic crowns could not be evaluated, as the included number of studies was too low, and no implant losses had occurred after observation periods of 3 years. Furthermore, no statements can be made regarding cemented or adhesively luted fixed restorations as the systematic literature review did not reveal such studies. Considering the so-called all-on-4 concept, meaning four implants being restored with a fixed prosthesis, the existing literature provides sufficient evidence for the edentulous mandible. Crespi et al. (2012) also implemented this concept for the edentulous maxilla and reported an implant survival of 98.96% after 3 years. Further evidence for the edentulous upper jaw, rendering the existing literature provides sufficient evidence for the edentulous mandible. Crespi et al. (2012) also implemented this concept for the edentulous maxilla and reported an implant survival of 98.96% after 3 years. Further evidence for the edentulous maxilla, irrespective of the type of restoration. Less than four implants have been suggested not to be feasible for the edentulous maxilla in an experts’ consensus conference and is not recommendable at the time being (Schley et al. 2013). This fact was proven by the present analysis that revealed unacceptable survival estimations after 5 years (69.7% [95% CI 61.75; 76.30]) and significantly higher implant loss rates per 100 implant years when compared to implant numbers of four and more [7.22 [95% CI 5.41; 9.64] vs. 2.31 [95% CI 1.56; 3.42]; P < 0.0001). Therefore, it was decided to merely include this group for an overall survival analysis, but to exclude it from further statistical evaluations and comparisons. No statistically significant differences for post-loading implant loss could be assessed when comparing bar or ball anchorage. Estimated implant survival was very high for both attachment types (ball: 98.31% [95% CI 96.46; 99.20]; bar: 98.27 [95% CI 97.73; 98.66]). Telescopic crowns could not be evaluated, as the included number of studies was too low, and no implant losses had occurred after observation periods of 3 years. Furthermore, no statements can be made regarding cemented or adhesively luted fixed restorations as the systematic literature review did not reveal such studies. Considering the so-called all-on-4 concept, meaning four implants being restored with a fixed prosthesis, the existing literature provides sufficient evidence for the edentulous mandible. Crespi et al. (2012) also implemented this concept for the edentulous maxilla and reported an implant survival of 98.96% after 3 years. For obvious reasons, this one study could not be used for statistical comparisons. However, retrospective clinical studies demonstrate comparable results (Malo et al. 2011, 2012). Additional subgroup analyses were conducted regarding the aspects implants surface (machined vs. rough) and different loading protocols. Different surface roughness values...
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Table 11. Estimated loss rates per 100 implant years [95% CI] and survival (%) [95% CI] for 4 implants excluded

| Surface Modification | Overall comparison | Mandible (fixed and removable) |
|----------------------|--------------------|--------------------------------|
| Machined             | 97.63 [97.09; 98.02] | 96.94 [96.31; 97.07] |
| Rough                | 99.41 [95.24; 99.55] | 98.16 [97.63; 98.38] |

Limitations

The presented results have to be interpreted with the following limitations:

The estimated implant loss rates and survival estimations were mostly derived from non-comparative studies. Due to a lack of high-quality studies (i.e., RCTs), the currently best option of receiving meaningful results is to analyze the best available evidence (mostly single arm cohort studies). Our focus was on potentially influencing aspects such as implant number, loading protocol and different prosthetic treatment options. Due to the high degree of separation, a statistical analysis considering all of the potential influencing factors simultaneously was not feasible. However, a multivariate Poisson regression model concerning the location of implants, the type of prosthesis, the surface of implants, and the loading protocol as main effects, was fitted to the data of univariate meaningful factors.

Due to the observational nature of the included studies, confounding of observable, as well as unobservable factors is an intrinsic limitation of our derived results. Of course, a future aim is to analyze which combination of the above-mentioned factors is decisive, and therefore, more well-designed RCTs are needed. However, in dentistry and especially in the field of implant dentistry, several aspects such as high treatment costs, long duration of treatment, and limiting inclusion criteria (edentulous patients not being satisfied with complete overdentures) render RCTs difficult at best. It has to be recognized that CONSORT and consequently PRISMA statements or the “Cochrane Handbook” are mainly intended for medical studies and do perfectly fit for study concepts such as placebo vs. active agent. If our analysis strictly adhered to these protocols, merely a few studies would have been included thus setting a limitation, as well. In the authors’ opinion, the inclusion of 54 studies with 9267 patients can be justified (Conrad & Albrektsson 2010).

