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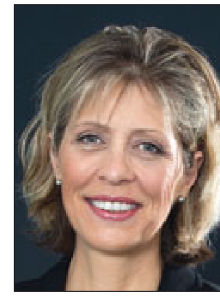
Optimal number of oral implants for fixed reconstructions: A review of the literature



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Background and aim: So far there is little evidence from randomised clinical trials (RCT) or systematic reviews on the preferred or best number of implants to be used for the support of a fixed prosthesis in the edentulous maxilla or mandible, and no consensus has been reached. Therefore, we reviewed articles published in the past 30 years that reported on treatment outcomes for implant-supported fixed prostheses, including survival of implants and survival of prostheses after a minimum observation period of 1 year.
Material and methods: MEDLINE and EMBASE were searched to identify eligible studies. Short and long-term clinical studies were included with prospective and retrospective study designs to see if relevant information could be obtained on the number of implants related to the prosthetic technique. Articles reporting on implant placement combined with advanced surgical techniques such as sinus floor elevation (SFE) or extensive grafting were excluded. Two reviewers extracted the data independently.
Results: A primary search was broken down to 222 articles. Out of these, 29 studies comprising 26 datasets fulfilled the inclusion criteria. From all studies, the number of planned and placed implants was available. With two exceptions, no RCTs were found, and these two studies did not compare different numbers of implants per prosthesis. Eight studies were retrospective; all the others were prospective. Fourteen studies calculated cumulative survival rates for 5 and more years. From these data, the average survival rate was between 90% and 100%. The analysis of the selected articles revealed a clear tendency to plan 4 to 6 implants per prosthesis. For supporting a cross-arch fixed prosthesis in the maxilla, the variation is slightly greater.
Conclusions: In spite of a dispersion of results, similar outcomes are reported with regard to survival and number of implants per jaw. Since the 1990s, it was proven that there is no need to install as many implants as possible in the available jawbone. The overwhelming majority of articles dealing with standard surgical procedures to rehabilitate edentulous jaws uses 4 to 6 implants.

Conflict of interest statement: *The authors declare that they have no conflict of interest.*

Introduction

Implants have changed prosthodontics more than any other innovation. Brånemark and co-workers' seminal work had one primary goal: to restore the edentulous jaw by means of fixed prostheses supported by 'titanium fixtures'. This aimed at 'restitutio ad integrum', while replacement of teeth with a removable prosthesis in the edentulous jaw is a 'restitutio ad similem'. While worldwide still many patients do not benefit from oral implants and remain with complete dentures (if any), implant retained and supported prostheses became a well accepted treatment modality for edentulism since the 1980s. Complaints about instability of complete dentures, impaired function and discomfort are associated with progressive atrophy of the jawbone and changes in the tissue structures after becoming completely edentulous[1].

Developments in prosthetic concepts and technology occurred in the 1980s[2]. Since then a rapid and broad evolution in implant-supported rehabilitation has occurred with an exponential increase in publications.

Clinicians tend to select the prosthetic type and design based on the number of implants that can be placed, meaning that more implants are needed for fixed than for removable prostheses. Such planning is prevalently bone driven. It appears that the better the bone is maintained, the more implants can be placed and the less replacement of tissues is necessary.

Yet even today, the scientific evidence for the required/optimal number of implants is weak. The literature often deals with implant survival rates as the main focus, e.g. in relation to different loading protocols or comparing between fixed and removable prostheses. Suggestions for the optimal number of implants and the related prosthetic designs are rather to be found in textbooks or reviews on treatment methods, technical aspects and biomechanical considerations[2-4].

While restoring the mandible often offers a broad range of options – fixed prostheses with different designs, removable prostheses with different attachment and retention systems – the maxilla is more restrictive. It requires more planning steps and offers even less options. The mandibular overdenture on two implants is well documented, is even suggested to be the gold standard of care and is also the outcome of consensus conferences[2,6,7]. Even one single implant may stabilise a mandibular overdenture, while up to 10 implants have been used for a fixed prosthesis in the edentulous maxilla[8]. Anecdotal patient reports with the replacement of each tooth by one implant have even been published.

The placement of multiple implants requires good bone conditions or comprises elective surgical procedures in patients with advanced jawbone resorption. This can require invasive surgery like sinus floor elevation (SFE) and grafting procedures or guided bone regeneration (GBR). In the posterior mandibular jaw nerve repositioning and augmentation are suggested, but this is invasive and it is preferred to use the interforaminal region. Procedures like sinus floor augmentation are well documented[9,10] but eventually accompanied by biological complications and risks. Moreover, when restoring the maxilla, the following criteria play a predominant role and must be considered: aesthetic appearance; facial morphology; the replacement of lost hard and soft tissues.

As a consequence, when discussing the number of implants to be placed in the edentulous jaw, various, sometimes controversial aspects must be outlined:

- different soft and hard tissue conditions with regard to the edentulous mandible vs. edentulous maxilla
- option of fixed or removable prosthesis
- distribution of implants, anatomic risks and surgical aspects
- aesthetics and facial appearance
- choice of material and design of prostheses
- type of retention and fixation of the prostheses
- type and timing of occlusal loading.

For the rehabilitation of the edentulous jaw, in particular the maxilla, decision-making for the prosthesis design and the choice between fixed and removable prostheses, morphological and functional criteria must be considered. They often play a greater role than the number of implants[3,11-13].

Prosthetic options related to implants are mostly not evidence-based but a result of (recent) clinical experience, anatomical conditions, patients' preferences and costs.

The aim of the present review was to identify reliable data on the fixed dental prostheses on oral implants in the edentulous jaw. The focus was placed on the number of implants that were used to support the prostheses.

Material and methods

This overview is based on an electronic search (Pubmed, Embase) of publications in the English language from the past 30 years. The search terms were: edentulous jaw; edentulous maxilla; edentulous mandible; dental/oral implants; number of implants; fixed prostheses; cross-arch; All-on-4; tilted implants. These terms were used in various combinations. Titles and abstracts were screened and for relevant studies a full-text analysis was performed. Besides the Medline search, a manual search was conducted in journals easily accessible within Bern University.

The search included the following journals: *Journal of Prosthetic Dentistry; International Journal of Prosthodontics; Journal of Implantology; The International Journal of Oral and Maxillofacial Implants; Clinical Oral Implants Research; Implant Dentistry; European Journal of Oral Implantology; Clinical Implant Dentistry and Related Research; International Journal of Oral and Maxillofacial Surgery; Journal of Periodontology;* and *The International Journal of Periodontics and Restorative Dentistry.* The search was limited to clinical studies on patients who were edentulous in one or both jaws.

Inclusion criteria

Short and long-term clinical studies were included with prospective and retrospective study designs and even case series, if relevant information could be obtained on the number of implants related to the prosthetic technique.

- The implant system should still be on the market (2013).
- The studies must be published in peer-reviewed journals.
- The studies on completely edentulous patients must report data for the maxilla and mandible separately.
- From the study data, the number of implants placed per edentulous jaw is reported or can be calculated.
- The study should include a minimum of 10 patients (preferably more) rehabilitated with a full fixed prosthesis in one or both jaws supported by implants.
- The follow-up time is ≥ 3.5 years. However, when particularly relevant, some 1-year reports were also considered.
- The prosthesis is (provisionally) cemented or screw retained, but only detachable by a dentist.
- The studies report on implant survival rates, or survival of the prosthesis.

