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## Internal vs. external connections for abutments/reconstructions: a systematic review

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### Conflict of interest

IS has acted as an advisor for VITA, and the University Department has research collaborations with 3M ESPE, Straumann, Astra, Ivoclar, DeguDent and Sirona. The remaining authors have no potential conflicts to declare.

**Key words:** external connection, implant connection, internal connection, systematic review

### Abstract

**Objectives:** The objectives of the review were (1) to evaluate the accuracy of implant-level impressions in cases with internal and external connection abutments/reconstructions, and (2) to evaluate the incidence of technical complications of internal and external connection metal- or zirconia-based abutments and single-implant reconstructions.

**Materials and methods:** A MEDLINE electronic search was conducted to identify English language publications in dental journals related to each of the two topics by inserting the appropriate keywords. These electronic searches were complemented by a hand search of the January 2009 to January 2012 issues of the following journals: *Clinical Oral Implants Research*, *The Journal of Prosthetic Dentistry*, *The International Journal of Prosthodontics*, *The International Journal of Periodontics and Restorative Dentistry*, *The International Journal of Oral Maxillofacial Implants*, *Clinical Implant Dentistry and Related Research*.

**Results:** Seven *in vitro* studies were included in the review to evaluate the accuracy of implant-level accuracy. No clinical study was found. There was no study that directly compared the influence of internal and external implant connections for abutments/reconstructions on the accuracy of implant-level impressions. All *in vitro* studies reported separately on the two connection designs and they did not use same protocol and, therefore, the data could not be compared.

Fourteen clinical studies on metal-based abutments/reconstructions and five clinical studies on zirconia-based abutments/reconstructions satisfied the inclusion criteria and, therefore, were included in the review to evaluate the incidence of technical complications. The most frequent mechanical complication found in both implant connection design when employing metal abutments/reconstructions was screw loosening.

**Conclusions:** Implant-level impression accuracy may be influenced by a number of variables (implant connection type, connection design, disparallelism between multiple implants, impression material and technique employed). Implant divergence appears to affect negatively impression accuracy when using internal connection implants.

Based on the sparse literature evaluating the incidence of technical complications of metal or zirconia abutments/reconstructions, it was concluded that:

- The incidence of fracture of metal-based and zirconia-based abutments and that of abutment screws does not seem to be influenced by the type of connection.
- Loosening of abutment screws was the most frequently occurring technical complication. The type of connection seems to have an influence on the incidence of the screw loosening: more loose screws were reported for externally connected implant systems for both types of materials. However, proper preload may decrease the incidence of such a complication.

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Since the introduction of the Brånemark system to the scientific community in the 1960s and 1970s, a large number of implant systems have been developed and have become available to the dental profession (Kirsch 1983; Brånemark et al. 1985;

Albrektsson et al. 1986; Babbush 1986). One of the features that has been the object of debate among the systems is the design of the connection that allows the prosthetic superstructure to be attached to the implants. From the beginning, the Brånemark system

was characterized by an external hexagon which was developed to facilitate implant insertion rather than to provide clinicians with an antirotational device (Brånemark et al. 1985). This external hexagon configuration has served well over the years and it has been incorporated in a number of competing systems. However, it has some drawbacks due to its limited height and, as a consequence, limited effectiveness when subjected to off axis loads (Weinberg 1993). Hence, it has been speculated that, under high occlusal loads, the external hexagon might allow for micromovements of the abutment, thus causing instability of the joint which may result in abutment screw loosening or even fatigue fracture (Adell et al. 1990; Jemt et al. 1991; Becker & Becker 1995).

Internal connections have been introduced to lower or eliminate these mechanical complications and reduce stress transferred to the crestal bone (Sutter et al. 1993; Norton 1997; Merz et al. 2000; Finger et al. 2003). A primary question is whether or not this may be true for all internal connection systems (Balfour & O'Brien 1995; Norton 1999; Steinebrunner et al. 2008) since, unlike the external hexagon connection, the internal connection configurations adopted by different companies are not alike. When analyzing the implant-abutment coupling of internal connecting systems, many differences have been described (Wiskott et al. 2007; Steinebrunner et al. 2008; Bernardes et al. 2009; Coppède et al. 2009; Tsuge & Hagiwara 2009):

- intimacy of approximation between the abutment's surface and the internal walls of the implant fixture (no friction vs. Morse taper),
- depth of penetration of the abutment in the fixture,
- presence of antirotational interlocking,
- number and shape of antirotational or guiding grooves (hexagon, trilobe, spline, etc.),
- abutment diameter at the platform level (matched vs. narrower, to generate a platform shift or switch),
- abutment screw dimension and material,
- screw preload,
- abutment materials allowed (titanium, precious metal alloys, full zirconia, zirconia with metal inserts).

These differences might have profound impact on the clinical procedures and protocols, chair-time dedicated to the patient, number of appointments, laboratory and component costs, maintenance intervals, and incidence of complications. Therefore, the clinician has to analyze the different biome-

chanical features and understand their implications to make a rational choice between an external and an internal connection system. The two aspects which were investigated by this review are implant-level impression taking and fixture-abutment/reconstruction joint stability.

When making an impression of dental implants, the goal is to produce a master cast that is the replica of the clinical situation. To this end, the technique and materials employed must allow the clinician to capture the three dimensional spatial relationship of the fixtures (or abutments). This is important especially when splinting multiple implants with a fixed dental prosthesis (FDP). Consequently, a primary goal to fulfill when fabricating such a restoration is to ensure that the reconstruction is passively adapted to all fixtures or abutments.

Factors that might generate impression distortion are premature removal of the impression from the oral cavity, deformation due to rigidity of the impression material, number and degree of undercuts present in the arch, lack of parallelism between the implants, depth and intimacy of the coupling between impression coping and fixture, direction of impression tray removal with respect to implant axis, undue torque applied to the impression coping screw when connecting the implant or abutment analogue to the coping itself embedded in the set impression.

A recent literature review (Lee et al. 2008) has looked at the influence that reported impression techniques (splint, pick up and transfer) and other clinical factors have on the accuracy of implant impressions. Forty-one *in vitro* studies were selected and their data compared. However, the majority of the studies in this review evaluated abutment-level impressions. Usually, there is no antirotational configuration in these abutments. Therefore, there was a need for a new literature review to investigate whether or not the different types of external and internal implant connection configurations influence the accuracy of fixture-level impressions of multiple implants and, thus, of the resulting definitive cast.