Regarding post-loading implant loss, the classical implant-prosthodontic rehabilitation concepts, that is bar- or ball-retained overdentures and screw-retained full-arch reconstructions, have shown an excellent outcome according to the present analyses. A certain number of implants seems to ensure a reliable outcome for implants with a fixed or removable restoration. However, prosthesis-related technical complications need to be taken into consideration, as well. Therefore, we plan to analyze technical complications and correlated complication-free rates for implant-supported prostheses, related to implant location and certain implant numbers, in another systematic review.
[cylindric, root-like], implant-abutment connection, bone-to-implant interface, or the difference of one- or two-piece implants could not be assessed. Furthermore, studies investigating implants in either local or augmented bone (four studies) were pooled. However, the analysis of augmented bone in the maxilla did not reveal negative results concerning estimated implant loss and corresponding survival rates. The duration of edentulism as a potential confounder could not be regarded either, but, in most studies, the “typical” completely edentate patient was subject of the investigation.

The analysis of biologic complications was not part of our focused question and explains why these complications were not evaluated in detail.

It is self-evident that the “best” choice of an implant-prosthodontic restoration, cannot simply be based on the analyzed and aforementioned aspects. Individual, patient-based circumstances determine any surgical or prosthodontic procedures. In this context, it was not possible to regard important facts such as patients’ preferences, esthetic complexity, maxillomandibular relationship, bone quality and quantity, soft tissue conditions, condition or type of restoration of the opposing jaw, or differences of treatment/manufacturing costs. Even though several authors gave information on the type of restoration in the opposite jaw (full denture, fixed or removable prosthesis), a conclusion, if implant outcome is affected by this factor, could not be evaluated.

Moreover, oral health-related quality of life (OHRQoL) is an omnipresent topic, and especially, the rehabilitation of the edentulous jaw by means of implant-prosthodontic procedures can offer a great potential of improving patients’ quality of life (Turkyilmaz et al. 2010). For the edentulous maxilla, in particular, there is a huge backlog demand for studies on OHRQoL. In this respect, Zembic & Wismeijer (2014) recently published an interesting approach. Patients received conventional complete dentures in a first step, and 2 months later, two implants were inserted – the implant-retained overdentures “provided some significant short-term improvements over conventional dentures in oral- and health-related quality of life”.

Many of the aforementioned parameters demand for a consolidated internal evidence, meaning the dentist’s experience, which serves as an important component of evidence-based medicine/dentistry. In combination with the external evidence (current state of science) and the patient’s values and

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**Table 12.** (a) Conventional loading vs. immediate loading (category < 4 implants excluded). (b) Comparison of immediate loading vs. conventional loading for mandible/fixed and mandible/removable

