

Mechanical and Technical Risks in Implant Therapy

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Purpose: To systematically appraise the impact of mechanical/technical risk factors on implant-supported reconstructions. **Material and Methods:** A MEDLINE (PubMed) database search from 1966 to April 2008 was conducted. The search strategy was a combination of MeSH terms and the key words: design, dental implant(s), risk, prosthodontics, fixed prosthodontics, fixed partial denture(s), fixed dental prosthesis (FDP), fixed reconstruction(s), oral rehabilitation, bridge(s), removable partial denture(s), overdenture(s). Randomized controlled trials, controlled trials, and prospective and retrospective cohort studies with a mean follow-up of at least 4 years were included. The material evaluated in each study had to include cases with/without exposure to the risk factor. **Results:** From 3,568 articles, 111 were selected for full text analysis. Of the 111 articles, 33 were included for data extraction after grouping the outcomes into 10 risk factors: type of retentive elements supporting overdentures, presence of cantilever extension(s), cemented versus screw-retained FDPs, angled/angularized abutments, bruxism, crown/implant ratio, length of the suprastructure, prosthetic materials, number of implants supporting an FDP, and history of mechanical/technical complications. **Conclusions:** The absence of a metal framework in overdentures, the presence of cantilever extension(s) > 15 mm and of bruxism, the length of the reconstruction, and a history of repeated complications were associated with increased mechanical/technical complications. The type of retention, the presence of angled abutments, the crown-implant ratio, and the number of implants supporting an FDP were not associated with increased mechanical/technical complications. None of the mechanical/technical risk factors had an impact on implant survival and success rates. INT J ORAL MAXILLOFAC IMPLANTS 2009;24(SUPPL):69–85

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Medical interventions involving surgical procedures for the insertion of devices such as stents, hip or knee prostheses, orthopedic devices, or dental implants are associated with risk. Before undergoing such interventions, the risks for failure or complications and chances of survival or success need to be carefully weighed by patients and professionals. A qualitative description of risk would relate a greater overall risk to a greater loss and greater likelihood that an event occurs.

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In medicine, a risk factor is a variable associated with an increased risk of disease or infection. Risks are correlational and not necessarily causal. Risk factors are evaluated by comparing the risk of those exposed to the potential risk factor to those not exposed. For the purpose of the present review, mechanical and technical risks were defined as follows:

- **Mechanical risk:** Risk of a complication or failure of a prefabricated component caused by mechanical forces.
- **Technical risk:** Risk of a complication or failure of the laboratory-fabricated suprastructure or its materials.

Mechanical and technical risks play a major role in implant dentistry. They may lead to increased rates of repairs and remakes, and to a waste of time and financial resources, and may even affect the patient's quality of life.

During treatment planning, constellations known to be associated with increased risk should be avoided. Risks associated with different treatment options must also be related to the financial consequences, especially when considerable price differences exist between the prosthetic options.

A series of systematic reviews were launched to estimate and compare the failure/complication rates to be expected with various types of fixed reconstructions on teeth and implants.¹⁻⁸ With some of the reconstructions, considerably increased rates of failures were estimated to occur over 10 years of function⁶: fixed dental prostheses (FDPs) with cantilever extensions on teeth (19.6%), combined tooth-implant-supported FDPs (22.3%), and resin-bonded FDPs (35.0%).

The protocols of the systematic reviews mentioned above were designed to include publications reporting on the prosthetic failure and complication rates with a particular design of a reconstruction, ie, full-arch FDPs on implants/teeth, short-span FDPs on implants and teeth, and single crowns, over at least 5 years.

Excluding multiple other factors that may mask a correlation with a particular risk factor seems to be difficult when combining data from cohort studies being performed at various centers. According to the definition of "risk factor" mentioned above, long-term studies that evaluated and compared the risk of those patients/reconstructions exposed to a certain risk factor to those not exposed to that risk factor in the same environment are of particular interest.

Therefore, the aim of this review was to systematically screen the literature for information answering the following focused question: Which mechanical/technical risk factors have an impact on implant-supported reconstructions?

MATERIALS AND METHODS

Search Strategy

A search in the MEDLINE (via PubMed) database from 1966 up to and including April 2008 was performed. Publications in English, German, French, and Italian in peer-reviewed journals were considered; abstracts were excluded. The search strategy applied was a combination of MeSH terms and free text words, including the following key words: *design, dental implants/risk, prosthodontics, fixed prosthodontics, fixed partial denture(s), fixed reconstruction(s), oral rehabilitation, bridge(s), removable partial denture(s), and overdenture(s)*.

A complementary manual search from 1986 up to April 2008 was carried out in the following journals: *Journal of Oral Rehabilitation, Journal of Prosthetic Dentistry, International Journal of Prosthodontics, International Journal of Periodontics & Restorative Dentistry, Clinical Oral Implants Research, and International Journal of Oral & Maxillofacial Implants*. In addition, the reference lists of articles selected for inclusion in this review were screened.

Selection Criteria

Randomized controlled trials (RCTs), controlled trials, and prospective and retrospective cohort studies with a mean follow-up time of at least 4 years were included. The material evaluated in one study had to include cases with the risk factor and cases without exposure to the risk factor.

The following inclusion criteria were used:

- Mean follow-up time \geq 4 years
- At least five patients included
- Studies on fully and partially edentulous patients
- Studies on fixed and/or removable implant-supported dental prostheses
- Studies on fixed dental prostheses with cantilever extension(s)
- Studies on implant-supported single-unit crowns
- Studies on implant- and/or tooth-implant-supported reconstructions
- Studies on cylindrical and/or cylindrical-conical solid-screw implants
- Clinical examination at the follow-up visits
- Detailed information on the characteristics of the implants and their supported reconstructions

The following exclusion criteria were used:

- Animal studies
- in vitro studies
- Studies based on patients' records, surveys, questionnaires, or interviews
- Studies focusing exclusively on finite element analysis (FEA)
- Studies focusing exclusively on implant length and/or diameter
- Studies focusing exclusively on patient-centered outcomes
- Reviews
- Case reports
- Abstracts

Validity Assessment

Two reviewers (UB and GES) screened titles and abstracts identified through the search for possible inclusion. The discrepancies were resolved by discussion. Publications of potential interest were obtained in order to evaluate the full text. Both reviewers screened the included publications independently using the inclusion criteria. Again, any disagreement was resolved by discussion between the two reviewers.