When fabricating an implant-supported FDP, one of the concerns of the clinician to ensure its longevity is to minimize mechanical complications. Many publications in the international literature deal with the incidence of screw loosening or fracture, as well as with the incidence of abutment and implant fracture. Four literature reviews (Pjetursson et al. 2004; Jung et al. 2008; Theoharidou et al. 2008; Sailer et al. 2009b) have provided an in depth analysis of the

topic. These papers point out and analyze the major factors that may cause mechanical complications:

- screw material (Tsuge & Hagiwara 2009),
- screw preload (Martin et al. 2001; Siamos et al. 2002; Otorp et al. 2005; Park et al. 2010),
- abutment material (Apicella et al. 2011; Kim et al. 2011),
- abutment rotational misfit (Binon 1995, 1996; Binon & McHugh 1996; Vigolo et al. 2008),
- implant-abutment connection configuration (Perriard et al. 2002; Maeda et al. 2006; Vigolo et al. 2008),
- implant angulation (Ha C-Y et al., 2011),
- thickness of implant neck walls (Meng et al. 2007; Lee et al. 2011),
- single vs. splinted crowns (Clelland et al. 2010; Nissan et al. 2010).

In particular, after the change of the abutment screw material in the 1990s, and the recommendation of system-specific torque values for these screws, the type of implant-abutment connection configuration has been pointed out as the most relevant variable that can ensure implant-abutment joint stability. It has already been postulated that internal implant-abutment connections demonstrate higher resistance to bending and improved force distribution over external configurations (Asvanund & Morgano 2011; Freitas et al. 2011) because of their:

- ability to dissipate lateral loads deeply within the implant and to resist joint opening due to the deep and rigid connection which creates a unified body, thus displaying a more favorable load distribution in the connection area (Steinebrunner et al. 2008; Bernardes et al. 2009; Sailer et al. 2009a; Seetoh et al. 2011); and
- improved shielding of the abutment screw from stress (Norton 1997).

The use of high-strength ceramics, previously alumina and nowadays zirconia, has provided an alternative to metal abutments (Happe et al. 2011). When using polycrystalline ceramic implant abutments in the clinical situation, there are concerns about the risk of fracture due to the material's brittle nature. This is especially true in internal connection systems, where the interlocking portion may be particularly thin. As a matter of fact, several manufacturing companies do not provide zirconia abutments for their narrow platform implants. *In vitro* studies have provided some insight into the behavior of ceramic abutments in different types of

implant systems (Vigolo et al. 2006; Sailer et al. 2009a; Nothdurft et al. 2010a; Klotz et al. 2011; Seetoh et al. 2011; Truninger et al. 2011), but it is difficult to draw from them clinically relevant recommendations. One of the difficulties in ascribing clinical value to the results of *in vitro* studies has to do with the lack of evidence for the diverse methods of loading implant abutments. They differ for: type of loading (static loading or dynamic fatigue loading, lateral-oblique loading [Tsuge & Hagiwara 2009] or rotational fatigue loading [Wiskott et al. 2007]); loading angle (from 0 to 90°); loading point (incisal edge or a non specified point on the palatal surface); applied load (light forces or forces which exceed the maximum bite force recorded in humans). It is debatable which is the most clinically relevant method. Therefore, it is the analysis of the clinical performance that can best demonstrate the reliability of this prosthetic device. Two very thorough systematic reviews on the performance of ceramic and metal implant abutments (Sailer et al. 2009b) and on zirconia abutments only (Nakamura et al. 2010) have been published recently. The former review includes 29 clinical and 22 laboratory studies selected from an initial pool of 7136 papers. The clinical studies were composed by RCT's, prospective and retrospective cohort studies with more than 3 years of follow-up time (Sailer et al. 2009b). Of this group, only five analyzed the clinical behavior of ceramic abutments, two made of densely sintered alumina (Andersson et al. 2001, 2003) which is no longer available on the market, two of zirconia (Glauser et al. 2004; Zembic et al. 2009), and one of zirconia with a titanium insert (Canullo 2007), for a total number of 166 abutments. In comparing the outcome of the studies on ceramic abutments to the one of the studies on metal abutments (which analyzed 4807 abutments), the authors concluded that no difference in the clinical performance of the two types of abutments could be noticed.

The review by Nakamura et al. (2010), on the other hand, looked specifically at four different areas of interest on zirconia abutments: mechanical properties, soft tissue response, plaque accumulation, and results from clinical studies. For this last search, only clinical studies with a minimum number of 20 subjects at baseline and at least a 1-year follow-up were identified and, eventually, only 3 were included (Glauser et al. 2004; Canullo 2007; Zembic et al. 2009). The authors reached the same conclusions as in the previous review, highlighting the fact

that, in this short- to medium-period of evaluation, no relevant mechanical complications occurred. Still, they cautioned that the number of abutments followed was too small for them to recommend a wide use of this prosthetic solution, also taking into consideration the fact that much still needs to be clarified about zirconia's aging process.

Thus, the aims of the present systematic review were to update the literature and to investigate the following:

1. if there is any significant difference in accuracy between implant-level impressions made on internal or external connection implant systems;
2. if there is any clinical evidence that abutments/prostheses for internal connection implant systems have less incidence of technical complications compared to abutments/prostheses for external connection implant systems in patients with implants to be restored with single metal-based and/or zirconia-based restorations.

## Materials and methods

The first focused PICO question of the present systematic review was whether or not the different types of external and internal implant connections for abutments/reconstructions influence the accuracy of implant-level impressions of multiple implants and, therefore, of the resulting master cast. A MEDLINE electronic search was conducted to identify English language publications in dental journals from 1990 to January 2012 related to fixture-level impressions by inserting the following keywords: "internal connection" OR "external connection" OR "implant abutment connection" OR "implant abutment interface" OR "implant divergence" OR "implant-level impression" OR "impression\*" AND "implant". To be included in this review, the study had to analyze implant-level impressions of two or more fixtures. Exclusion criteria were, therefore, the following: single implants, and abutment-level impressions.

The initial search yielded 1127 titles. After the initial screening, the search was narrowed to 120 abstracts. After evaluation of these abstracts, 15 articles were selected for full text reading and only 7 for inclusion in the review (Table 1). All are *in vitro* studies since no clinical study was found. A manual search of the January 2009 to January 2012 issues of the following journals did not

provide any additional references: *Clinical Oral Implants Research*, *The Journal of Prosthetic Dentistry*, *The International Journal of Prosthodontics*, *The International Journal of Periodontics and Restorative Dentistry*, *The International Journal of Oral Maxillofacial Implants*, *Clinical Implant Dentistry and Related Research*.