| Number of study populations | Number of patients | Number of implants | Total number of post-loading implant losses | Total exposure time (implant years) | Estimated loss rate per 100 implant years (95% CI) | Estimated 3-year implant survival (%) (95% CI) | Estimated 5-year implant survival (%) (95% CI) | P-value |
|-----------------------------|--------------------|-------------------|-------------------------------------------|-----------------------------------|-----------------------------------------------|-----------------------------------------------|-----------------------------------------------|---------|
| (a) Overall comparison       |                    |                   |                                           |                                   |                                               |                                               |                                               |         |
| Conventional                  | 56                 | 1773              | 5968                                      | 1269.52                          | 0.24 (0.19; 0.29)                             | 99.79 (99.71; 99.87)                           |                                               | 0.0151  |
| Immediate                     | 45                 | 361               | 3966                                      | 2469.90                          | 0.40 (0.27; 0.63)                             | 98.79 (98.63; 98.95)                           |                                               | <0.0001 |
| Fixed                         | 17                 | 598               | 1461                                      | 2891.64                          | 0.17 (0.12; 0.23)                             | 99.50 (99.33; 99.68)                           |                                               |         |
| Conventional                  | 9                  | 209               | 3691.64                                   | 2469.90                          | 0.27 (0.15; 0.50)                             | 99.19 (98.50; 99.58)                           |                                               |         |
| Immediate                     | 9                  | 209               | 3691.64                                   | 2469.90                          | 0.27 (0.15; 0.50)                             | 99.19 (98.50; 99.58)                           |                                               |         |
| Removable (maxilla and mandible) | 30               | 1175              | 3232                                      | 1788.03                          | 0.32 (0.25; 0.40)                             | 98.90 (98.65; 99.15)                           |                                               |         |
| Fixed                         | 14                 | 3512              | 2546.00                                   | 1256.60                          | 0.49 (0.38; 0.62)                             | 98.55 (98.15; 98.97)                           |                                               |         |
| Immediate                     | 10                 | 1143              | 2884.18                                   | 1288.18                          | 0.08 (0.02; 0.32)                             | 99.76 (99.04; 99.94)                           |                                               |         |
| Removable (maxilla and mandible) | 14               | 1175              | 3232                                      | 1788.03                          | 0.32 (0.25; 0.40)                             | 98.90 (98.65; 99.15)                           |                                               |         |
| Fixed                         | 14                 | 3512              | 2546.00                                   | 1256.60                          | 0.49 (0.38; 0.62)                             | 98.55 (98.15; 98.97)                           |                                               |         |
| Immediate                     | 10                 | 1143              | 2884.18                                   | 1288.18                          | 0.08 (0.02; 0.32)                             | 99.76 (99.04; 99.94)                           |                                               |         |
| Maxilla (fixed and removable) | 39                | 1175              | 3232                                      | 1788.03                          | 0.32 (0.25; 0.40)                             | 98.90 (98.65; 99.15)                           |                                               |         |
| Fixed                         | 14                 | 3512              | 2546.00                                   | 1256.60                          | 0.49 (0.38; 0.62)                             | 98.55 (98.15; 98.97)                           |                                               |         |
| Immediate                     | 10                 | 1143              | 2884.18                                   | 1288.18                          | 0.08 (0.02; 0.32)                             | 99.76 (99.04; 99.94)                           |                                               |         |
| Mandible (fixed and removable) | 5                | 1175              | 3232                                      | 1788.03                          | 0.32 (0.25; 0.40)                             | 98.90 (98.65; 99.15)                           |                                               |         |
| Fixed                         | 9                  | 2394              | 6140                                      | 3010.98                          | 0.64 (0.42; 0.97)                             | 98.12 (97.71; 98.57)                           |                                               |         |
| Immediate                     | 5                  | 2394              | 6140                                      | 3010.98                          | 0.64 (0.42; 0.97)                             | 98.12 (97.71; 98.57)                           |                                               |         |
| Mandible/fix edentate        | 5                  | 1175              | 3232                                      | 1788.03                          | 0.32 (0.25; 0.40)                             | 98.90 (98.65; 99.15)                           |                                               |         |
| Fixed                         | 9                  | 2394              | 6140                                      | 3010.98                          | 0.64 (0.42; 0.97)                             | 98.12 (97.71; 98.57)                           |                                               |         |
| Immediate                     | 5                  | 2394              | 6140                                      | 3010.98                          | 0.64 (0.42; 0.97)                             | 98.12 (97.71; 98.57)                           |                                               |         |
| Mandible/fix edentate        | 5                  | 1175              | 3232                                      | 1788.03                          | 0.32 (0.25; 0.40)                             | 98.90 (98.65; 99.15)                           |                                               |         |
| Fixed                         | 9                  | 2394              | 6140                                      | 3010.98                          | 0.64 (0.42; 0.97)                             | 98.12 (97.71; 98.57)                           |                                               |         |
| Immediate                     | 5                  | 2394              | 6140                                      | 3010.98                          | 0.64 (0.42; 0.97)                             | 98.12 (97.71; 98.57)                           |                                               |         |
wishes, a participatory decision-making process can be developed (Türp & Antes 2013). This procedure provides a reasonable degree of safety for both patient and dentist.