Data Extraction

Collectively, the outcome variables included:

- Implant-related mechanical and technical risk factors
- Abutment-related mechanical and technical risk factors
- Suprastructure-related mechanical and technical risk factors

Depending on the presence or absence of a specific mechanical or technical risk factor, survival and success rates of implants, abutments, and related suprastructures were extracted from the publications. *Survival* was defined as presence of the implant, abutment, and/or its suprastructure in situ in its original extension at follow-up examination with or without complications. *Success* was defined as presence of the implant, abutment, and/or suprastructure in situ without any mechanical or technical complications during the entire follow-up period.

From the included papers, the following information was extracted: the number of patients examined, the mean age of the patients, the mean observation time, the number of implants restored, the implant system used, the designs of the reconstructions under examination, and the study design applied. Finally, the major findings related to harm to the suprastructure, prosthetic components of the implant systems, peri-implant tissues, implants, and results of statistical analyses were noted and grouped according to potential risk factors.

RESULTS

Of the 3,568 titles resulting from the online search, 111 were selected for full text review after reading the abstract. From the 111 full-text articles, 33 were included for data extraction. Two additional articles were included based on a manual search (Fig 1).

The data from 35 publications were grouped according to 10 risk factors identified after screening the literature:

- Type of retentive elements supporting overdentures
- Cantilever extension(s) on fixed dental prostheses (FDPs)
- Cemented versus screw-retained FDPs
- Angled/angulated abutments
- Bruxism
- Crown-to-implant ratio
- Length of the suprastructure
- Prosthetic materials
- Number of implants supporting an FDP
- History of mechanical/technical complications

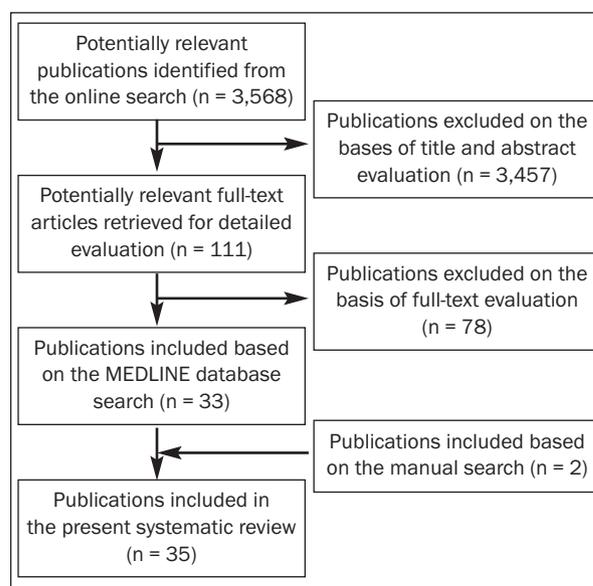


Fig 1 Selection process used to identify the included publications.

Retentive Elements of Overdentures (Tables 1 and 2)

Eight studies dealing with mandibular overdentures in which the allocation of patients to different treatment groups was performed in a randomized manner were identified (Table 1). Naert et al compared 12 patients with Dolder bars to 12 patients with ball attachments and 12 patients with magnets.⁹ At 5 years, the highest retention measured by means of a dynamometer amounted to 1,240 g in the bar group, followed by 567 g in the ball attachment group, and only 110 g in the magnet group.⁹ When questions about prosthesis stability and cleaning comfort were ranked on a scale from very bad (1) to excellent (9), mean rankings were statistically significantly lower in the magnet group compared to the ball and bar groups. Patient satisfaction related to chewing comfort and phonetics did not change significantly over the 5 years. In the magnet group, however, a significant decrease in general satisfaction and in satisfaction with denture stability was noted ($P < .03$).

In a later publication by Naert et al,¹⁰ unfortunately no detailed information related to prosthetic complications over 10 years of observation was presented. Similar failure rates for the implants were noted in the three groups of overdentures.

Gotfredsen et al found less frequent events for patients receiving ball attachments (19 cases, 0.6 events per year) than for patients receiving a round

Table 1 Randomized Controlled Trials with Edentulous Mandibles Restored with Various Overdenture Designs on Different Implant Systems: Results after 5 and 10 Years of Observation

Study	Year	No. of patients	Mean age, y (range)	Mean observation time	No. of implants	Implant system	Overdenture design	Type of study	Summary of results
Naert et al ¹⁰	1999	36	63.7 (36–85)	60 mo	72	Nobel Biocare	12 Dolder bar 12 magnet 12 ball	Prospective randomized RCT	Retention of denture: bar > ball > magnet Reduction of retention in % of original value similar Complications: magnet > ball > bar More hyperplasia with bar More ulcers with ball Satisfaction: comfort with stability significantly reduced with magnet No risk factor for implant loss
Gotfredsen et al ¹¹	2000	26	64 (52–78)	60 mo	52	Astra Tech	11 round bar 19 ball	Prospective randomized RCT	Complications per year per patient 1.0 for bar, 0.6 for ball No risk factor for implant loss
Meijer et al ¹²	2004	90	54.0 (38–77) 56.6 (35–79) 52.8 (38–74)	60 mo	180	30 IMZ 30 Nobel Biocare 30 Straumann	All Dolder bar (90)	Randomized (envelope) RCT	No risk factor for implant loss
Timmerman et al ¹⁵	2004	110/103	39–87	8.3 y	274	Straumann	36 ball 37 bar on 2 implants 37 bar on 4 implants	Randomized RCT	Satisfaction with retention, stability decreased with ball No difference in change of satisfaction Two implants with bar best solution NR
Meijer et al ¹³	2000	61	59 ± 11	5 y	122	29 IMZ 32 Nobel Biocare w/ Ackermann clips	61 round bars	Computerized balancing	Multiple prosthetic revisions Precision attachment system in the overdenture with frequent fractures and loosening Implant survival: IMZ 93%; Nobel Biocare 86%
Visser et al ¹⁶	2005	60	NR	60 mo	180	IMZ	30 two implants and bar, 30 four implants and bar	Prospective comparative	Tendency for more prosthetic aftercare with two implants and bar More soft tissue complications with four implants and bar No difference in satisfaction No risk factor for implant loss
Meijer et al ¹⁴	2004	61	59±11 55±12	120 mo	122	29 IMZ 32 Nobel Biocare w/ Ackermann clips	61 round bars	Randomized computer-model RCT	Very high incidences of technical/prosthetic complication and failures Measured by clinical implant performance score: similar scores for the two systems No risk factor for implant loss
Naert et al ¹⁰	2004	36	63.7 (36–85)	120 mo	72	Nobel Biocare	12 Dolder bar 12 magnet 12 ball	Prospective randomized RCT	No more information on technical prosthetic complications compared to Naert et al 1999 No risk factor for implant loss

NR = not reported; RCT = randomized controlled trial.