The second focused PICO question was whether or not an internal connection of the implant-supported prostheses can influence the technical complication rates when compared to an external connection for patients with single implants to be restored with metal-based and/or zirconia-based FDPs. A MEDLINE electronic search was initially conducted to identify English language publications in dental journals by inserting the following keywords: "implant internal connection" OR "implant external connection" OR "implant abutment connection" OR "implant abutment interface" OR "implant abutment" OR "screw loosening" OR "screw fracture" OR "screw retention" OR "screw complication" OR "mechanical complication" OR "technical complication" OR "failure" OR "load fatigue" AND "implant". The following limits were activated: humans, clinical trial, meta-analysis, randomized controlled trial, review, clinical trial, phase I, clinical trial, phase II, clinical trial, phase III, clinical trial, phase IV, comparative study, controlled clinical trial, multicenter study. As for PICO question 1, also this electronic search was complemented by analyzing the reference list of previous literature reviews and by hand search of the January 2009 to January 2012 issues of the same journals.

The general electronic search produced 1336 titles. After the initial screening of these titles, the search was narrowed by further defining terms and limits that would help identify pertinent clinical studies investigating the performance of, on one side, metal abutments/reconstructions and, on the other, zirconia abutments/reconstructions. For the search on metal abutments, the following keywords were inserted: "dental implant" OR "implant abutment" AND "metal". This produced 422 abstracts. After analyzing these abstracts, 22 articles were selected for full text reading.

For the search on zirconia abutments, instead, the following keywords were used: "dental implant" AND "implant abutment" AND "zirconia". This search produced 104 titles. It was then narrowed down by limiting it to clinical studies and RCT's on humans, and by specifying the time frame to the

Table 1. *In vitro* studies on implant-level impression accuracy

Authors and year of publication	Implant brand (manufacturer)	Connection type	No. of implants to be connected	Distance between implants (mm)	Degree of implant divergence or convergence	No. of impressions and technique	Coping type	Splinting method	Impression material	Evaluation method	Outcome
Vigolo et al. (2004)	Certain (Biomet 3i)	Internal	Four in a fully edentulous arch	Posterior implants (#1 and #4): 28.2 Anterior implants (#2 and #3): 12.9	Almost 0°	15 15 15	Square Square Square	None Floss and resin Abraded and adhesive-coated copings	Medium viscosity PE	Profile projector (2-D)	Improved accuracy was achieved when the square copings joined by resin were used
Cabral and Guedes (2007)	SIN (Sistema de Implante Nacional)	Internal (parallel hex)	2	20	0°	15 15 15 15	Tapered Square Square Square	None None Resin Resin sectioned and welded	VPS (putty soft and light body in 1-step procedure)	Profile projector (2-D)	No statistically significant differences Technique with square copings with resin sectioned and welded produced a model that was more similar to the master metal framework Square copings splinted with resin showed the worst accuracy
Choi et al. (2007)	Astra 5T (Astra Tech)	Internal, with a 11° taper and hexagon	2	10	0° 8°	10 10 10 10	Square Square Square Square	Resin sectioned and welded None Resin sectioned and welded	Low viscosity VPS	Framework deformation (3-D evaluation with strain gauges)	Accuracy of impressions was similar for splinted and non splinted copings, and for parallel and 8° divergent implants
Assuncao et al. (2008)	Conexao (Conexao Prosthesis System)	External	2	n.r.	25°	10 10 10	Square Square Square	None Floss and resin in bulk Abraded copings Abraded and adhesive-coated copings	Medium viscosity PE	Digitalization of model and 2-D measurement of implant analogues' inclination	Square copings abraded by aluminum oxide produced the most accurate master casts Implants perpendicular to the surface tend to generate less displacement of the transfer coping than inclined implants All replicas were different from the reference model, especially for the angulated implant Best techniques: copings splinted either with a prefabricated resin bar or a direct resin bridge, sectioned and then welded again
Filho et al. (2009)	Conexao (Conexao Prosthesis System)	External	2	n.r.	25°	6 6 6 6	Square Square Square Square	None Resin in bulk Resin sectioned and welded Prefabricated resin bar	Medium viscosity PE	Digitalization of model and 2-D measurement of implant analogues' inclination	Digitalization of model and 2-D measurement of implant analogues' inclination

Table 1. (continued)

Authors and year of publication	Implant brand (manufacturer)	Connection type	No. of implants to be connected	Distance between implants (mm)	Degree of implant divergence or convergence	No. of impressions and technique	Coping type	Splinting method	Impression material	Evaluation method	Outcome
Sorrentino et al. (2010)	Winsix Implant System (BioSAF)	Internal, with parallel walls and apical engaging hex	4 in a partially edentulous arch	Posterior implants (#1 and #4); 21.4Anterior implants (#2 and #3); 8.7	0°	10 10 10 10	Square, 1 mm hex Square, 2 mm hex Square, 1 mm hex Square, 2 mm hex	None	Medium PE viscosity Medium PE viscosity Medium VPS Medium viscosity Medium viscosity Medium VPS	Profile projector (2-D)	With parallel implants and use of polyethers, 2 mm connections produced more accurate casts
Jang et al. (2011)	Implantium (Dentium)	Internal	2	14.5	0° 5° 10° 15° 20°	10 10 10 10	Square, 1 mm hex Square, 2 mm hex Square, 1 mm hex Square, 2 mm hex	None	Medium PE viscosity Medium PE viscosity Medium VPS Medium viscosity Medium VPS Medium viscosity Medium VPS	Profile projector (2-D)	With nonparallel implants, VPS resulted in more accurate casts, especially when 1 mm connections were used
						10 for each angulation	Square	None	Medium PE viscosity Medium VPS	Profile projector (2-D)	A statistically significant difference was found for the 20° divergent implants

n.r., not reported; PE, polyether; VPS, vinylpolysiloxane.

period from January 2009 to January 2012 since the reviews by Sailer et al. (2009b) and Nakamura et al. (2010) had examined the previous years' publications very thoroughly. In this way, the number was reduced to six papers whose full text was read. The manual search produced four additional newly published studies on zirconia abutments (Nothdurft & Pospiech 2010b; Ekfeldt et al. 2011; Hosseini et al. 2011; Kim et al. 2012).

Only clinical studies, RCTs, prospective and retrospective cohort studies, were included in this review. Furthermore, these studies had to fulfill the following inclusion criteria:

- a mean follow-up of at least 3 years for metal abutments/reconstructions and 1 year for zirconia abutments/reconstructions;
- the abutments had to support single restorations;
- the patients had to be examined clinically at the follow-up intervals;
- detailed information about the connection type and the type of abutments being used had to be reported;
- abutment and prosthetic complications had to be reported.

The exclusion criteria applied were the following:

- alumina based abutments/reconstructions;
- insufficient information about the connection type and/or the type of abutments used;
- splinted FDPs.

The alumina-based abutments/reconstructions were excluded since they are no longer available on the market.