Exclusion criteria:

- The main study goal was advanced surgical techniques such as SFE, extensive grafting, etc.
- The number of patients and implants was not clearly defined.
- The study material reported on patients but the intent of the study was to demonstrate technical procedures.
- The study reported on patients with interfering systemic/local factors: trauma; tumour resection; radiotherapy; chemotherapy; Sjögren syndrome; Parkinsons disease; cleft palate; and other specific rare diseases.

Data extraction

The two reviewers extracted the data independently. If differences in the interpretation existed, agreement was sought by joint evaluation.

The main objective of the present data collection was to identify the number of implants used to support the fixed prostheses. Therefore the studies reported on various endpoints: survival of implants; survival of prostheses; crestal bone level; biological and technical complications; patient satisfaction; and quality of life were collected. If the implant sites (anterior/posterior) were not specified, it did not lead to exclusion of the studies. Such studies were also included if they accounted for the number of implants.

A few more recent studies that presented specific topics such as tilted implants, immediate loading, implants in extraction sockets or zygoma implants were also included when information about the number of implants could be obtained. This allowed for comparisons with the ‘standard’ procedures and for general considerations regarding the number of implants to be used.

From the identified papers, the following variables were used for the analysis:

- number of patients
- number of edentulous jaws
- number of implants
- number of implants per prosthesis
- implant diameter
- implant length
- implant location
- survival rate of implants
- number of prostheses

- survival rate of prostheses
- prosthetic complications
- segmentation of prosthesis
- cantilever (length)
- study type
- study duration
- smoking.

Statistical analysis

Since this is a critical but not a systematic review, a meta-analysis could not be performed. The calculation of implant survival and of drop-outs, along with the criteria for survival and success often varied. The goal of this extensive review was to relate the number of implants used to support the fixed prostheses and their outcome, and to formulate conclusions and suggestions regarding the number of implants. Thus, only descriptive statistics are reported.

Results

Description of the studies

The last electronic search for the screening process was performed in December 2013. The first hit from a MEDLINE search delivered over 4830 titles. A narrower search led to 1021, which was broken down to 222 articles, including some obtained by hand search. After the screening of these titles and abstracts for full analysis, 36 studies were included. Seven of these were excluded for final data extraction since they reported on the same patient groups at various time points or provided insufficient numbers. Thus the final analysis was based on 29 papers (see Table 1: 14-42). These publications cover a period of 30 years from 1981 onwards.

All but three articles[14-16] included the Brånemark system; respectively the Nobel Biocare implant system. Among the selected 29 publications, three[17-19] and two papers respectively[20,21] each included the same patient groups. Thus, the basic pool on patients, implants and prostheses covered in the present review is provided by 26 datasets.

The study endpoint of these publications was not the number of implants. The outcomes did not focus on the optimal number of implants to support the prostheses. Only one study compared 4 vs. 6 implants to support the prostheses in the edentulous jaw[22]. The latter paper analysed patients treated by Brånemark himself in the early days. Depending on the available bone volume in between the mental foramina and in between the maxillary sinuses, either 4 or 6 implants were placed. All patients had a 10-year follow-up. There was no statistical difference for the implant survival rates whether 4 or 6 implants were placed.

With two exceptions, no randomised clinical trials were found, and these two studies did not compare different numbers of implants supporting the prosthesis[23,24]. Five multi-centre (MC) studies[15,25-28] were found.

Eight studies were retrospective, while eighteen were prospective. Three of them had only a 1 to 2 years observation time[29-31]. Four of the 18 prospective studies and one retrospective study claimed follow-up times up to 10, 15 or 20 years. However the average observation time was much less[22,26,32-34]. Nevertheless, 14 studies calculated cumulative survival rates for 5 and more years (with censored data) and provided documentation on withdrawn patients and implants respectively. Only 2[16,35] out of the 26 datasets reported on less than 40 study patients, while 19 had >50 or >100 up to >800 patients included. Thirteen studies reported on both jaws, while 6 and 7 studies respectively each comprised either the maxilla or the mandible. More female patients and more mandibular jaws were identified in the 26 datasets.

Apart of the 26 datasets, 17 articles on immediate loading, fourteen papers on tilted implants, respectively – the so-called All-on-4 concept, and 7 articles on zygoma implants were also considered for the present review. They were selected from the final search on 222 abstracts and titles.

Number of patients, jaws and implants (Table 1)

It appears that the concept of placing the implants in the interforaminal area and within the bicuspid maxillary zone to support a cross-arch one-piece fixed prosthesis is represented by all but one report[15]. However, information on the prosthetic design is often not available. The analysis of the selected arti-

Table 1 An overview of the literature.

Author	No. of patients female / male	Jaw, max / mand	No. of impl. / prosthesis	Study type	Impl. type	Other information
Adell et al, 1981 [25]	371 230 / 141 age 53, 20–77	Total 410 max mand 191 / 219	Total 2768 max: 6 / mand: 6 (few 5 or 7)	MC P	Br	
Albrektsson et al, 1988[27]	ca. 1000 age 28–63	Total 1641 max mand 918 / 723	Total 7996 , max: 4.2 mand: 5.3	MC R	Br	
Zarb and Schmidt, 1990a,b,c[17,81,91]	46 36 / 10 age 49.9 (28–63)	Total 49 max mand 6 / 43	Total 274 max: 6 mand: 6 (4–7)	P	Br	yrs of previous edentulousness loss of impl. = OD
Adell et al, 1990[26]	700 399 / 301 age 55.3	Total 700 max mand 272 / 428	Total 4636 max: 6 mand: 6	MC P	Br	many drop-outs
Ahlqvist et al, 1990[29]	48 30 / 18 age	Total 50 max mand 17 / 33	Total 269 max: 4.8 (4–6) mand: 5.3 (5–6)	P	Br	jaw classification
Friberg et al, 1991[30]	780 ?? age 31->70	Total 780 max mand 289 / 491	Total 4641 max: 5.3, mand: 5.3	P	Br	
Jemt, 1991[31]	384 215 / 169 age 32–84	Total 391 max mand 99 / 292	Total 2199 max: 5.9., (4–6) mand: 5.5 (5–6)	P	Br	jaw classification
Naert et al, 1992 a,b / Quirynen et al, 1992[20,21]	90 56 / 34 age 53.7 (15–88)	Total 99 max mand 42 / 57	Total 599 (6) max: 5.8, mand: 5.7	P	Br	jaw classification years of edentulism (loss of implants = OD)
Brånemark et al, 1995[22]	156 100 / 56 age 20–80	Total 156 max: 84 (14, 70) mand: 72 (13, 59)	Total 782 4 little (108), 6 normal (674)	P	Br	jaw classification, yrs of edent, short impl. 7 / 10 mm, anat-gonistic teeth
Jemt, 1994[39]	76 28 / 48 age	76 max	Total 449 6 (few 5)	R impl.	Br	jaw classification
Ericsson et al, 1997[35]	11	11 mand	Total 63 6 (few 5)	R	Br	
Friberg et al,1997[40]	103 54 / 49 age 59 (33–83)	Total 102 max: 33 mand: 69	Total 563 5–6	MC P	Br	jaw classification
Arvidson et al, 1998[14]	107 64 / 43 age	107 mand	Total 618 6 (few 5)	P	Astra	
Friberg et al, 2000[32]	49 45 / 4 age 63 (38–93)	49 mand	Total 247 4–6 average: 5	P	Br	
Eliasson et al, 2000[38]	119 71 / 48 age 21->80	119 mand	Total 476 mand: 4	P	Br	2 different prosthesis frame-work
Jemt et al, 2002[23]	58 25 / 33 age 60 (38–74)	58 max	Total 349 6	RCT	Br	2 different prosthesis frame-work
Ferrigno et al, 2002[15]	85 ?? age 59 (35–79)	55 max, 40 mand	Total 760 8	MC P	ITI	some with SFE, segmented bridgework (4 per jaw)
Ekelund et al, 2003[33]	47 33 / 14 age 53 (34–67)	47 mand	Total 273 6 (few 5)	P	Br	

Table 1 *(cont.)* An overview of the literature.