Table 2 Further Studies on Reconstructions of Edentulous Jaws

Study	Year	No. of patients	Mean age, y (range)	Mean observation time	No. of implants	Implant system	Designs of reconstruction	Study design	Findings
Bergendal and Engquist ¹⁷	1998	49	66	62 mo	1.15	Nobel Biocare (12–106 mo) 8-y life table	Round bar/ball 18 maxillary/ 32 mandibular RCT	Random assignment	Risk of complication: old components, new components Bone anchorage–lever arm was a risk factor More denture fractures with bar versus ball (no framework) More implant loss in maxilla (25%) versus mandible (0%) No risk factor for implant loss
Dudic and Mericske-Stern ¹⁸	2002	119	63 (40–90)	9.3 y (5–15 y)	258	Straumann	75 round bar or ball versus 44 rigid bar	Consecutive patients	No significant difference in time to change of retention mechanism between resilient and rigid Rate of prosthetic maintenance service = event per patient per year at 5 years (no significant difference between the 2 retention systems) For resilient: more complications with retainers, more denture base resin fractures, hyperplasia, relining For rigid: fracture of bar extension, retightening of female part Rates at 5 years similar, advantage for rigid related to time needed for service. No risk factor for implant loss
Nedir et al ¹⁹	2006	55	NR	8-y life table	145	Straumann	41 ball/14 bar	Consecutive patients	Event rate per year: 1.5 with ball, recurrent events 0.9 mm with bar Free of complications 57.1% with bar, 24% with ball ($P < .04$)
Oetterli et al ²⁰	2001	90/70	67.8 (41–89)	60 mo	180	Straumann	Supportive surface, bent clipbars, U-shaped extension bars, mandible β : angle between axis connecting implants and mandibular hinge axis	Consecutive patients	Supportive surface and position of implant as well as retention mechanism No risk factor for implant loss
Ferrigno et al ²¹	2002	233	59.4 (35–79)	10-y life table	1286	Straumann	Maxilla: full-arch prosthesis 55; Milled bar 19; Dolder bar 16 Mandible: full-arch prosthesis 40; Milled bar 84 Dolder bar 44	Prospective multicenter	Survival of prosthesis: Maxilla: full-arch prosthesis 96.4%; Milled bar 94.7%; Dolder bar 87.5% Mandible: full-arch prosthesis 100%; Ball anchor 99%; Dolder bar 98% Implant success: Maxilla: full-arch prosthesis 92.1%; Milled bar 92.2%; Dolder bar 86.9% Mandible: full-arch prosthesis 96.2%; Ball anchor 93.7%; Dolder bar 93.9%
Tinsley et al ²²	2001	48	(37–80)	4–6 y	181	Calcitec HA-coated	21 FDP vs 27 bar, mandible (23 bars on 3 implants, 4 on 2 implants)	Prospective	Catastrophic results: 50% of overdentures were remade, 30% required a reline Only 83% implant survival HA implants lost a lot of bone

NR = not recorded; FDP = fixed dental prosthesis.

bar (11 cases, 1.0 events per year).¹¹ Over 5 years, 48 complications/repairs were observed in the ball group and 53 in the bar group. Mainly during the first year of function, there were statistically significantly more complications/repairs in the bar group. However, some of the technical complications were related to the devices needed for radiographic standardization.

Meijer et al¹² followed overdentures with Dolder bars on three different implant systems (IMZ, Nobel Biocare, and Straumann). Over 5 years, there was no effect on the implants and no information was presented on prosthetic aspects. In an earlier report by the same group comparing overdentures on IMZ and Nobel Biocare implants, multiple prosthetic revisions were noted.¹³

When the same patients were followed over 10 years,¹⁴ the 56 surviving overdentures with round bars and Ackermann clips required 256 prosthetic actions, including replacement of broken abutments and loose clip screws, placement of new bars or gold cylinders and new or fastening clips, relining of maxillary or mandibular dentures, repair of denture bases or teeth, readjustment of occlusion, and provision of new maxillary and mandibular dentures—with no obvious difference between the IMZ and Nobel Biocare groups. A clinical implant performance scale was used to score the events. With a mean score of 1.3 for the IMZ group and 1.2 for the Nobel Biocare group, the clinical outcomes appeared to be similar.

Three types of overdenture designs were compared comprehensively using a computerized random allocation procedure.¹⁵ Thirty-six overdentures were attached to two ball anchors, 37 to a bar on two implants, and 37 to a bar on four implants. General satisfaction with phonetics, esthetics, and social functioning remained high. The score reflecting satisfaction with retention and stability of the overdenture decreased significantly in the group with two ball attachments.

Comparing 30 overdentures with bars on two implants to 30 overdentures with bars on four implants, Visser et al¹⁶ found a tendency for more biological complications with four implants but a higher need for prosthetic aftercare on two implants (not statistically significant).

Six additional studies were found in which overdentures with different attachment systems were compared longitudinally. In these studies, allocation of the groups was not performed using randomization (Table 2).

Forty-nine patients with maxillary and mandibular overdentures were followed over 62 months (range 12 to 106 months).¹⁷ When patients received overdentures either on ball anchors or on a round bar, the overdentures that were not reinforced with a metal

framework were at high risk of fracturing. In the bar group, 30 of 36 patients required denture repairs. In the maxilla, 25% of the originally placed implants were lost compared to none in the mandible. The amount of bone anchorage in relation to the lever arm was higher in the lost implants (mean lever arm–bone anchorage ratio of 1.3) than in all implants placed (a mean lever arm–bone anchorage ratio of about 1).

Over an observation period of 5 to 15 years (mean 9.3 years), 119 patients with implant-supported overdentures were monitored at regular intervals.¹⁸ The rate of prosthetic maintenance per patient over 5 years was similar for the resilient and rigid types of fixation applied. However, the characteristics of the complications differed. Whereas resilient attachments had more complications with retainers, more denture base resin fractures, mucosal hyperplasia, and denture relines, the rigid support attachments had more fractures of bar extensions and needed retightening of female parts. It was obvious that rigid fixation was an advantage, since less time was required for services. The time to the first change of a component was not significantly different for resilient versus rigid attachments.