**Statistical analysis**

Failure and complication rates were calculated by dividing the number of events (failures or complications) as the numerator by the total time of the reconstructions being under observation as the denominator. The numerator could usually be extracted directly from the publication. The total exposure time was estimated by multiplying the mean follow-up time by the number of constructions under observation.

For each study, event rates for the reconstructions were calculated by dividing the total number of events by the total reconstruction exposure time in years. For further analysis, the total number of events was considered to be Poisson distributed for a given sum of construction-years and Poisson regression with a logarithmic link-function and

**Table 2. Clinical studies on complications of single-implant metal abutments and metal-based reconstructions**

Authors and year of publication	Study design	Setting	Mean follow-up (years)	Implant system (manufacturer)	No. of abutments	No. of abutments at end of time interval	Abutment material	Location in arch	No. of screw loosening	No. of screw fractures	No. of abutment fractures
<b>Internal connections</b>											
Wennstrom et al. (2005)	Prospective	University	5	Astra (Astra Tech)	41	32	Titanium	Maxilla and mandible	3	0	0
Bragger et al. (2005)	Prospective	University	10	ITI (Straumann)	69	64	Titanium	n.r.	1	0	0
Cooper et al. (2007)	Prospective	University	3	Astra (Astra Tech)	54	43	Titanium	Anterior maxilla	0	0	0
Gotfredsen (2012)	Prospective	University	10	Astra (Astra Tech)	20	19	Titanium	Anterior and premolar maxilla	2	0	0
				<b>Total</b>	<b>184</b>	<b>158</b>			<b>6</b>	<b>0</b>	<b>0</b>
<b>External connections</b>											
Henry et al. (1996)	Prospective	Private practice	5	Brånemark (Nobel Biocare)	107	86	Titanium	Anterior maxilla	28	1	0
Andersson et al. (1998)	Prospective	Private practice	5	Brånemark (Nobel Biocare)	65	58	Titanium	Maxilla and mandible	0	0	0
Scheller et al. (1998)	Prospective	University	5	Brånemark (Nobel Biocare)	99	97	Titanium	Maxilla and mandible	0	0	0
		Private practice; multicenter									
Wannfors & Smedberg (1999)	Prospective	Hospital	3	Brånemark (Nobel Biocare)	80	76	34 Titanium, 44 Gold	Maxilla and mandible	14	0	0
Cho et al. (2004)	Prospective	University	3.2	Brånemark (Nobel Biocare)	213	213	Gold	Posterior mandible/maxilla	24	0	n.r.
Vigolo et al. (2006)	Prospective	University	4	Osseotite (Biomet 3i)	40	40	20 Titanium, 20 Gold	16 max. premolar, 16 max. molar, 8 mand. molar	0	0	0
Jemt (2008)	Retrospective	University	Up to 15	Brånemark (Nobel Biocare)	47	32	Titanium	Maxilla and mandible	20	0	0
Schropp & Isidor (2008)	RCT	University	5	Osseotite (Biomet 3i)	42	34	Titanium or Gold	Maxilla and mandible	0	0	0
Zembic et al. (2009)	RCT	University	3	Brånemark (Nobel Biocare)	40	28	Titanium	Maxilla and mandible	0	0	0
Jemt (2009)	Retrospective	University	10	Brånemark (Nobel Biocare)	18	13	Titanium	Anterior and premolar regions	2	0	0
				<b>Total</b>	<b>751</b>	<b>677</b>			<b>88</b>	<b>1</b>	<b>0</b>
n.r., not reported.											

**Table 3. Clinical studies on complications of single-implant zirconia abutments and zirconia-based reconstructions**

Authors and year of publication	Study design	Setting	Follow-up (months)	Implant system	No. of abutments	No. of abutments at end of time interval	Abutment material	Reconstruction material	Cement retained	Screw retained	Location in arch	Screw loosening	Screw fractures	Abutment fractures
<b>External connection</b>														
Glauer et al. (2004)	Prospective	Private practice	49.2 (mean)	Brånemark (Nobel Biocare)	54	36	Zirconia	All ceramic (leucite glass ceramic)	36	0	25 incisors 14 canines 15 premolars	2 (at 8 months and at 27 months)	n.r.	0
Zembic et al. (2009)	Prospective RCT	University	36 (mean)	Brånemark (Nobel Biocare)	20	18	Zirconia	17 all ceramic 1 metal-ceramic	16	2	2 canines, 11 premolars and 5 molars	0	0	0
				<b>Subtotal</b>	<b>74</b>	<b>54</b>		<b>Subtotal</b>	<b>52</b>	<b>2</b>		<b>0</b>	<b>0</b>	<b>0</b>
<b>Internal connection</b>														
Canullo (2007)	Prospective	Private practice	40 (mean)	TSA (Impladent)	30	30	Zirconia with titanium insert	All ceramic	30	0	12 incisors, 4 canines, 4 molars	0	0	0
Nothdurft & Pospiech (2010b)	Prospective	University	12	XiVE S plus (Friatec)	40	40	Zirconia	All ceramic (zirconia supported)	40	0	Posterior	0	n.r.	0
Hosseini et al. (2011)	RCT	University	12	Astra (Astra Tech)	38	38	Zirconia	Zirconia	38	0	Premolars	0	0	0
				<b>Subtotal</b>	<b>108</b>	<b>108</b>		<b>Subtotal</b>	<b>108</b>	<b>0</b>		<b>0</b>	<b>0</b>	<b>0</b>
				<b>Total</b>	<b>182</b>	<b>162</b>		<b>Total</b>	<b>160</b>	<b>2</b>		<b>0</b>	<b>0</b>	<b>0</b>

n.r., not reported.

total construction-time per study as an offset variable were used (Kirkwood & Sterne 2003). Robust Poisson regression (by calculating robust standard errors for the summary rates) were used to obtain a summary estimate and 95% confidence intervals of the event rates, which incorporated possible heterogeneity among studies. Three-year survival proportions were calculated via the relationship between event rate and survival function  $S$ ,  $S(T) = \exp(-T \times \text{event rate})$ , by assuming constant event rates. Cumulative incidence estimates were calculated as  $1 - S(T)$ . Multivariable Poisson regression was used to formally compare different types of reconstructions (with internal or with external connection design). All  $P$ -values are two-sided and analyses were performed using Stata®, version 12 (Stata Corp., College Station, TX, USA).