Author	No. of patients female / male	Jaw, max / mand	No. of impl. / prosthesis	Study type	Impl. type	Other information
Engfors et al, 2004[41]	133 79 / 54 age 83 (80–93)	44 max, 95 mand	Total 761 max: 6 mand: 5	R	Br	patients aged >80 yrs
Astrand et al, 2004[24]	33 / 33 38 / 28 age 61.5 (35–74)	35 max 104A, 107 B 31 mand 80 A,80 Br	Total 371 6 (few 5)	RCT	Astra Br	comparison Astra / Br
Jemt and Johansson, 2006[42]	76 28 / 48 age 60.1 (32–75)	76 max	Total 456 6	PR	Br	
Friberg and Jemt, 2008[36]	75 36 / 39 age 62.5 (20–80)	max wide jaw 33 narrow jaw 42	Total 505 6 or 7	R	Br	jaw classification location of implants
Örtrop and Jemt, 2009[34]	155 age 67 (39–86)	155 mand	Total 821 4–6 mean 5.3	R	Br	different framework fabrication compared
Gallucci et al, 2009[28]	45 26 / 19 age 59.5 (34–78)	45 mand	Total 237 5 (4–6)	MC P	ITI	
Mertens and Steveling, 2011[16]	17 12 / 5 age 55.6 (41–69)	17 max	Total 106 6	P	Astra	no implant in jawbone = 4
Hjalmarsson et al, 2011[37]	80 age 43 / 37	max: 40 test 40 control	Total 513 mostly 6	R	Br / ITI Astra Biomet	external / internal connection 4 implant systems abutment / implant level compared 3 different frameworks

cles revealed a clear tendency to plan 6 implants per prosthesis. Nevertheless, the number of implants installed was sometimes limited by the limitation of available bone and/or the arch size, resulting in 4 or 5 implants. Vice versa, although rarely, 7 or 8 implants per prosthesis were reported within the same study groups. The 26 data sets listed in Table 1 represent a total of 4833 patients, who received a total of 31353 implants in 5586 jaws. This accounts for an average number of 5.6 implants per jaw.

The average number per jaw related to the maxilla and mandible is not different, but a greater variation is observed for the maxilla. One study made a clear differentiation between limited bone volume = 4 implants and sufficient bone volume = 6 implants[22]. Some other comparisons within the study groups were made by some authors such as narrow and wide crest[36], submerged vs. non-submerged[35] or internal vs. external connection[37]. These comparisons were not related to the number of number of supporting implants and were thus not further considered in this review.

For the mandibular interforaminal region, 4 to 6 implants were reported with a high prevalence for 5. One study exclusively installed 4 implants in the mandible[38], while only one study reported on 8 implants per jaw (both maxilla and mandible)[15]. This concept includes the installation of implants in the molar areas, which eventually required a sinus floor elevation. All other studies limited themselves to standard surgical procedures with placement of the implants in the interforaminal area of the mandible and in areas ventral to the sinuses in the maxilla.

Survival of implants and prostheses (Tables 2 and 3)

Many investigators observed some early implant losses, i.e. at abutment connection or during the first year of loading[19,25,30,21,31,39,40]. Thus critical implants were lost early during follow-up. Studies dealing with success need to apply strict, clearly defined and generally accepted success criteria to allow comparisons to be made. A few reports

Table 2 Survival rates.

Author	No. of patients	No. of impl. / prosthesis	Study duration	Impl. type	Survival (%) implants	Survival (%) prosthesis
Adell et al, 1981[25]	371	Total 2768 max: 6 / mand: 6 (few 5-7)	MC prosp., 1–9 yrs	Br	>5 yrs max: 81–88% / mand: 91–97% development and routine groups most implant loss in first year	max: 89–96% mand: 100% development group 79–100%
Albrektsson et al, 1988[27]	ca. 1000	Total 7996, max: 4.2 mand 5.3	MC, retro. data at 3,5, 7–8 yrs	Br	after 5 yrs in situ max: 89% poor bone maxilla mand: 98%	
Zarb and Schmidt, 1990a,b,c[17-19]	46	Total 274 max: 6 mand: 6 (4–7)	prosp 4–9 yrs	Br	after 4 to 9 yrs in situ, average survival: max: 96.3% mand: 83.7%	loss = conversion to OD
Adell et al, 1990[26]	700	Total 4636 max: 6 mand: 6	MC prosp. 1–20 yrs	Br	after 5,10,15 yrs still in situ 92–78% 98–86% development and routine groups	prosthesis stability at 15 yrs: max: 95% / 92% mand: 99–100%
Ahlqvist et al, 1990[29]	48	Total 269 max: 4.8 (4–6) mand: 5.3 (5–6)	prosp. 2 yrs survival	Br	at 2 yrs in situ: max: 89% mand: 97% without early loss, cluster effect	prosthesis stability: 98% (96%); one prosthesis remade on 3 implants
Friberg et al, 1991[30]	780	Total 4641 max: 5.3 mand: 5.3	prosp. first year	Br	at 1 yr in situ: 1.5% did not integrate max: 97 mand: 99.4	
Jemt, 1991[31]	384	Total 2199 4–6 max: 5.9 mand: 5.5	prosp. 1 year	Br	in situ after 1 yr: 98.1	survival: 99.5%
Naert et al, 1992a,b, Quirynen et al, 1992[20,21]	90	Total 599 6 max: 5.8, mand: 5.7	prosp. follow-up 1–7yrs	Br	CSR at 7 yrs 92.6 max: 91.6% mand: 95% most losses early, in 18% of jaws impl. lost	CSR: 93% 98.3% cantilever length
Brånemark et al, 1995[22]	156	Total 782 4 little 6 normal max/ mand	prosp. up to 10 yrs: all patients 10 yrs examined	Br	CSR at 10 yrs max: (4) 78.3%, (6) 81.3% mand: (4) 88.4% (6) 93.3%	CSR: max: 93.2% mand.: 78.3%
Jemt, 1994[39]	76	Total 449 max: 6 (few 5)	retro 5 yrs at 5 yrs: still 62 patients, 350 impl.	Br	at 5 yrs 92.1 in situ cluster effect of impl. loss in 2 patients more short impl. (7 mm) failed	
Ericsson et al, 1997[35]	11	Total 63 mand: 6 (few 5)	retro 5 yrs at 5 yrs: 61 impl. examined	Br	CSR after 5 yrs 96.8 submerged vs. non submerged no diff	
Friberg et al, 1997[40]	103	Total 563 5–6 max / mand	3 centres, prosp. 5 yrs follow-up at 5 yrs: 86 patients examined	Br	CSR at 5 yrs, more lost in maxilla max: 87 mand: 99.7 clustering effect	CSR: 97%
Arvidson et al, 1998[14]	107	Total 618 mand: 6 (few 5)	prosp. 5 yrs follow-up at 5 yrs: 91 patients examined	Astra	CSR at 5 yrs = 98.7	CSR: 100%
Friberg et al, 2000[32]	49	Total 247 mand: 4–6 average: 5	prosp. 1–10 yrs follow-up at 5 yrs: 37 pat / 193 impl. at 10 yrs: 25 pat / 125 impl.	Br	CSR at 5 yrs 95.5 CSR at 10 yrs 92.3 short impl. 7 mm and 6 mm 1.9% early failure (7 mm, thin diameter)	after failure = conversion to OD

Table 2 *(cont.)* Survival rates.