The amount of aftercare in patients with overdentures was assessed cumulatively up to 8 years by Nedir et al.¹⁹ The percentage of overdentures remaining free from complications was 57% for the bar devices but only 24% for overdentures with ball anchors ($P < .04$); 1.5 events per year were noted in the ball attachment group, whereas 0.9 events per year per patient occurred in the bar group.

Anatomical, morphologic, and prosthetic variables are considered to be of importance when selecting a particular implant position. Oetterli et al²⁰ evaluated the casts and clinical parameters of 90 edentulous patients, each one with two intraforaminal implants supporting an overdenture. The angle β between the virtual axis connecting both implants and the mandibular hinge axis was measured on mounted casts. The supporting surface was identified between bent clip bars and U-shaped extension bars. Seventy patients could be evaluated clinically after 5 years. The positions and retention mechanism of mandibular implants supporting an overdenture had little influence on the clinical parameters assessed. No data related to technical/mechanical complications were reported.

The long-term function (10-year life table) of overdentures was compared to the clinical outcome with full-arch fixed prostheses in a study including 233 patients receiving 163 overdentures and 95 fixed full-arch prostheses.²¹ The survival rates for overdentures on Dolder bars were 87.5% for the maxilla and 97.7%

for the mandible. Survival of full-arch prostheses was 96.4% in the maxilla and 100% in the mandible. Overdentures on milled bars had a 94.7% survival rate in the maxilla, and overdentures on ball anchors in the mandible had a 98.8% survival rate.

One study reported a dramatic incidence of implant loss (27% over 4 to 6 years), remakes of overdentures (50%), and relinings (30%).²² Handling such frequent catastrophic events would be highly impracticable in daily clinical practice.

Fixed Dental Prostheses (FDP) with Cantilever Extension(s) (Table 3)

In four papers, the presence of a cantilever extension as a potential risk for technical/mechanical complications was assessed. In the oldest report, dramatically higher failure rates with cantilever extensions > 15 mm were noted.²³ In 25 patients, 24 edentulous mandibles and four edentulous maxillae were restored with full-arch fixed bilateral cantilever prostheses on five to six implants. The prostheses were grouped into those with a cantilever length of > 15 mm and those with ≤ 15 mm (range 5 to 22 mm). The prostheses were followed from 20 to 80 months. Of the 28 prostheses, 12 had to be remade. Practically all of those were originally designed with cantilever extensions > 15 mm.

Comparing 24 FDPs with cantilever extensions to 26 FDPs without cantilever extensions over 5 years in 45 consecutive patients, Wennström et al²⁴ did not find any negative effect on the peri-implant conditions. The six technical complications noted were not related to the cantilever extensions.

Romeo et al²⁵ collected clinical and radiographic data from 42 FDPs with a cantilever extension and 137 FDPs without a cantilever extension. The cumulative survival rates of the implants reached 94.4% with the risk "cantilever extension" and 96.5% without the risk "cantilever extension," as assessed in a 7-year life table analysis. Radiographic success was defined as absence of bone loss > 1 mm during the first year of loading and 0.2 mm/year thereafter. Clinical success, defined as absence of probing pocket depths > 3 mm, was observed in 76.3% of cases with cantilever extensions and in 73.8% of cases without cantilever extensions.

Nedir et al¹⁹ presented data on consecutive patients treated with implant-supported removable or fixed prostheses and single crowns on implants. Seventeen of the fixed reconstructions had a cantilever extension and 228 did not. Up to 8 years follow-up, the authors found technical complications in about 30% of the reconstructions with cantilever extensions but in only 8% of the reconstructions without cantilever extensions.

Romeo et al²⁶ collected radiographic and clinical information on fixed dental prostheses in 49 partially

edentulous patients. Fifteen of the FDPs had a distal cantilever extension and 34 a mesial cantilever extension. After a mean follow-up of 4 years, no negative effects related to the presence of the mesial or the distal cantilever extension were found.

Cemented Versus Screw-Retained Dental Prostheses (Table 4)

In a prospective randomized study, 12 cemented and 12 screw-retained crowns were constructed on implants to replace missing lateral incisors.²⁷ Four years after loading, no differences in peri-implant conditions and no prosthetic complications were noted.

In two other reports, similar rates of complications were noted over 5 years with cemented and screw-retained crowns and FDPs.^{19,28} It should be noted, however, that the group with cemented reconstructions was considerably larger in both studies. The screw-retained reconstructions in the study by De Boever et al²⁹ demonstrated twice as many complications as the cemented ones: 29/127 cemented (22.8%) and 26/45 screw-retained (57%) reconstructions demonstrated technical/mechanical complications ($P < .001$). In 21 of the 26 interventions, however, only retightening was required.

Angled/Angulated Abutments (Table 5)

Two studies focusing on the potentially negative influence of nonparallel implants requiring the placement of angled abutments were found. In a report by Sethi et al,³⁰ misangulations ranged from 0 to 45 degrees. Of 3,101 implants, 264 implants with an abutment angulation of > 15 degrees were compared to 352 implants with a more axial abutment (≤ 15 degrees). Over 10 years, the angulation had no effect on the probability of survival of the implants. However, no information on mechanical/technical complications was available.

A more sophisticated method of analyzing angles was presented by Koutouzis and Wennström in 2007.³¹ Standardized photographs were taken of the maxillary and mandibular study casts in occlusion and then with guide pins in place. Thus, within the superimposed image, the inclination of the implants in relation to the occlusal plane was obtained. Finally, interimplant inclinations in both mesiodistal and buccolingual directions were obtained. Axial implants were defined as ranging from 0 to 4 degrees and nonaxial implants from 12 to 30 degrees. The 36 axial and 33 nonaxial implants yielded similar bone remodeling over 5 years, as assessed in radiographs. Moreover, there was no increased risk of mechanical/technical complications associated with tilted implants.³¹

Table 3 Extension

Study	Year	No. of patients	Mean age, y (range)	Mean observation time	No. of implants	Implant system	Designs of reconstruction	Study design	Findings
Wennström et al ²⁴	2004	45	57 ± 10.3 62 ± 8.5 mo	5 y	130	Astra Tech	24 FDPs with extension 26 FDPs without extension Short FDPs	Consecutive patients	6 complications in 5 y not related to presence of extension No influence on peri-implant condition
Shackleton et al ²³	1994	25	NR	20–80 mo	NR	Nobel Biocare	28 full-arch prostheses with extensions ≤ 1.5 cm and > 1.5 cm	5-y survival	Length > 1.5 cm dramatically more fractures 12/28 remakes No influence on implant loss
Romeo et al ²⁵	2004	NR	NR	4 y after loading	379	Straumann	42 FDP with extensions 137 FDP without extensions	3.8 y survival	Implant survival FP with extensions (94.4%) Implant survival FP without extensions (96.1%)
Nedir et al ¹⁹	2006	NR	NR	8-y life table	NR	Straumann	17 with extensions 228 without extensions	Consecutive	29.4% complications versus 7.9% P < .01

NR = not recorded, FDP = fixed dental prosthesis.