## Results

Table 1 illustrates the results of the search to PICO question 1. Seven *in vitro* studies were identified (Vigolo et al. 2004; Cabral & Guedes 2007; Choi et al. 2007; Assunção et al. 2008; Filho et al. 2009; Jang et al. 2011; Sorrentino et al. 2011). The ones by Vigolo et al. (2004), Cabral & Guedes (2007) and Sorrentino et al. (2011) analyzed the outcome of impression techniques on parallel implants, while that by Sorrentino et al. (2011) and the remaining four looked into the problem of impression distortion of non parallel implants. All studies used a setup with two implants embedded in a reference model, with the exception of the ones by Vigolo et al. (2004) and Sorrentino et al. (2011) which used a full arch model with four implants. The studies by Assunção et al. (2008) and Filho et al. (2009) were conducted on the same external connection implant system (Conexao; Conexao Prosthesis System, Sao Paulo, Brazil), whereas the other five on internal connection implants (Certain, 3i Biomet, Palm Beach Gardens, FL, USA; SIN, Barcelona, Spain; Sistema de Implante Nacional; Astra ST, Astra Tech, Möln-dal, Sweden; Winsix Implant System, BioSAF, London, UK; Implantium, Dentium, Seoul, Korea).

The studies either tested specimens with internal or specimens with external implant-abutment connections. None of the studies compared the influence of internal vs. external connections on distortion in impression making. The parameters that were analyzed included implant divergence (none vs. up to 20°) (Choi et al. 2007; Jang et al. 2011; Sorrentino et al. 2011), coping type (square vs.

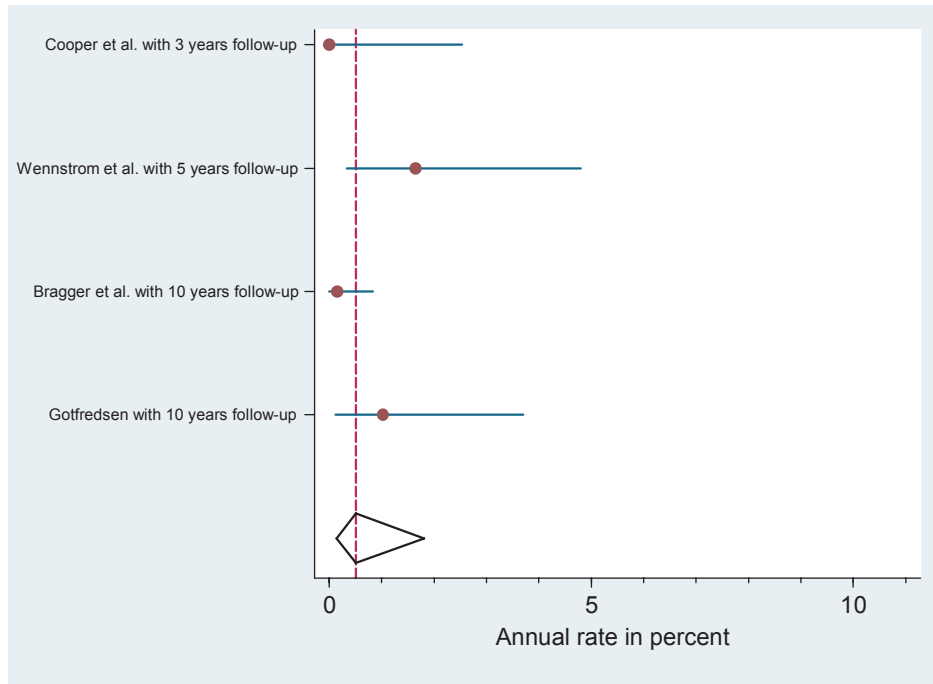


Fig. 1. Annual rate (per 100 years) of metal abutment/reconstruction screw loosening in internal configuration implants.

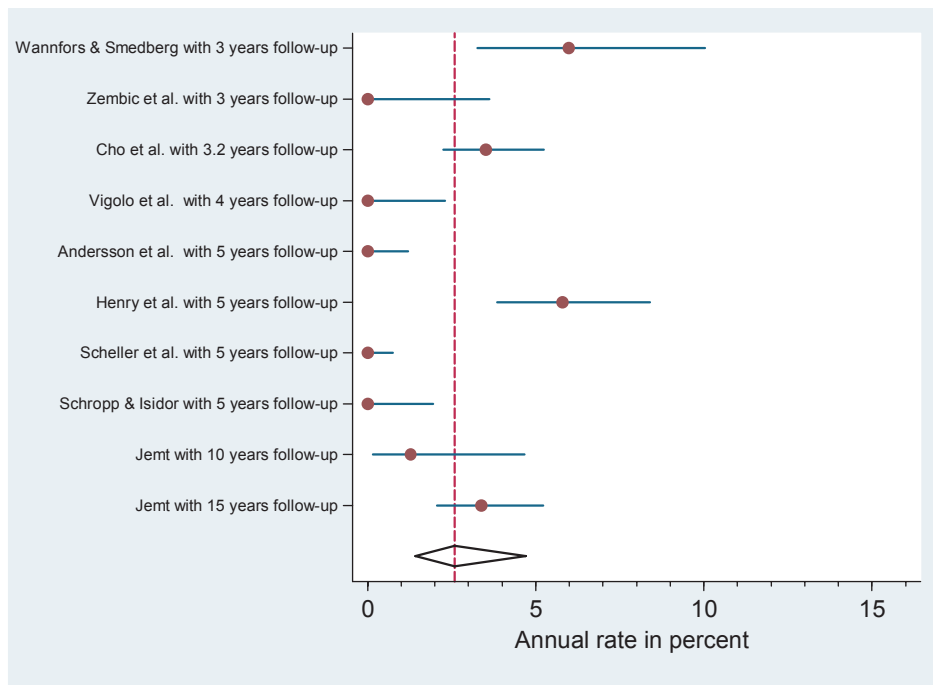


Fig. 2. Annual rate (per 100 years) of metal abutment/reconstruction screw loosening in external configuration implants.

tapered) (Cabral & Guedes 2007), depth of engagement of the internal hexagon by the square impression coping (1 vs. 2 mm) (Sorrentino et al. 2011), coping splinting method (none, adhesive coating, abraded copings, floss and resin in bulk, resin sectioned and welded) (Vigolo et al. 2004; Cabral & Guedes 2007; Choi et al. 2007; Assunção et al. 2008; Filho et al. 2009) and impression

material (medium viscosity polyether vs. polyvinylsiloxane) (Sorrentino et al. 2011). Due to a lack of standardized comparable studies, this part of the review had to be performed narrative.