Author	No. of patients	No. of impl. / prosthesis	Study duration	Impl. type	Survival (%) implants	Survival (%) prosthesis
Eliasson et al, 2000[38]	119	Total 476 mand: 4	prosp. 3 yrs and 5 yrs at 3 yrs: 105 pat at 5 yrs: 53 pat	Br	97.1 successful 2.9% implants lost in the study	
Jemt et al, 2002[23]	58	Total 349 max 6	RCT 5 yrs examined at 5 yrs: 50	Br	CSR at 5 yrs = 91.4 / 94.4 2 different prosthesis frameworks clustering effect (all impl. lost in 2 patients)	
Ferrigno et al, 2002[15]	85	Total 760 max: 8	MC prosp. up to 10 yrs, 5 yrs data of 288 implants	ITI	CSR success at 5 yrs max: 92.1% mand: 96.25%, no heavy smokers	
Ekelund et al, 2003[33]	47	Total 273 mand: 6 (few 5)	prosp. follow-up to 20 yrs 30 pat / 179 implants examined at 20 yrs	Br	CSR 98.9% at 20 yrs more bone loss at mesial implants	survival: 100% at 20 yrs (2 prostheses remade)
Engfors et al, 2004[41]	133	Total 761 max: 6 mand: 5	retro 5 yrs at 5 yrs 76 patients examined 162 / 240 impl.	Br	CSR at 5 yrs: mand: 99.5 max: 93	CSR: max: 92.2 mand: 100%
Astrand et al, 2004[24]	33 / 33	Total 371 max / mand 6 (few 5)	RCT prosp. 5 yrs observation time at 5 yrs: 170 A 176 Br	Astra Br	At 5 yrs: CSR 98.4% A CSR 94.6% Br bone slightly more stable at Astra	
Jemt and Johansson, 2006[42]	76	Total 456 max: 6	retro follow-up to 15 yrs, 25 patients.	Br	CSR 97.2 at 5 yrs / 90.9 at 15 yrs early implant losses	CSR: at 5 yrs: 97.2% at 10 yrs: 95.4% at 15 yrs: 90.6%
Friberg and Jemt, 2008[36]	75	Total 505 wide: 226 narrow: 279 6 or 7 max	retro 7 yrs at 7 yrs still 181 / 209 implants	Br	CSR at 7 yrs wide bone crest: 94.5 / narrow bone crest: 93.6 smokers	
Örtrop Jemt, 2009[34]	155	Total 821 4–6, mand mean 5.3	retro 15 yrs at 15 yrs 65 patients examined	Br	CSR 98.7 at 15 yrs different frameworks	CSR: 91.7% Ti: 89.2 Gold 100%
Gallucci et al, 2009[28]	45	Total 237 mand: 5 (4–6)	MC prosp. 5 yrs follow-up all examined at 5 yrs	ITI	at 5 yrs implant survival: 100%, cross arch successful patients: 86.7	CSR: 95.5% cantilever length
Mertens and Steveling, 2011[16]	17	Total 106 max: 6	prosp. at 5 yrs, at 8 yrs 16 patients examined	Astra	survival at 8 yrs: 99% bone loss: 0.3 mm +-0.7 success: 96% smokers included	CSR: 100%
Hjalmarsson et al, 2011[37]	80	Total 513 max mostly: 6	retro 5 yrs patients available at 5 yrs recruited	Br, ITI Astra Biomet	survival at 5 yrs 98.6 / 97.6 loaded 100% / 99% external / internal connection	

described in detail the criteria of success. They differentiate between survival and success sometimes by involving crestal bone measurements[14-16]. But such criteria varied among the studies and did not allow for comparison of success rates. Thus it is adequate to use the term survival in the present review.

In early reports[25,26] a distinction was made between development groups – representing the learning curve with the implant-supported fixed prostheses concept – and the routine groups. For the development groups, often a lower survival rate is reported with more complications (including technical aspects of the prosthesis).

Table 3 Prospective studies with 5 years' CSR.

Author	No. of patients	Jaw, max / mand	No. of impl. / prosthesis	Number examined	Impl. type	Survival (%) implants
Friberg et al, 1997[40]	103	max: 33 mand: 69	Total 563 5–6	86 patients examined	Br	CSR: max: 87 mand: 99.7
Arvidson et al, 1998[14]	107	107 mand	Total 618 6 (few 5)	91 patients examined	Astra	CSR: 98.7
Friberg et al, 2000[32]	49	49 mand	Total 247 4–6	37 patients examined	Br	CSR: 95.5
Eliasson et al, 2000[38]	119	119 mand	Total 476 4	53 patients examined	Br	CSR: 97.1
Jemt et al, 2002[23]	58	58 max	Total 349 6	50 patients examined	Br	CSR: 91.4 / 94.4
Ferrigno et al, 2002[15]	85	55 max, 40 mand	Total 760 8	288 implants examined	ITI	CSR: max: 92,1%, mand: 96.25%
Astrand et al, 2004[24]	33 / 33	35 max 31 mand	Total 371 6	246 implants examined	Astra Br	CSR: 98.4% A, CSR: 94.6% Br
Gallucci et al, 2009[28]	45	45 mand	Total 237 5 (4–6)	45 patients examined	ITI	CSR: 100%

In early studies and up to the 1990s, the implant surfaces were mostly machined. For machined surfaces, a slightly lower survival rate is observed as compared to the slightly rough surfaces used today with most available implant systems.

Overall, the survival varies between 78% (the minimum observed for the maxilla in the development group) and 100% (maximum for mandible). Life table analysis and censored data were used and 14 articles reported on the cumulative survival rates at 5, 10 or more years. From these data, the average survival rate was between 90% and 100%. The Cumulative Survival Rate (CSR) at 5 years exclusively obtained from prospective studies is summarised separately in Table 3. It ranged from 87% to 92.1% for the maxilla and from >95 up to 100% for the mandible. A 'clustering' effect was sometimes observed[23,29,39,40], meaning that the majority of implant failures occurred within one or a few patients. This effect was more typical for maxillary implants and in the early phase. Some studies found that the trend for failures was more obvious in the severely atrophied maxilla, with poor bone quality and short implants[20,22,25-27,29,30,32,38,41]. This led some investigators to hypothesise that a minimum number of ≥ 4 of ≥ 10 mm length might be necessary.

If implants failed within a study group, then no distinction was made whether these implants were integrated in a prosthesis with a 4, 5 or 6 implant support.

Crestal bone measurements (Table 4)

Seventeen studies, especially prospective ones[14,16,20,23-25,29,32-34,36-42] included some outcomes on crestal bone measurements. Annual radiographic measurements were not systematically taken and some studies only performed those in selected patient groups[25]. A distinction between the healing phase and first year of loading versus the follow-up periods was often made, meaning that more bone loss was observed in the first period (i.e. from implant placement to abutment connection and first year of loading) with up to 1.5 mm loss, than in the follow-up period with little changes (e.g. ≤ 0.2 mm per year) for successful implants.