Table 4 Cemented Versus Screw-Retained

Study	Year	No. of patients	Mean age, y (range)	Mean observation time	No. of implants	Implant system	Designs of reconstruction	Study design	Findings
Vigolo et al ²⁷	2004	12	NR	4 y after loading	24	Biomet 3i	12 cemented	12 screw-retained	Prospective randomly assigned No complications at all No influence on bone and soft tissue
Brägger et al ²⁸	2001	85	55.7 (23–83)	50.8 mo	130 implants 142 teeth	Straumann	40 I-I 58 T-T 18 I-T	Retrospective cohorts	13/79 cemented with complications 3/26 screw-retained with complications (ns) No influence on implant loss
Nedir et al ¹⁹	2006	NR	NR	8-y life table	NR	Straumann	189 cemented 32 screw-retained	8-year life table	No significant difference in complication rate No influence on implant loss
De Boever et al ²⁹	2006	105	25–86	62.5 ± 25.3 mo	283	Straumann	FDP/Crown 45 screw-retained versus 127 cemented	Consecutive	29 complications out of 127 (22.8%) 26 complications out of 45 (57%) P < .001 No influence on implant loss

NR = not recorded; ns = not significant; FDP = fixed dental prosthesis; I-I = implant-to-implant FDP; I-T = implant-to-tooth FDP; T-T = tooth-to-tooth FDP.

Table 5 Angulation Versus No Angulation

Study	Year	No. of patients	Observation time	No. of implants	Implant system	Factors	Finding for reconstruction	Finding for implants
Sethi et al ³⁰	2002	NR	10 y	3,101	Ankylos	From 0–45 degrees; 264 implants > 15 degrees, 352 implants ≤ 15 degrees	No information on prosthetic complications	Survival probability for implants NS
Koutouzis and Wennström ³¹	2007	38	5 y	69	Astra Tech	36 axial (0–4 degrees inclination) versus 33 nonaxial (1.2–30 degrees)	No increased risk of technical complications	No influence on bone loss around implants

NR = not recorded; NS = not significant.

Table 6 Bruxism

Study	Year	No. of patients	Mean age, y (range)	Mean observation time (range)	No. of implants	Implant system	Design of reconstructions	Type of study	Findings
Brägger et al ²⁸	2001	85	55.7 (23–83)	56.8 mo	103 (142 teeth)	Straumann	FDPs: 40 I-I; 58 I-T; 18 I-T	Retrospective cohorts	13/75 nonbruxers (17.3%) had technical complications and 6/10 bruxers (60%) had complications $P < .01$ No influence on implant loss
Eikfeldt et al ³²	2001	54	NR	NR	301	Nobel Biocare	Edentulous maxillary FPD or overdenture; 27 with clustered implants loss (50%) vs 27 with no such loss (control)	Clustered failures as test group versus matched control group	In the test group with clustered losses, there were 7 patients with bruxism Heavy influence on implant loss
De Boever et al ²⁹	2006	105	25–86	65.2 ± 25.3 mo	283	Straumann	23 bruxers, 80 nonbruxers 43 reconstructions at risk in bruxers 126 reconstructions at risk in non-bruxers	Consecutive	17/43 (39%) had complications in the bruxing group 29/126 (23%) had complications in the non-bruxing group; $P < .001$ No influence on implant loss
Tawil et al ³³	2006	109	53.6 (22–80)	53 (12–108) mo	NR	Nobel Biocare	123 FPDs: 22.6% bruxers, 5.9% occasional bruxers, 71.4% nonbruxers	Consecutive patients	22.6% of the patients were defined as bruxers; they had 50% of the veneer fractures; however, ns No significant influence on implant loss
Nedir et al ¹⁹	2006	26 bruxers 189 nonbruxers	NR	8-y life table	72	Straumann	26 bruxers/ 189 nonbruxers	Consecutive	No statistically significant increase in complication rate for FDPs and overdentures NS

NR = not recorded; FDP = fixed dental prosthesis; NS = not significant; I-I = implant-to-implant FDP; I-T = implant-to-tooth FDP; T-T = tooth-to-tooth FDP.

Bruxism (Table 6)

Based on clinical experience, probably every dentist would group bruxers into a high-risk category for technical and mechanical complications and failures. Even implant fractures seem to occur more frequently in bruxers according to case reports. The present literature search indicated five studies in which bruxers were compared to nonbruxers. In two of the clinical reports, statistically significantly higher rates of mechanical/technical complications (ie, 17.3% and 23%) and failures (ie, 60% and 39%) were found in bruxers compared with nonbruxers.^{28,29} In two additional publications, trends toward more frequent mechanical/technical complications and implant losses were observed in bruxers.^{32,33} Nedir et al,¹⁹ however, found no increased rate of complications in FDPs and overdentures in bruxers compared to nonbruxers.

Crown-to-Implant Ratio (Table 7)

Adopted from perioprosthodontic concepts, the crown-to-implant (C:I) ratio might also be a negative biomechanical factor to be considered in implant-supported reconstructions. If the ratio of the supracrestal leverage increases, unfavorable forces and load may be transmitted to the implant. If the crown and the supracrestal implant components have the same length as the osseointegrated part of the implant, the crown-to-implant ratio is 1. It may be logical to expect less favorable load conditions with a crown that is twice as long as the implant, and vice versa.

Three clinical studies were found in which implants and their fixed reconstructions were grouped into ranges of C:I ratios. In 123 FDPs, no significant influence of the parameter C:I on the peri-implant conditions was found over a mean observation period of 53 months.³³ Similar results were obtained by Rokni et al³⁴ over 4 years and Blanes et al³⁵ over 5 years. However, all three studies were restricted to radiographic analyses and did not report mechanical/technical complications.

Length of the Suprastructure (Table 8)

In 105 partially edentulous patients, 283 implants were placed and restored with 80 single crowns, 39 double crowns, and 38 three- to four-unit FDPs.²⁹ Over 5 years, 25% of the single crowns, 35% of the double crowns, and 44% of the three- to four-unit FDPs demonstrated a complication. Of the necessary clinical repairs, 36% were solved by recementation and 30% by retightening the screws. Longer reconstructions seemed to be more prone to complications.