Dissimilar final outcomes resulted from the seven studies. In the study by Vigolo et al. (2004), improved accuracy of the definitive casts was achieved when square impres-

sion copings joined by resin were used. Cabral & Guedes (2007) did not find statistically significant differences between the various techniques employed; however, the technique which used square impression copings with sectioned and welded resin produced a model that was more similar to the master metal framework compared to the technique which used square copings simply



splinted with resin. In the Choi et al. study (2007), the accuracy of impressions was similar for splinted- and non-splinted copings, and for parallel and 8° divergent implants. Assunção et al. (2008) demonstrated that square copings abraded by aluminum oxide produced the most accurate definitive casts. In the study by Filho et al. (2009), all replicas were different from the reference model, especially for the angulated implant. The best technique was the one which used copings splinted either with a prefabricated resin bar or with a direct resin bridge, sectioned and then welded again. In the Sorrentino et al. study (2011), the use of polyether impression material and of square impression copings with 2 mm inserts produced more accurate definitive casts in case of parallel implants; on the other hand, the vinylpolysiloxane (VPS) impression material resulted in more accurate casts, especially when square impression copings with 1 mm inserts were used in case of nonparallel implants. Finally, Jang et al. (2011) showed that a statistically significant difference in impression accuracy was found for the 20° divergent implants.

The final outcome of the review concerning PICO question 2, consists of 16 pertinent clinical studies on metal abutments and metal-based reconstructions and of five clinical studies on zirconia abutments and zirconia-based reconstructions, which have reported on screw loosening, screw fracture and abutment fracture (Tables 2 and 3). Of the included studies, 4 were RCTs, 13 were prospective and 2 retrospective studies. No RCT was found directly comparing internal and external connection implant systems.

#### **Metal abutments and metal-based reconstructions**

All the studies on metal abutments and metal-based reconstructions were RCTs or prospective with the exception of two on the external connection which were retrospective. Ten were on the same external hex connection configuration (Biomet 3i, Brånemark System, Nobel Biocare, and Osseotite) and four on two internal connections which were considered very similar in design (ITI, Straumann, and Astra, Astra Tech). Therefore, the authors have pooled the numbers in order for comparisons to be made. The total numbers of abutments which were included in the clinical analysis for the external and internal connections are 751 and 184, respectively, which became 677 and 158 at the end of the follow-up intervals. The abutments applied were in titanium, except 277 plus an undisclosed number for the pool of 34 implants reported by

Schropp & Isidor (2008), which were made out of gold alloy. These abutments were all manufactured for the external connection.

The most frequent mechanical complication found in both implant connection design was screw loosening. Screw fracture was a rare event (one event reported in all identified studies), while no abutment fracture was reported. Only 2 studies on the internal connection and 2 on the external connection followed up their patients for 10 years or longer while all the others were 5 years or shorter. The summary estimates for the 3-year cumulative incidence of abutment fracture were 0.0% (95% CI: 0.0–0.9%) for the internal connection design and 0.0% (95% CI: 0.0–0.3%) for the external one. The 3-year cumulative incidence of screw fracture was 0.0% (95% CI: 0.0–0.9%) for the internal and 0.1% (95% CI: 0.0–0.5%) for the external connection design, respectively. Finally, a 3-year cumulative screw loosening incidence of 1.5% (95% CI: 0.4–5.3%) and 7.5% (95% CI: 4.2–13.1%) was recorded for the internal and the external connection design, respectively. The annual rate of screw loosening was highly heterogeneous in reconstructions with internal configurations (Fig. 1) and 5.1 times higher (95% CI: 1.4–18.6%) than for reconstructions with external design (Fig. 2), but not clearly lower in university settings compared to other clinical settings (rate ratio = 0.6, 95% CI [0.16–2.37%],  $P = 0.47$ ).

#### **Zirconia abutments and zirconia-based reconstructions**

A total of five studies were included in the review on zirconia abutments and zirconia-based reconstructions, two on the same external connection implants (Brånemark System, Nobel Biocare) (Glauser et al. 2004; Zembic et al. 2009) and three on different internal connection implants: TSA System (Impladent) (Canullo 2007), XIVE S Plus (Friatec) (Nothdurft & Pospiech 2010b), and Astra (Astra Tech) (Hosseini et al. 2011) (Table 3). Except for the last two, the other studies had been included in the previous reviews. The studies by Glauser et al. (2004), Zembic et al. (2009) and Canullo (2007) reported on follow-up periods of 3 years or longer, while the remaining two only of 1 year. The publication by Nothdurft & Pospiech (2010b), however, illustrates a prospective study run in a University setting that is supposed to continue for 5 years.

No abutment and screw fractures were reported in studies describing external and internal connection designs resulting in an estimated annual rate of screw and abutment

fractures of 0.0% (95% CI: 0.0–2.0%) both for external and internal connection designs. The number of abutments taken into consideration was very small. At the end of the time interval analyzed, only 54 zirconia abutments for the external and 108 for the internal configuration were available for analysis. While the number of abutments for the internal connection implants had not changed from the start of the investigations, that for the external connection implants had changed due to patient dropout: 36 out of 54 in the Glauser et al. study, and 18 out of 20 in the Zembic et al. study. The only complication reported was loosening of 2 screws (at 8 and at 27 months intervals) in the former study. However, the incidence of screw loosening in the dropouts was not reported. Based on the available data, the annual rate of screw loosening between internal (summary estimate of annual rate = 0.0%, 95% CI: 0.0–2.1%) and external designs (summary estimate of annual rate = 0.8%, 95% CI: 0.1–3.0%) was observed.

All abutments were one-piece zirconia, with the exception of the 30 TSA abutments which had a titanium insert, and were supported with either single cemented restorations (160) or single screw-retained restorations (2). No statistically significant difference ( $P = 0.66$  for difference) has been found based upon abutment material (full zirconia vs. zirconia with metal insert) or retention of the restoration (screwed abutment with cemented crown vs. screw-retained implant restoration).

Almost all crowns cemented on the zirconia abutments were made of metal-free materials (leucite glass ceramic or zirconia supported). Only one was made of metal-ceramics. Some authors have specified that the crowns were provided with occlusal contact in centric, and that there were no contacts in excursive movements. The only mechanical complication reported in relation to the crowns was minor chipping of the veneering ceramic.

## **Discussion**

Impression taking of multiple implants with an internal connection differs in many respects from that of implants with an external connection. Some internal connection configurations have an intimate fit with the respective impression copings which may make withdrawal of the impression more difficult and, therefore, may generate a higher degree of distortion. Furthermore, external

connection implants can accommodate a larger degree of divergence than internal connection systems due to the limited height of the external hex. Thus, depending on the degree of divergence and internal connection configuration, variables such as impression technique (rigid splint vs. no splint), impression material (more rigid vs. more elastic), and choice of impression copings (engaging vs. non engaging) will influence impression accuracy.