This way of considering crestal bone alterations is based on articles from the early to mid-1980s. More crestal bone loss was observed in the maxilla. Some authors mentioned above-average bone loss in a few patients[20,34,36,37,40,42]. Two papers mentioned that more crestal bone loss was found around mesial implants[29,33].

The reasons for increased bone loss were unclear, but smoking was occasionally addressed as a negative factor.

Table 4 Crestal bone alterations.

Authors	No. of impl. / prosthesis	Study duration	Impl. type	Crestal bone level alterations
Adellet al, 1981[25]	Total 2768 max: 6 / mand: 6 (few 5–7)	MC prosp., 1–9 yrs	Br	after first year, mean 1.2, then 0.1 mm only selected groups impl. fracture with accelerated bone loss more prominent in maxilla
Ahlqvist et al, 1990[29]	Total 269 max: 4.8 (4–6) mand: 5.3 (5–6)	prosp. 2 yr survival after 2 yrs	Br	average loss after 2 yrs: max 1.7, mand 1.1, more loss in max more loss at mesial implants: 1.9 m / 1.3 mm
Naert et al, 1992 a,b Quirynen et al, 1992[20, 21]	Total 599 max: 5.8, mand: 5.7	prosp. follow-up 1–7 yrs	Br	jaw classification, healing: max 1.2 mm, mand. 0.86 mm, then 0.1 to 0.2 per yr max: 20.9%, mand: 5.4% more loss than average
Jemt, 1994[39]	Total 449 max: 6 (few 5)	retro 5 yrs at 5 yrs still 62 patients, 350 impl.	Br	jaw classification at 5 yrs average: 1.2 +-0.58
Friberg et al,1997[40]	Total 563 5–6 max / mand	3 centres, prosp. at 5 yrs 86 pat. examined	Br	bone los first year: 0.3–0.4 mm, thereafter 0.1 mm per yr some sites with ≥ 2 mm
Arvidson et al, 1998[14]	Total 618 mand: 6 (few 5)	prosp. at 5 yrs 91 pat. examined	Astra	minimal bone loss = success radiographs at 1, 3 and 5 yrs average <1 mm after 5 years
Friberg et al, 2000[32]	Total 247 mand: 4–6 average: 5	prosp. 1–10 yrs follow-up at 5 yrs: 37 pat / 193 impl. at 10 yrs 25 pat / 125 impl.	Br	short implants (6 or 7 mm), 2 different diameters first yr; 0.5+-0.6 at 5 yrs: 0.7+-0.8 at 10 yrs: 0.9+-0.6
Eliasson et al, 2000[38]	Total 476 mand: 4	prosp. 3 yrs and 5 yrs at 3 yrs: 105 pat at 5 yrs 53 pat	Br	no average values frequency analysis of changes of 0, 1 mm, >1 mm loss per site, 10% short implants
Jemt et al, 2002[23]	Total 349 max: 6	RCT 5 yrs examined at 5 yrs: 50	Br	average 0.59 +-0.97 at 5 yrs no diff. in bone loss between 2 frameworks
Ekelund et al, 2003[33]	Total 273 mand: 6 (few 5)	prosp. follow-up to 20 yrs 30 patients / 179 implants examined at 20 yrs	Br	at 20 yrs: little bone loss: 1.6 +-9 mm 24% more loss than average up to 5.9 mm more loss at mesial implants
Engfors et al, 2004[41]	Total 761 max: 6 mand: 5	retro 5 yrs at 5 yrs 76 pat examined 162 / 240 impl.	Br	bone loss average: max: 0.7, mand. 0.6 mm slightly more loss in >80 years old
Astrand et al, 2004[24]	Total 371 max / mand 6 (few 5)	RCT prosp. 5 yrs observation time at 5 yrs: 170 A 176 Br	Astra Br	at 5 years Astra vs Br max: 1.74+-+-0.45 / 1.98 +-0.21 mand: 1.06 0.19 / 1.38 +- 0.17 stat. not significant
Jemt and Johansson, 2006[42]	Total 456 max: 6	retro follow-up to 15 yrs, 25 patients	Br	bone loss at 5, 10, 15 yrs: 0.5 +-0.47/ 0.6+-0.6 / 0.5 +-0.6 15.% / 23.6% /18% up to >3 mm loss
Friberg and Jemt, 2008[36]	Total 505 wide / narrow 6 or 7 max	retro 7 yrs at 7 yrs still 181 / 209 implants	Br	bone loss at 5 yrs: 0.64 to 0.74 +-0.65 some with >1.5 mm loss, more loss in smokers
Örtrop and Jemt, 2009[34]	Total 821 4–6, mand mean 5.3	retro 15 yrs at 15 yrs 65 patients examined	Br	at 15 yrs Ti vs. Gold framework: 0.59+- 0.56 / 0.98+-0.64 13.7% >1.2 up to 5.9 mm 28% >1.2 up to 5.9 mm
Mertens and Steveling, 2011[16]	Total 106 max: 6	prosp. at 5 yrs , at 8 yrs 16 patients examined	Astra	regular Rx: average loss: 0.3 +-0.72 after 8 yrs 0 up to 4.56 mm longer impls. slightly more loss
Hjalmarsson et al, 2011[37]	Total 513 max: mostly 6	retro 5 yrs patients available at 5 yrs recruited	Br, ITI Astra	bone loss at 5 yts: 1-1.2 mm (3 diff groups) 16%-27% of implants >1.9 mm lost

Table 5 Complications.

Author	No. of impl. / prosthesis	Resin / teeth fracture	Veneering fracture	Frame-work fracture	Abutment screw	Gold screw	Phonetics diction	Lip/cheek biting	Others
Adell et al, 1981[25]	max: 6 mand: 6			yes	yes	yes			ill fitting denture
Albrektsson et al, 1988[27]	max: 4.2 mand: 5.3						yes		
Zarb and Schmidt, 1990a,b,c[17,18,19]	max: 6 mand: 6 (4–7)			yes		yes	yes		food trapping
Jemt, 1991 Jaw classification	max: 5. 9., mand: 5.5	yes	yes			yes	yes	yes	air escape
Naert et al, 1992 a,b Quirynen et al, 1992[20,21]	max: 5.8, mand: 5.7		yes	yes	yes	yes	yes		fractures: impl. cantilever
Brånemark et al, 1995[22]	Total 782 4 little (108), 6 normal (674)								more risk of compl. max. 4 implants
Jemt, 1994[39]	6 (few 5)	yes		yes	yes	yes	yes	yes	change design
Ericsson et al, 1997[35]	6 (few 5)					yes			
Friberg et al, 2000[32]	4–6 average 5				yes				
Eliasson et al, 2000[38]	mand: 4	yes		yes					(gold / titan framework)
Jemt et al, 2002[23]	6	yes				yes			gold / titan soft tissue affection
Engfors et al, 2004[41]	max: 6 mand: 5	yes		yes	yes	yes	yes	yes	
Astrand et al, 2004[24]	6 (few 5)		yes	yes		yes	yes		
Jemt and Johansson, 2006[42]	6	yes	yes	yes			yes		hyperplasia, fistula
Örtrop Jemt, 2009[34]	4–6 mean 5.3	yes	yes	yes	yes	yes		yes	laser welded vs. gold alloy
Gallucci et al, 2009[28]	Total 237 5 (4–6)	yes				yes		yes	length of canti-levers
Hjalmarsson et al, 2011[37]	mostly 6		yes				yes	yes	wear, new design, occl adjustment

Prosthesis related complications (Table 5)

Data of prosthetic/technical complications that could be extracted from the studies[17-25,27,28,31,32,34,35,37-39,41,42] are given in Table 5. Seventeen articles listed in Table 5 reported occasionally, or in detail, on prosthesis survival/stability. Nine calculated a prosthesis based survival rate[14,16,21,22,28,34,40-42], see Table 2). It appears that in all but one[15] of the selected articles for the present review, the basic prosthetic concept is cross-arch, screw-retained. The choice of the number of implants was adopted from the early publications[17-19,25,26]. This prosthetic concept was described together with technical procedures in Brånemark et al's standard book on osseointegration, published in 1985[2]. The prosthesis was designed around a metal framework and the prevalent veneering material was resin; or resin teeth were mounted and resin denture material added. This type of prosthesis was either described or was visible from the illustrations in the selected papers. A distinction was clearly made between the crown design and the hybrid design by one study[21]. Ceramic veneering was occasionally mentioned in a few studies. Four studies reported on specific technologies and compared different fabrications of frameworks[23,34,37,38].