Prosthetic Materials (Table 9)

In addition to gold alloys, other metal alloys have been used to fabricate prosthetic frameworks. A longitudinal study was carried out to compare two cast framework alloys with different mechanical properties: gold alloy and silver-palladium.³⁶ Fixed implant-supported mandibular prostheses were constructed in 26 edentulous patients. The frameworks in group A were cast with Chicago IV gold alloy, and those in group B were cast with Palliag M silver-palladium alloy. Acrylic resin teeth were used and heat cured onto the frameworks. Frameworks had a distal cantilever extension of 10 mm, and the patients received maxillary complete dentures with acrylic teeth. The number of screw loosening (11 in group A and 13 in group B) as well as other technical complications were similar in the groups over 5 years of observation.

In another study, after random assignment, conventional ceramometal cast frameworks were fabricated for FDPs on one side of the jaw in 21 patients, while 21 laser-welded titanium frameworks with low-fusing porcelain were constructed for FDPs on the other side of the jaw.³⁷ An additional cohort of 21 cases with laser-welded titanium frameworks with low-fusing porcelain was added. Fifteen events of fractured porcelain veneer were noted over 5 years with the combination titanium/low-fusing porcelain, compared to three events with the conventional ceramometal FDPs.

In a study by Hedkvist et al, 36 patients were provided with 46 FDPs on 207 implants.³⁸ While 37 prostheses used the conventional implant/abutment configuration, 19 prostheses were placed directly at the implant level (Cresco Ti Precision, Astra Tech). Thirty-three patients with 43 prostheses could be reexamined after 5 to 8 years of function. Technical complications included six resin fractures and one porcelain fracture. These were not related to the type of framework used.

Andersson et al conducted a multicenter study in 32 patients with 105 implants.³⁹ Nineteen short-span FDPs were seated on 53 ceramic abutments (Ceradapt alumina ceramic, Nobel Biocare) and 17 were mounted on 50 titanium abutments. After 5 years, 30 patients with 29 FDPs could be re-examined. Only one of the ceramic abutments failed.

In all four of the above-mentioned studies, no effects on the peri-implant conditions of the different materials used for frameworks or abutments were detected.

Table 7 Crown-to-Implant Ratio

Study	Year	No. of patients	Mean age, y (range)	Mean observation time (range)	No. of implants	Implant system	Crown-to-implant ratio	Type of study	Findings
Tawil et al ³³	2006	109	59.6 (22–80)	53 mo	262	Nobel Biocare	123 FDPs ranged from C:I < 1 to > 2 for 234 implants. 30 were < 1, 8 > 2	Consecutive patients	No influence on bone loss No risk factor for implant loss
Rokni et al ³⁴	2005	74	53 (20–76)	46 mo	199	Endopore	22: ≤ 1.0 157: 1.1–2.0 20: > 2.0	Consecutive patients	No influence on bone loss No risk factor for implant loss
Blanes et al ³⁵	2007	83	NR	6 (5–10) y	192	Straumann	8: 0–0.99 133: 1–1.99 51: ≥ 2	Consecutive patients	No influence on bone loss No risk factor for implant loss

NR = not recorded; C:I = crown-to-implant ratio; FDP = fixed dental prosthesis.

Table 8 Length of Reconstruction

Study	Year	No. of patients	Mean age, y (range)	Mean observation time (range)	No. of implants	Implant system	Type of study	Design of reconstruction	Findings
De Boever et al ²⁹	2006	105	25–86	62.5 ± 25.3 mo	283	Straumann	Consecutive patients	80 SC 39 two connected crowns 38 3- to 4-unit FDP	25% of SC had complications 35% of two connected crowns had complications 44% of 3- to 4-unit FDP had complications, P < .04

SC = single crowns; FDP = fixed dental prosthesis.

Number of Implants Supporting an FDP (Table 10)

In the early days of osseointegration, the number of implants used per reconstruction to replace teeth was preferably kept high. Already by 1995, however, it was reported that the function of full-arch prostheses over 10 years was the same when 14 cases with FDPs on four implants were compared to 70 cases with FDPs on six implants in the maxilla and 13 prostheses on four implants were compared to 59 on six implants in the mandible.⁴⁰ The survival rates for individual implants and prostheses were similar in the groups at the end of a 10-year observation period.

As a concept for the restoration of free-end situations with FDPs on implants, it was advocated to preferably place three implants not aligned but rather offset. The distribution of load would thus prevent implant failures and complications with screw loosening.

In a report by Eliasson et al,⁴¹ 63 FDPs were fixed on two implants and 83 FDPs on three implants. Over 9.5 years (range 5 to 18 years), the survival rates of the FDPs were similar: 96.8% and 97.6%, respectively. FDPs on two implants had more screw loosening ($P < .05$); in FDPs on three implants, more porcelain fractures ($P < .05$) were observed.

Farzad et al⁴² applied measurements of implant stability and found somewhat higher ISQ (Implant Stability Quotient) values assessed by means of Osstell readings at implants supporting three-implant prostheses compared to two-implant prostheses. Apart from that, no differences were observed in the 30 FDPs on two implants and the 74 FDPs on three implants followed over 4 years.

History of Complications (Table 11)

In two studies, odds ratios for reconstructions with previous complications ending in failure were statistically significantly increased compared to reconstructions that had not had previous complications (Table 11).^{43,44} Of 30 failed reconstructions, 15 had already had major so-called retrievable complications (odds ratio 3.55, $P < .001$). Altogether, 214 crowns or FDPs were observed over 4.2 years.⁴³ When 69 single crowns, 33 FDPs on implants, and 22 tooth-implant-supported FDPs were followed over 10 years (range 8 to 12 years), the odds ratio for technical failure of those reconstructions with a previous loss of retention reached 17.6 (95% CI: 3.6 to 86.4). The odds ratio for a suprastructure failure was 11.0 (95% CI: 2.1 to 57.9) for reconstructions with a history of porcelain fractures ($P < .01$).⁴⁴

DISCUSSION

Data Extraction

The main objective of this report was to extract published evidence related to mechanical/technical risk factors for any kind of damage to an implant-supported reconstruction. We searched for technical and/or biological complications or failure rates experienced with or without exposure to a certain mechanical/technical characteristic. Studies related to implant surfaces, loading protocols, tooth-implant-supported reconstructions, implant length, and width of the platform were excluded.