If part or all of the configuration of the internal connection has parallel walls, two types of impression copings are usually provided by the manufacturer: one that is well adapted and captures the internal antirotational feature, which is necessary to make individualized abutments (engaging or non rotational impression coping), and one that may contact just the shoulder area, avoiding contact with the inner walls to allow for easier withdrawal (non engaging or rotational impression coping). The latter type can be used only when fabricating fixture-level screw-retained FPD's. Use of the engaging impression copings in these instances will probably result in a misfit of the framework due to the rigid fit of the components. Withdrawal of an impression with multiple single implants requires flexure of the impression material, whether using the closed- or open-tray impression copings.

Choi et al. (2007) have limited the degree of divergence to 8° because the system that was used in their study (Astra ST, Astra-Tech), according to what is stated by the authors, does not allow for a greater divergence if the engaging copings are employed since it can introduce strain in the impression material. Therefore, the path of insertion (or path of removal) of the implants to be restored should be known before the restorative procedures are initiated. Furthermore, unlike other investigators who have employed polyethers, Choi et al. have employed a low viscosity VPS with the idea of reducing permanent deformation of the impression due to the more elastic behavior of this material. However, since no other material was used with the same setup and, thus, no comparison was made, it is not possible to infer that the low degree of deformation cannot be matched by other elastomeric impression materials as well.

In a study on multiple external hexagon implants on which standard abutments had been placed, Vigolo et al. (2003) warned of the importance of avoiding any movement of the impression copings inside the impression material throughout the procedures that are carried out when fabricating the definitive

cast. The same authors, in another study (Vigolo et al. 2004), stated that the removal of the impression from internal connection implants is likely to produce a higher level of stress between the impression material and the impression copings, than from external hexagon implants. This stress may hypothetically induce permanent deformation of impression material or movement of the impression copings inside the impression material.

Distortion of an impression which is attempting to capture the relative positions of two or more implants in the same arch manifests itself as a change in the position, orientation or relative inclination of the implant analogues in the stone model produced. Any study evaluating distortion only in two dimensions is, by definition, of limited clinical value. The fact that a study may demonstrate little or no linear change of the implant analogues in one plane is of limited clinical significance. This is why the study by Choi et al. (2007) is of interest since it is the only one that attempted to evaluate impression distortion three-dimensionally in the 2-implant setup. To do so, the authors used a metal framework which was passive on the master model. After applying to it strain gauges, they connected it to the implant analogues enclosed in the study models produced by two different VPS impression techniques, one where the squared impression copings were left non splinted and one where the same copings were joined with a standardized autopolymerizing acrylic resin splint, sectioned 15 min before impression making and then welded again with the same resin. The results of the study showed no difference in the outcome of the two techniques. As a matter of fact, both were equally distorted and no samples showed perfect fit with the metal framework.

#### **Metal abutments and metal-based reconstructions**

The great majority of the studies included in the review on metal abutments and metal-based reconstructions were either RCTs (2) or prospective (10) and only two were retrospective. This implies that the data that can be extracted are of an acceptable quality. However, there was no RCT that directly compared implant-abutment stability in external vs. internal connection implants.

In selecting the studies for this review, a decision was made to include only those that reported on single-implant-supported restorations (SIR). The reason for this was that single-implant crowns are subjected to torsional

forces that may influence negatively the implant-abutment stability and screw retention, thus potentially exposing in a more effective manner the role of the connection design. In this respect, implant location in the arch may also have an influence on the incidence of screw loosening or fracture. Unfortunately, not enough information has been provided by those authors regarding complication rates in order for meaningful conclusions to be drawn.

The abutment materials were either titanium or gold alloy. Since in the reporting of the mechanical complications, no indication was given as to which abutment material was affected, no attempt has been made to differentiate them.

Screw loosening was by far the mechanical complication that occurred more frequently with metal SIRs, regardless of the fact that they were made for an external- or an internal connection fixture. The incidence, however, was statistically significantly lower for the latter than it is for the former. It is interesting to note that many of the earlier studies did not apply standardized protocols for the tightening of the screws at predetermined torque levels (Henry et al. 1996; Wannfors & Smedberg 1999; Cho et al. 2004; Jemt 2008) and, even if it was done, the material of such screws (titanium) did not allow reaching high preloads. This has been shown to be a major factor that can explain such complications. For example, in the study by Jemt (2008), 47 single external connection implants placed in the anterior maxilla were followed up for as long as 15 years. The incidence of mechanical complications in this group of patients was relatively high: 20 of the crowns required retightening of the abutment screw. In the materials and methods section, the author stated that the titanium screws had been hand tightened. As a consequence, when loosening occurred, 15 of the 20 titanium screws were replaced by gold screws. Once that was done, the problem was resolved.

One of the major advancements for the stability of the abutment-fixture joint has been the change of the screw's material and surface treatment to allow a sensible increase in preload, along with the recommendation to always tighten the screw with torque controller that applies a calibrated force (for an abutment screw, generally, from 25 to 35 Ncm). This is particularly important with an external connection implant.

One study (Cho et al. 2004) demonstrated that implant diameter has an influence on screw loosening only when the screws are hand torqued. Of 213 implants restored with

SIRs, 68 were wide diameter and 145 were standard diameter implants. The former showed 5.8% screw loosening, whereas the latter showed a 14.5% incidence in a 3–7 year longitudinal study. When these loose screws were tightened with a torque driver, the authors did not observe loosening of screws any longer.

#### Zirconia abutments and zirconia-based reconstructions

The use of zirconia implant abutments is increasing, mainly due to aesthetic motivations. The aims of the review on zirconia abutments and zirconia-based reconstructions were to assess the scientific evidence that justifies their use, analyze the mechanical complications that can be encountered with their clinical application, and to investigate whether there is a difference in behavior when a zirconia abutment is used with an external or with an internal connection system. From the data analyzed, it seems that the incidence of mechanical complications with zirconia abutments ranges from very low to absent, irrespective of the platform.

With respect to the situation photographed by the previous two systematic reviews dealing with ceramic abutments (Sailer et al. 2009b; Nakamura et al. 2010), only four new studies have appeared, three prospective (Nothdurft & Pospiech 2010b; Hosseini et al. 2011; Kim et al. 2012) and one retrospective (Ekfeldt et al. 2011). The Nothdurft & Pospiech (2010b), Hosseini et al. (2011) and the Ekfeldt et al. (2011) studies have a follow-up of only 1 year, except for a small group of patients of the last publication who were recalled for a retrospective analysis after 3 years of function; the fourth study, instead (Kim et al. 2012) reports the results after a median time period of 42 months. However, the publications by Ekfeldt et al. (2011) and Kim et al. (2012) had to be excluded from the current review due to lack of data on the patient population clinically examined.