According to the prevalently utilised prosthetic technology, fracture of veneering material, resin tooth or resin denture base fractures, loosening of screws (gold screw, abutment screw) and some fractures of frameworks were typical and frequently listed as technical, prosthesis related complications. Fracture of an opposing complete denture was occasionally mentioned. Additionally biological complications such as soft tissue hyperplasia, fistulae, TMJ problems, occlusal wear, plaque accumulation or the fracture of an opposing complete denture were also occasionally mentioned. Patient-related problems and complaints were food trapping and phonation with air escape. Specific attention to the length of distal cantilevers was given in two papers[21,28]. Cementation or screw retention on the other hand was not an issue in the papers, which were also considered. Only one study[15] reported cemented prostheses. The prosthesis design and technical complications identified in the study groups were not specified according to the number of supporting implants per prosthesis (4, 5 or ≥ 6 implants).

Immediate loading/tilted implants (All-on-4) and zygoma implants (Tables 6, 7 and 8)

The articles related to these topics are listed in Tables 6 to 8. They will not be discussed in detail, but reviewing these articles adds further information and considerations to the question of the number of implants to be used for fixed prostheses.

Since they report more recent treatment concepts with special surgical techniques, the observation periods are shorter, as shown in Table 1.

Immediate loading: This has been defined as loading within 24 to 48 h after implant insertion, but some studies report even 13 days from implant placement to the prosthesis connection. The number of implants placed per prosthesis varied from 4 to 10[8,43-58]. For the maxilla, four papers reported the use of 7 to 10 implants[8,45,46,56], while only one study[52] reported on 4 to 5 implants. With regard to the mandible, 4 to 5 implants were placed in two studies[50,53] and only 3 implants in two others[49,57]. On average, the patients received 5.8 implants per jaw and the idea was to place 6 implants.

The transition from the failing dentition to complete edentulism by means of immediate installation of implant-supported fixed prostheses is discussed in various publications. Immediate implant placement into fresh extraction sockets is reported in three studies[53,54,58]. Such procedures were combined with immediate provisional prostheses, providing cross-arch fixation. Problems with provisionals, such as fractures, are mentioned. In one study, representing only three patients, the simultaneous completion of immediate loading in both jaws was described[45]. The distribution of utilised implants was similar to previous publications[4,15].

Tilted implants: The reports on tilted implants[59-72] also comprised immediate loading and/or flapless procedures. The prevalent number of implants was 4 as in the All-on-4 concept, i.e. two tilted, two axial implants[65,66]. Four studies[59,60,62,64] on tilted implants reported 5 or 6 implants in the maxilla, meaning that 3 or 4 implants were axially placed. Only 4 implants were systematically installed in the mandible in all studies. One RCT[72] compared 2 vs. 4 implants to support a fixed prosthesis.

Zygoma implants: Extra-maxillary anchorage in the zygomatic bone is used to deal with the atrophic maxilla. It avoids extensive grafting procedures[73-79]. The prevalent number per prosthesis was 4 or 5 implants and the average number of implants per jaw was 4.5. Some studies report exclusively on 4 zygoma implants per prosthesis[75] or a combination of 2 zygoma and 2 or more axial maxillary implants.

Discussion

Publications on osseointegration in oral rehabilitation from the 1980s and 1990s include a number of long-term observations on large patient populations. The attitude of today has somewhat changed, with shorter observation periods and smaller patient groups.

One recent systematic review on fixed prostheses in complete edentulism[80] identified only two reports on fixed prostheses in the maxilla and nine (including both jaws) for the mandible with a minimum of 50

Table 6 Immediate loading.

Author	Jaw	No. of patients	No. of implants	Study type duration	Impl. type	Survival %	Comments
Schnitmann et al, 1997[43]	mand	10	(60) 6	retro 10 yrs	Br	100, 84.7	some submerged, some immediate loading
Olsson et al, 2003[44]	mand	10	(61) 6	prosp. 1 yr	Br	93.4	immediate (2 to 9 days) impl. loss due to infection, stable bone
Degidi et al, 2005[8]	max	43	(388) 8–10, Ø 9	retro 5 yrs		98	impl. failures in first 6 months, large diameter more often failed
Gallucci et al, 2005[45]	max mand	3 / 3	(42) max: 8 mand: 6	<1 yr	ITI	100	immediate max / mand in one patient, good stability of bone, prosthesis segmented, cemented
Collaert De Bruyn, 2008[46]	max	25	(195) 7–9	prosp. 3 yrs	Astra	100	within 24 hours, very little bone loss, more in smokers
Fischer, 2008[47]	max	24	(142) 6 (2 only 5)	prosp. 5 yrs	ITI	95	good bone stability, RFA same as for late loading
Bergkvist et al, 2009[48]	max	28	(168) 6	prosp. 32 months	ITI	98.2	within 24 hours, bone loss like standard healing, most lost after healing when loading started
Hatano et al, 2011[49]	mand	132	(396) 3	retro Ø 5 yrs 1 to 10 yrs	Br	96.7	implants mostly 13 mm, failures in first 6 months, all replaced, prosthesis survival 92.4%
Friberg et al, 2005[50]	mand	152	750 5 (few 4)	retro 1 yr	Br	CSR 97.5	loading after 13 days, good crestal bone stability
Erkarpers et al 2011[51]	max	51	(306) 6	MC prosp.	??		loading within 24 h, satisfaction measured (OHIP-49) 3 times, very good scores
Malo et al, 2011[52]	max	221	(995) 4–5 mostly 5	retro 5 yrs	Nobel	78.5 to 92.4%	implants in different position, posterior more failure, biolog. compl., smokers more problems
Gillot et al, 2011[53]	mand	105	(448) Ø 4 few 5–6	pros. 4 months	Nobel	98.2	40% of impl. in fresh extraction socket, no diff. to healed bone
Gillot et al, 2012[54]	max	113	(675) 6 (3 pat. 5)	retro 6 months	Nobel	99.1	impl. in fresh extraction socket, more immediate impl. failed, fractures of provisionals
Komjoama et al, 2012[55]	max mand	19 max 10 mand	(165) 6 few 7 / 4	prosp. ≥ 1 yr	Br	100	teeth in a hour, some increased BoP, ulcera crestal bone loss >1.5 mm bone loss frequent
Covani et al, 2012[56]	max mand	19	(184) 8 max 6 mand	retro 4 yrs	Osse-an Intra-L	CSR 95	immediate implants, immediate loading
Rivaldo et al, 2012[57]	mand	33	(99) 3	retro 18 months	Nobel	100	crestal bone loss similar at mesial and distal impl.
Barbier et al, 2012[58]	max	20	(120) 6	18 months	Astra	100	immediate impl. and loading combined (24 h) CAD/CAM prosthesis, stable bone

patients for a minimum of 5 years. Thus the majority of studies in the present review were excluded in the latter report. The authors concluded that the evidence on the optimal number of implants to be used to carry fixed prostheses was not available. Although from a statistical and systematic review point of view this conclusion is correct, the omission of so much pertinent information about therapeutic concepts and clinical procedures obliterates the issue. Another review paper on the same subject also complained about the weak study designs and consequently the weak evidence[81]. By including more clinical data, the present review tries to come to some conclusions regarding the number of implants needed in the edentulous jaws.