Assessment of Complications and Failures

To compare the outcomes with implant-supported reconstructions achieved in different patient populations, useful parameters for statistical analyses should be provided. Standardization of the criteria used in the assessment of the frequency, the kind of events observed, and the severity of the damage is required. Of particular interest were, therefore, the various attempts of authors to score and describe the outcomes related to experiences with implant-supported reconstructions.

According to Dudic and Mericske-Stern,¹⁸ categories of prosthetic problems with overdentures included:

- Complications and failures of implant-related parts (abutments, bars and anchors, retainers, occlusal screws)
- Mechanical and structural failures of prostheses (denture base, teeth, prosthetic design, fabrication of new dentures)
- Prosthesis-related adjustments (relining, occlusion, esthetics, hyperplasia)

The rates of prosthetic maintenance services (events per patient) were calculated for comparable periods of time (per year, per 2 years, per 5 years) and according to the three categories.¹⁸ The rates of prosthetic maintenance per patient over 5 years were similar for resilient and rigid types of fixation; however, the characteristics of the complications were different. An additional useful parameter for statistical analyses was also assessed by calculating the time to the first event for resilient and rigid attachment systems.

In other reports, a clinical implant performance scale (CIP) was used.¹⁴ This included scores from 0 to 4, as follows:

Table 9 Material Aspects

Study	Year	No. of patients	Mean age, y (range)	Mean observation time (range)	No. of implants	Implant system	Design of reconstruction/materials used	Type of study	Findings
Murphy et al ³⁶	2002	26	60	5 y	NR	Astra Tech	13 FDP mandible Chicago IV gold alloy A 13 FDP Palliag M silver palladium B	Not randomized	Similar number of events for technical complications No influence on bone loss; no risk factor for implant loss
Jemt et al ³⁷	2003	42	56 ± 11 50 ± 12	5 y	170	Nobel Biocare	21 FDP ceramometal cast framework left 21 FDP ceramometal cast framework right with low-fusing porcelain 21 with titanium framework prosthesis with low-fusing porcelain	Groups arranged at random, split mouth	No difference in prosthesis survival, more porcelain chips with titanium 19% versus 10% ($P > 0.3$) No risk factor for implant loss No more bone loss
Hedkvist et al ³⁸	2004	36	NR	5-8 y	207	Nobel Biocare	27 prostheses with abutment 19 at implant level, Cresco Ti Precision	Consecutive	No difference in complication rates No difference in bone loss around implants
Andersson et al ³⁹	2003	32/30	NR	5 y	105/103	Nobel Biocare	53 ceramic abutments (Ceradapt alumina ceramic) 50 titanium abutments 19 FDP on ceramic abutments 17 FDP on titanium abutments/29 left Short FDP	Consecutive	Patients satisfied with esthetics Only one ceramic abutment failed No influence on implant bone loss

NR = not recorded, FDP = fixed dental prosthesis

Table 10 Number of Implants

Study	Year	No. of patients	Mean age, y (range)	Mean observation time (range)	No. of implants	Implant system	Design of reconstruction/materials used	Type of study	Findings
Eliasson et al ⁴¹	2006	178	65 (32-91)	9.5 (5-18) y	375	Nobel Biocare	63 FDP on 2 implants 83 FDP on 3 implants Free-end situations	Not randomized	Survival rate 96.8%/97.6% More screw loosening with 2 implants; $P < .05$ More porcelain fractures with 3 implants; $P = .05$
Farzard et al ⁴²	2004	34	62 (43-80)	3.9 y	210	Nobel Biocare	30 FDP on 2 implants 74 FDP on 3 implants	Not randomized	No influence on implant loss and bone loss Small difference in ISQ value No influence on reconstruction No influence on implant loss
Brånemark et al ⁴⁰	1995	156	NR	10 y	882	Nobel Biocare	Maxilla: 14 FDP on 4 implants 70 FDP on 6 implants Mandible: 13 FDP on 4 implants 59 FDP on 6 implants	Age- and gender-matched groups	Function of prostheses over 10 y was same All mandibular prostheses stable 1/14 on 4 implants lost 6/70 on 6 implants lost in the maxilla Survival of implants 88.4%/ 93.4% Higher risk to lose an implant if only 4 were placed

NR = not recorded; ISO = implant stability quotient; FDP = fixed dental prosthesis.

Table 1.1 Complications Leading to Failures

Study	Year	No. of patients	Mean age, y (range)	Mean observation time (range)	No. of implants	Implant system	Design of reconstruction/materials used	Type of study	Findings
Parein et al ⁴³	1997	152	55.7 (14–90)	4.2 y	392	Brånemark	56 SC on implants 168 FDP on implants	Consecutive	Of 30 failures with reconstructions, 15 had major so-called retrievable complications before Odds ratio 3.55; $P < .001$
Brägger et al ⁴⁴	2005	89	58.9 (28–88)	10 (8–12) y	160 (24 teeth)	Straumann	69 SC on implants 33 FDPs H 22 FDPs I-T	Prospective	Loss of retention leading to technical failure; Odds ratio 17.6 (3.6–86.4); $P < .001$ Fracture of porcelain leading to technical failure; Odds ratio 11.0 (2.1–57.9); $P < .004$

SC = single crowns; FDP = fixed dental prosthesis; H = implant-to-implant FDP; I-T = implant-to-tooth FDP.

0: Success, no complications

- 1: Minor complications, such as: gingival hyperplasia, relining of maxillary or mandibular dentures, readjustment of occlusion, clip loosening, coping/screw loosening, broken abutment, a slight disturbance of the mental nerve, probing depth = 6 mm, or x-ray score 1 with PPD 5 mm
- 2: Complications with a chance of recovery or stabilization of the present situation, such as: correction of a non-fitting superstructure, fracture of the superstructure, a severe disturbance of the mental nerve, x-ray score 1 with PPD 6 mm, or x-ray score 2 with PPD 5 mm
- 3: Serious complications that may lead to failure of the implant system: X-ray score 2 with PPD 6 mm or x-ray score 3
- 4: Failure of the implant system: removal of one or two implants after placement of the suprastructure

The x-ray score 0 related to no apparent bone loss; 1, to a reduction $< 1/3$ of the length of the implant; 2, to a reduction between $> 1/3$ and $< 1/2$ of the implant length; and 3, to a reduction $> 1/2$ of the implant length.