Conclusions

Considering the above-mentioned limitations, the following conclusions can be drawn:

- Only four of the included studies report on observation periods of more than 10 years.
- The current evaluations show a successful outcome for screw-retained fixed restorations and bar- or ball-retained overdentures in the completely edentulous jaw. Disregarding more than the included potential confounders (such as anatomic situation, bone quality, jaw relation, implant-related components) and relating to the estimated post-loading implant loss, exclusively, the following statements can be made:
  - Maxilla:
    - [a] The insertion of six or more implants for a fixed reconstruction in the maxilla reveals favorable results. Considering the “all-on-4” concept for the maxilla, one study (Crespi et al. 2012) with an acceptable level of evidence was found, revealing a satisfactory outcome. For obvious reasons, this one study could not be used for a meaningful statistical comparison.
    - [b] The insertion of four implants for a removable overdenture in the maxilla reveals satisfying results. Data on minimal concepts with <4 implants in the maxilla is scarce and demonstrated significantly worse results, calling for a cautious and controlled application of these therapeutic options.
  - Mandible:
    - [a] The insertion of four implants for a fixed restoration in the edentulous mandible reveals satisfying results. However, it has to be noticed that five or more implants showed a slightly better outcome.
    - [b] The insertion of two implants for a removable overdenture in the mandible shows favorable results. However, it has to be noticed that four implants revealed a slightly better outcome. Furthermore, four implants with a removable prosthesis had a better outcome than four implants with a fixed prosthesis in the mandible. Data on the minimal concept with only 1 implant is scarce and shows promising results. However, the results are negatively influenced when using machined-surfaced implants and an immediate loading protocol (Liddelow & Henry 2010). The application of this therapeutic option can only be recommended, when the insertion of 2 or more implants is not feasible, e.g. due to economic reasons.
  - In general:
    - [a] Implants with fixed prostheses show slightly but significantly better results than removable prostheses regarding both jaws.
    - [b] Rough-surfaced implants demonstrated favorable results compared to machined implants.

Future research

Consequential suggestions for future research: Future RCTs should investigate different attachment systems with different implant numbers, especially for 1 vs. 2 implants in the mandible and <4 implants in the maxilla. Furthermore, the comparison of 4 implants vs. >4 implants with a fixed prosthesis in the maxilla and mandible would be desirable.

General suggestions for future research: Clinical studies should not only concentrate on implant success rates but also on the patients’ benefit with regard to quality of life, improvement of mastication abilities, hygiene capability, psychological aspects, and financial considerations.

Acknowledgements: The authors would like to thank Prof. Dr. Jürgen Becker, Prof. Dr. Irena Sailer, Prof. Dr. Frank Schwarz, and Prof. Dr. Dr. Wilfried Wagner for their support.

Conflict of interest

The authors declare that they have no conflict of interest related to this article.

Source of funding

As this systematic review served as a basis for an experts’ consensus conference (7th International Expert Meeting of the CAMLOG Foundation), it was partially supported by the CAMLOG Foundation.

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Table 13. Estimates with corresponding standard errors and P-values resulting from the multivariate Poisson regression model

| Factor/Interaction                          | Estimate | Standard Error | P-value |
|---------------------------------------------|----------|----------------|---------|
| Intercept                                   | -4.7007  | 0.7327         | <0.0001 |
| Jaw                                         | 0.0108   | 0.7610         | 0.9866  |
| Type of prosthesis                         | -2.4227  | 0.1921         | <0.0001 |
| Surface of implant                         | 0.7254   | 0.1913         | 0.0001  |
| Loading protocol                           | 1.0085   | 0.7427         | 0.1745  |
| Jaw-loading protocol                       | -2.6806  | 0.7790         | 0.0006  |
| Conventional vs. immediate (mandible)      | -1.6721  | 0.2748         | <0.0001 |
| Conventional vs. immediate (maxilla)       | 1.0085   | 0.7427         | 0.1745  |
| Mandible vs. maxilla (conventional)        | -2.6698  | 0.2048         | <0.0001 |
| Mandible vs. maxilla (immediate)           | -0.9976  | 0.2677         | 0.9866  |

Post-loading implant loss in edentulous jaws

Table 13: The estimates with corresponding standard errors and P-values resulting from the multivariate Poisson regression model.
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Supporting Information

Additional Supporting Information may be found in the online version of this article:

Appendix S1. PRISMA 2009 Checklist.