Table 7 Tilted implants / All-on-4.

Author	Jaw	No. of patients	No. of implants	Study type duration	Impl. type	Survival %	Comments
Capelli et al, 2007[59]	max mand	65	(342) max 6 mand 4	prosp. 33–85 Ø 55 months	Osseotite Biomet 3i	mand: 100%, max: 98%	immediate implants
Tealdo et al, 2008[60]	max	21	(111) average 5 (few 6)	prosp. 13–28 Ø 22 months	Osseotite Biomet 3i	92.8%	immediate, few implants in extraction sockets prosth. survival 100%
Agliardi et al, 2010[61]	max	20	(120) 6	prosp. 18–42 Ø 27	Nobel	max: 98.3% mand: 99.7	immediate
Pomares, 2010[62]	max mand	30	(218) max 6 mand 4	retro 1 yr	Nobel	98%	immediate immediate, CAD CAM Nobelguide, some technical compl., template fracture, crestal bone
Francetti et al, 2010[63]	max mand	47	(196) 4	prosp. 30–60 22–40 months	Nobel	100%	immediate, crestal bone: no diff., tilted vs. axial
Degidi et al, 2010[64]	max	30	(210), 5 3 axial 2 tilted	prosp. 3 yrs	Dentsply	97.8% axial 99.2% tilted	immediate, welded frameworks, bone level similar
Malo et al, 2011[65]	mand	245	(980) 4	prosp. up to 10 yrs	Nobel	98% (5 yrs) 93% (10 yrs)	All-on-4 concept, immediate
Malo et al, 2012[66]	max	242	(968) 4	retro Ø 3.5 yrs	Nobel	98%	All on-4 concept, immediate
Weinstein et al, 2012[67]	mand	20	(80) 4	prosp. 20–48 Ø 30.1	Nobel	100%	extremely atrophied jaw
Grandi et al, 2012[68]	mand	47	(148) 4	MC prosp. 12–84	J Dental Care	100%	post extraction, immediate impl. immediate loading
Francetti et al, 2012[69]	max mand	47	(198) 4	prosp. 36–66 months	Nobel	10%	immediate, regular bone level measurements, no sig. diff,. between max / mand
Malo et al, 2013[70]	max	70	(280) 4	retro Ø 36 months	Nobel	96.4% (drop-outs)	all tilted implants, 83 trans sinus, many complications and bone loss, immediate
Krennmair et al, 2013[71]	max	38	(152) 4	retro 5–7 yrs Ø 66.5	Nobel	100, axial 98.6 tilted	degree of tilting, length of cantilevers, no influence on bone loss, resin and tooth fractures
Cannizzaro et al, 2013[72]	mand	60	(180) 2 or 4	RCT 1 yr	Osseotite Biomet 3i	100%	immediate, some technical comp. fixed prosth. on 2 or 4 impl. No diff. of bone level

The rehabilitation of edentulism by means of fixed prostheses has always been a priority goal in prosthodontics. The first long-term results were reported in Sweden[25] and by the Toronto study[17-19]. Overdentures were not considered a viable solution at this time. In these early days, restorations for the edentulous mandible predominated. The prostheses were designed around a metal-framework from metal-alloys with acrylic veneering. The so-called 'wrap-around' technique with prefabricated acrylic denture teeth and denture base material to compensate for lost hard and soft tissues was also applied with a hybrid design (where the prosthesis material was not in contact with the alveolar mucosa). This type of prosthesis was often labelled the 'Toronto bridge'. All these early fixed prostheses were supported preferably by more than 4 implants, mostly by 5 or 6. One reason for the selection of this number of implants was the perceived risk of early implant failures. Thus, in spite of the lack of osseointegration that might be detected at abutment connection, or in spite of failures in the first year of loading, a sufficient number (4) of remaining implants, hopefully located on both sides of the jaw, would still be available to support the prosthesis. The implants were placed in the interforaminal/anterior regions, avoiding surgical risks such as the vicinity of the mental nerve or sinus and therefore shortened dental arches became necessary. In these early days,

Table 8 Zygoma implants.

Author	No. of patients	No. of implants	Study duration	Impl. type	Survival %	Comments
Malevez et al, 2004[73]	55	103 zyg 2–6-axial	6–48 months	Nobel	100% for zygoma	all zygoma impl. with osseointegration 52 fix prost., 3 removable
Becktor et al, 2005[74]	16	31 zyg 74 axial	retro 9–69 months	Nobel	90.3% for zygoma	zygoma and standard impl. lost,, poor hygiene, sinusits, local infection
Stiévenart and Malevez, 2010[75]	20	(80) 4 zyg	prosp. 6–40 months	Nobel	CSR: 96	10 pat. 2-stage , 10 pat. immediate, severe atrophy, 3 impl. lost in 1 pat., Procera bridge
Bedrossian, 2010[76]	36	(172) 2 zyg 2–4 axial	prosp. up to 7 yrs	Nobel	100% (after loading)	sinus infection, 2 zyg. mobile during healing, replaced
Malo et al, 2013[77]	350	(1542) 4 (few 5) 747 zyg, 795 axial	pros 1–5 yrs	Nobel	CSR: 98.2 zyg 5 yrs 94.4%	immediate, prosthesis survival 99%, biological compl., technical compl. bruxism
Degidi et al, 2012[78]	10	(40) 4 2zyg, 2 axial	prosp. 12 months	Nobel	100%	immediate, welded framework intraorally
Testori et al, 2013[79]	32	(190) 5 4–5	retro 1 yr	Nobel	98.4%	mucositis, screw loosening, chipping, bone level no diff.

the implants had a 'smooth' (machined) surface and the probability of lack of osseointegration after the healing phase was greater than nowadays with slightly rough surfaces.

Fixed full arch prostheses with the implants located in the anterior zone exhibit a possible risk of cantilever fracture. One could also speculate that cantilevers are longer in prostheses supported by only 4 implants as compared to 6, but this also depends on the anterior-posterior spread. Framework fractures were reported, but the fracture location was not specified and the cantilevers' length varied and mostly was not measured. From the available data it could not be extracted whether the prostheses were designed according to the shortened dental arch concept. In a systematic review, which included partial and complete fixed prostheses, frequent technical complications were veneer chipping and fracture, screw loosening and de-cementation[82]. Another study confirmed these observations[83]. Loading patterns of fixed cantilever prostheses were investigated and demonstrated maximum loading forces on the distal implants adjacent to the cantilevers[84,85]. Although higher stress in the cortical bone around the implants was registered, in single cases it was shown that with this treatment concept bone apposition could be observed underneath the cantilevers in the posterior zone of the mandibular jaw[86]. In spite of these increased stresses around distal implants, two studies reported on more crestal bone loss, with some bone loss at mesial implants[29,33].