Pooling wide ranges of biological and technical complications in the same category may mask clinically important differences between groups.⁴³

In 2006, Nedir et al grouped prosthetic complications of overdentures into foreseeable and nonforeseeable events.¹⁹ Change of female parts of the spherical attachment, change of the clip, and relining were categorized as foreseeable. Mechanical retention problems, repair and replacement of the overdenture, and complications of the opposing complete denture were unforeseeable complications in the overdenture group. For the fixed restoration group, complications were graded as minor or major. A fracture was considered major if it affected esthetics, caused the metal framework to be visible, resulted in a missing interproximal contact point, or caused the patient to complain of tongue- or masticatory-related discomfort. Major fractures resulted in a prosthesis remake; minor fractures did not lead to remakes.

In a series of systematic reviews on complication and failure rates reported with various types of reconstructions on teeth and implants, the extracted data were listed as the estimated event rates per 100 reconstructions per year, considering the actual exposure time and assuming no change in the long-term risk intensity.⁶ Statistically significantly increased failures rates were calculated for cantilever FDPs on teeth and tooth-implant-supported FDPs compared to FDPs on teeth without extension, implant-supported FDPs, and single crowns on implants over 10 years. In addition, statistically signifi-

cantly increased complication rates were calculated for loss of vitality and loss of retention when comparing cantilever FDPs with conventional FDPs. The 5-year complication rates were similar for the implant-supported FDPs and single crowns.

Risk Factors Affecting the Implants

The most obvious and clinically relevant finding in this review is that almost none of the technical/mechanical risk factors extracted seemed to affect the implant per se or the surrounding bone. This is very surprising, since for many years overload, nonaxial loading, and biomechanical stress were considered the main reasons for implant losses.

Risk Factors Affecting the Suprastructures

Eight studies presented comparisons of prosthetic outcomes with overdentures using different attachment systems and implant components in the edentulous mandible—the best model in prosthodontics to perform RCTs. The groups compared, however, were so diverse that an analysis of the combined data was not feasible.

Some of the overdenture designs, however, indicated clinically relevant increased risks.

Satisfaction of the patients with the retention of an overdenture was affected by the attachment mechanism and seemed to be best with bar devices. The amount of aftercare was higher with spherical attached systems in most of the reports. Fractures of dentures occurred frequently if no metal frameworks were constructed, especially with bar devices.

In two of four included reports, the presence of a cantilever extension in an FDP on implants did not lead to increased failure or complication rates.^{24,25} The reported higher rate of failures with FDPs on implants was restricted to very long cantilever extensions (> 15 mm).²³ The small number of FDPs with cantilever extensions in the report by Nedir et al may not be representative.¹⁹

Findings from a meta-analysis of a systematic review on implant-supported short-span FDPs with cantilever extensions yielded estimated survival rates of 94.4% (95% CI: 87.0 to 97.6) after 5 years and 89.1% (95% CI: 75.7 to 95.3) after 10 years.⁴⁵

The lack of a negative effect of cantilever extensions in FDPs on implants is in contrast to the increased complication and failure rates reported with cantilever extensions in FDPs on teeth.⁴ For treatment-planning aspects, this mechanical/technical advantage of implant-supported reconstructions is of considerable importance.

In three of four publications comparing complications/failures with screw-retained versus cemented FDP crowns, the retention mechanism could not be

identified as a risk factor. Both of two extracted papers on angled abutments did not indicate that angulations > 15 degrees for the abutments and the prosthesis had any effect on the outcome. The patient risk factor bruxism resulted in significantly increased event rates in two studies, in trends for higher rates in two studies, and in no difference in one report.

From a retrospectively assessed cohort of 368 patients with 838 endosseous implants, 19 cases were selected in which there were technical/mechanical complications such as implant fractures, abutment fractures, screw loosening, occlusal wear, or damage to the prosthesis.⁴⁶ The 19 patients were evaluated for sleep bruxism using polysomnographic analysis. Most of the bruxism episodes occurred during light sleep and did not cause arousal, and the patients were unaware of the nocturnal parafunctional habits. Bruxism was reported to have continued despite the fact that all these patients were provided with a nightguard.

Crown-to-root ratio, material aspects, and the number of implants placed were not identified as risk factors for increased failure/complication rates. The complexity of a reconstruction, expressed as the number of units, was identified as a risk in only one study, and having had a previous complication was identified as a risk in two.

The implant length in relation to the height of the suprastructure as well as the number of implants needed to physically support an FDP and assure its function are risk factors related to the quality and quantity of the osseointegration and the torque needed to disrupt the “chemical” and histologic bonding between the supporting bone and the implant surface.

Efforts to improve osseointegration in implant dentistry by modifying the surface characteristics, such as the topography and chemistry, have led to much more reliable clinical results compared to the original machined implants when using shorter and fewer implants.^{47,48}

Limitations/Critical Remark

The fact that some of the mechanical/technical characteristics evaluated were not identified as true risk factors in this review does not mean that they are not, in fact, risks. Limitations of the study designs, too many uncontrollable variables, small number of subjects, etc, may have hidden the actual facts in some of the studies.

CONCLUSIONS

- Mandibular overdentures: Independent of the retentive element system used, patients required multiple prosthetic services during the observation period (six RCTs). Technical/mechanical complications occurred more frequently with a ball attachment than with a bar retentive system (one RCT). With respect to retention, patients were most satisfied with a bar retentive system, followed by ball anchors, and least satisfied with magnets (one RCT). Metal frameworks protected overdentures from fractures (one consecutive case study).
- The presence of cantilever extensions was not associated with increased mechanical/technical risks for implants supporting short-span FDPs (three consecutive case studies).
- The presence of cantilever extensions > 15 mm was associated with an increased risk of full-arch FDP fracture compared with the presence of cantilever extensions ≤ 15 mm (one consecutive case study).
- No increased mechanical/technical risks for FDPs were observed in three of four studies (one prospective, one retrospective, and one consecutive case study) comparing screw-retained versus cemented reconstructions.
- The presence of angled/angulated abutments was not associated with increased mechanical/technical risks for implant-supported FDPs (one consecutive case study).
- Increased mechanical/technical risks for FDPs were observed in bruxers in four of five studies (two retrospective and two consecutive case studies) comparing bruxers and nonbruxers.
- The crown-to-implant ratio was not associated with implant loss and marginal bone loss of implants supporting FDPs (2 consecutive case studies).
- Increased mechanical/technical risks for FDPs were observed in 1 study (consecutive cases) comparing 3- to 4-unit FDPs with single crowns and double crowns.
- Increased mechanical/technical risks for FDPs were observed in two studies (consecutive case studies) comparing FDPs with and without a history of complications.
- Regarding the survival/success rate of the implant, none of the 10 listed mechanical/technical risks had an influence.

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