A more recent concept introduced a titled position for the posterior implants. It was mostly combined with immediate loading. A reduced number of implants was proposed, namely 4. A recent systematic review[87] reported good short-term outcomes for this concept that mostly utilised only 4, sometimes 5 (2 axial and 2 to 3 tilted) implants. The prosthesis design comprised distal cantilevers. This arrangement of the implants should reduce the number of implants to a minimum and increase the arch of extension and support of cross-arch fixed prostheses. As a consequence, the cantilever length will decrease. A meta-analysis found stable marginal bone levels with no difference between axial and tilted implants[88]. Another study, although reporting a 100% survival rate, observed ongoing bone loss around immediately loaded implants that were installed during a flapless procedure following the All-on-4 concept[89].

Comparisons of implant survival or success data among authors are not meaningful since methodologies and criteria vary considerably. The most stringent success criteria should rely on annual crestal bone measurements with standardised radiographs. For many reasons, this annual follow-up documentation was not provided in most of the selected studies for the present review. Some single implants exhibited more marginal bone loss than the expected 0.1 to 0.2 mm per year[90]. A meta-analysis comparing three implant systems found bone loss below or much below such cut-off values for defining success[91]. The implants exhibited different neck configurations and abutment connections and nowadays much attention is paid to the implant shoulder design with or without platform switching[92]. This aspect was not considered in the studies of the present data set.

In the present review, the maxilla is less represented and leads to lower survival rates as compared to the mandible. A review on immediate implant placement confirms that more information is available for the mandible[93]. One review on exclusively maxillary implants[94] comprised studies with various grafting procedures and immediate implant placement. One relevant outcome of the review was that placement of >6 implants results in a higher survival rate as compared to <6 implants that were installed within the bicuspid area and not having a support in the molar zone. One could argue that due to the atrophied maxilla, only 4 or 5 implants were placed, and thus this would confirm the observation that maxillary implants may more frequently fail in poor bone. The review identified different survival rates for machined and slightly rough surfaces, particularly with regard to grafted and native bone.

Some studies reported that only a small number of implants could be placed in the maxilla due to insufficient bone volume, and associated with this condition an increased failure rate was reported. In the 1990s, a surprisingly high failure (>20%) rate for maxillary overdentures was reported[31,95-97]. A critical analysis revealed that the indication for overdentures was often given in an emergency situation[98], meaning that overdentures were a substitute for failing fixed prostheses. When properly planned, overdentures led to excellent survival rates[99-102]. The marginal bone surrounding the implants was maintained at the same level as with fixed prostheses[98,103], also in ridges with advanced atrophy. Three studies of the present review reported on the transition from fixed prosthesis to overdentures due to implant losses[19,20,32].

Some studies tried to classify complications of implant-prostheses by means of categories that could be generally be applied to prosthetic reconstructions[101,104]. Still today clear criteria to report on technical complications, repair and maintenance service are not binding and not applied in the same way. Therefore, survival includes minor or major complications that required repair and adjustments that may be within the range of normal maintenance service or exceed it. The distinction between maintenance to support long-term function and complications may be based on the frequency of events that occur within a given observation time.

Beside the experiences with cross-arch fixed prostheses that often had a hybrid design, efforts were made to fabricate porcelain fused to metal fixed prostheses with a crown design, with the aim of improving aesthetics and prosthesis quality. Such frameworks are large, of heavy weight and misfit could not be avoided. Based on laboratory measurements it was concluded that passive fit cannot be reached by conventional techniques[105]. Thus segmentation was preferred, with the consequence that a symmetrical anterior/posterior distribution of the implants was suggested. However, limited clinical research was conducted on the concept of placing 8 implants, with segmentation into 4 prosthetic units[4,15,45]. One study exhibits this approach to locate the implant position for fixed prosthesis in the mandible and maxilla[15]. Thus, giving up the concept of cross-arch splinting, the authors suggest segmenting the fixed prosthesis into three parts as follows: 6 × 4, 3 × 3, 4 × 6 for the mandible and 6 × 4, 3 × 1, 1 × 3, 4 × 6 for the maxilla. This way of restoring the edentulous jaw with fixed prosthesis is a treatment concept, which is described[4] but not frequently present in clinical research. It is concluded that cross-arch fixed prostheses require a smaller number of implants than when segmentation of the frameworks is planned.

Survival of a prosthesis means that the same prosthesis, or at least the same type of prosthesis, is still in function at the end of the reported study period. It does not mean that complication did not occur or that repairs and adaptation were not necessary. Some studies observed temporary functional problems with phonation, diction, cheek and lip biting with fixed prosthesis. These were observed already in the 1980s[106], and now again reported with the recent All-on-4 technique[107].

The prostheses-related complications that were encountered also reflect the techniques typically used to fabricate the prostheses. Screw loosening was frequently reported, as well as chipping of resin denture base material or of resin denture teeth, and some fractures of frameworks occurred. Cantilever fracture, as could be expected, was not specifically reported and the percentage of framework fractures was low among all complications, but is accompanied by higher investment and costs for repair. Fracture and technical complications of provisional prostheses that were regularly utilised when doing immediate loading were often observed. Thus immediate loading may be a comfortable and quick solution, as expressed by measurements with the OHIP questionnaire[51] but accompanied by higher costs. A systematic review found a high complication rate with fixed prostheses. Although these events may not lead to complete failures, they require a considerable amount of repair and maintenance, which means time and cost[108].

By means of modern CAD CAM technologies with titanium and high strength ceramics, the cross-arch fixed prostheses supported by 4 to 6 implants is taken up again with a titanium or zirconia framework and optimised design, mostly exhibiting cantilevers. Such frameworks are processed in one piece, are of high precision and are lightweight as compared with metal-alloys. This evolution of technologies will translate into a better predictability of treatment outcomes and will simultaneously enhance more uniform material quality. Laboratory studies that were based on real patient cases confirmed high precision of fit and accuracy with titanium and zirconia using different CAD CAM technologies[109].

These days, computer assisted planning has shown that the feasibility of implant-supported prostheses becomes more predictable with regard to the available bone, the need of tissue replacement, the number of implants to be optimally placed and aesthetics when using these methods[13,110-112]. Modern technologies will set future directions in planning and fabrication prostheses for the edentulous jaw.

Conclusions

Long-term results and RCTs comparing different numbers of implants and designs for fixed prostheses in the edentulous jaws are not available. The selected articles of the present review exhibit a great heterogeneity and differences in methodology to report on survival of implants, prostheses, crestal bone loss and complications. In spite of a dispersion of results, similar outcomes are reported with regard to survival, bone stability and with a different number of implants per jaw. The fact that such data do not show up indicates that the number of implants is not a major issue.

The review cannot show which other parameters influenced the treatment concepts and subsequently the selection of the number of implants. The size of the jaw, inter-jaw relation (sagittal class) opposing dentition, minimum or maximum distance between adjacent implants etc. were not reported to be used as diagnostic research criteria. However, the overwhelming majority of articles dealing with standard surgical procedures to rehabilitate edentulous jaws report on 4 to 6 implants. The latter number appeared more frequently in studies on immediate loading, while the All-on-4 concept brings another reduction to 4 or rarely 5 implants.

Since the 1990s, it was proven that there is no need to install as much implants as possible in the available jawbone[22]. Even 4 implants can suffice to support cross-arch prostheses if implants are ≥ 10 mm long[22,38].

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