The Ekfeldt et al. study (2011) was a retrospective analysis of 185 implants followed for at least 1 year and restored with either a zirconia abutment and a cemented all ceramic crown or a zirconia-supported crown screw-retained to the fixture itself. The implants were subdivided in 124 external connections (Brånemark system), 53 internal connections (Replace Select), and 8 non specified implant systems. At the 1 year interval, 172 implant restorations were examined since 10 patients were lost due to a patients' change in residence. The mechanical complications recorded are limited: two zirconia abutments

with metal inserts (for the Replace fixtures) had broken, one at delivery and one after 2 months of function, and one screw-retained crown had become loose, after 8 months. Twenty-five patients who had been treated over 3 years before were recalled for a clinical reexamination. These 25 patients had been treated with 40 implant supported restorations, of which 25 were zirconia-supported crown screw-retained to the fixture itself. At the 3 year recall, none of the abutments exhibited fractures or screw loosening.

The most recent study (Kim et al. 2012) is a prospective cohort study in a University setting that assessed the 5-year survival of alumina-toughened zirconia abutments produced by one company used for implant-supported restorations. A total of 611 external hex implants of different brands were placed in 213 patients to support 328 fixed restorations and were followed from a minimum of 1 month to a maximum of 12.8 years (mean of 42 months). According to the data published, about half of the restorations have been followed for more than 3 years and about 20 for more than 8 years. It appears that 20 restorations were lost to follow-up, but, apparently, they were counted as survivals. Two-hundred-seventy-four restorations did not experience any complication and were accounted for, whereas 31 had mechanical complications: 23 screw loosening, 2 abutment screw fractures, 6 abutment fractures. An interesting finding is that of the 25 screw loosening and fracture, 22 were single units (20.5% of 107 single units) and 3 multiple units (1.6% of 190 multiple units), 24 were posterior (10% of 239 posterior restorations) and only 1 anterior restoration (1.7% of 58 anteriors). Of the six abutment fractures, four were single units (3.7% of 107 abutments) whereas five were located in the posterior area (2.1% of 239 units). Therefore, these complications were shown to be significantly associated with the restoration's number of prosthodontic units and the type of prostheses (single crown vs. FPD). The authors of that study have concluded that care must be taken in the use of alumina-toughened zirconia abutments for single molar restorations. Unfortunately, there were two relevant shortcomings in this study: firstly, there was no clear indication of the number of abutments belonging to the multi-unit prosthetic groups. Since the authors often referred to the number of restorations and not to the number of abutments, confusion ensues and it is not possible for the reader to understand how many zirconia abutments were actually lost when a restora-

tion failed. Secondly, there is no indication of the time at which the different complications have taken place. For these reasons, the article was excluded from the current review.

Implant companies provide zirconia abutments for both external and internal connection systems, but, for the latter configuration, some companies have chosen to offer abutments with metal inserts to decrease the risk of fracture of what would be the thinnest portion of the abutment. In one of only two clinical studies that recorded abutment fracture (Ekfeldt et al. 2011), the two abutments that failed, one at delivery and the other after 2 months of function, had a metal insert. This is in apparent contradiction with the results of *in vitro* studies that suggest that two-piece zirconia abutments with a secondary coupling abutment or a metallic insert withstand higher bending moments than one-piece internally or externally connected abutments (Sailer et al. 2009a; Truninger et al. 2011). In the Nothdurft & Pospiech paper (2010b), the authors specified that nearly all 40 full zirconia abutments had to be custom-shaped in the occlusal aspect and along the chamber. For that purpose, they were reshaped with diamond grinding tools under water irrigation. It is worthwhile to mention that no fracture has ensued after 12 months.

A publication with the results of a scanning electron microscopy analysis of five clinically fractured one-piece zirconia abutments suggests that fractures may occur because of friction stresses generated by the fixation screw or to overpreparation and thinning of the lateral walls (Aboushelib & Salameh 2009). The retrieval of the fractured portion of a zirconia abutment from an internal connection implant systems with a specially modified back-action tapper has even been the object of a short communication (Roe et al. 2011). In their study, Glauser et al. (2004) mentioned that a minimum thickness of 0.5 mm should be maintained; otherwise, the abutment may fracture.

The main problem with the studies reviewed is that the number of zirconia abutments is limited and the observation periods are rather short. Larger samples and a longer follow-up are needed for final conclusion, especially in view of the fact that zirconia, like all ceramics, is prone to aging and accumulative damage, thus inducing a decrease in the physical properties (Zembic et al. 2009). The consequences of zirconia's low temperature degradation may also require a longer time interval to be exposed (Deville et al. 2005). It is highly desirable

that future research projects will address this issue comparing not only implants with internal and external connections, but also the different designs of connections.

## Conclusions of focused question 1

No *in vivo* nor *in vitro* study was found that directly compared the influence of internal vs. sexternal implant connections for abutments/reconstructions on implant-level impression accuracy. All *in vitro* studies reported separately on the two connection designs and used different protocols. Therefore, the data cannot be compared and no clinical recommendation can be made.

On the basis of the studies reviewed, the following considerations can be mentioned:

1. Implant-level impression accuracy may be influenced by the implant connection type (internal vs. external), the design of the connection, lack of parallelism

between multiple implants, the impression material, and the technique employed.

2. It appears that implant divergence influences the impression accuracy when using internal connection implants.

## Conclusions of focused question 2

Within the limitations of the low number of studies included in the present review, the following consensus statements can be made:

1. The incidence of fracture of metal-based and zirconia-based abutments does not seem to be influenced by the type of connection.
2. The incidence of abutment screw fracture does not seem to be influenced by the type of connection, neither with metal-based nor with zirconia-based abutments.

3. Loosening of abutment screws was the most frequently occurring technical complication. The type of connection seems to have an influence on the incidence of the screw loosening: more loose screws were reported for externally connected implant systems for both types of materials. To minimize the screw loosening incidence of both external- and internal connection abutment/reconstructions, it is highly recommended to tighten the retention screws at the recommended torque level.

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## Excluded studies and reasons for exclusion

- Abboud, M., Koeck, B., Stark, H., Wahl, G. & Paillon, R. (2005) Immediate loading of single-tooth implants in the posterior region. *The International Journal of Oral & Maxillofacial Implants* 20: 61–8. Reason for exclusion: lack of information for abutment material.
- Andersen, E., Saxegaard, E., Knutsen, B.M. & Haanaes, H.R. (2001) A prospective clinical study evaluating the safety and effectiveness of narrow-diameter threaded implants in the anterior region of the maxilla. *The International Journal of Oral & Maxillofacial Implants* 16: 217–224. Reason for exclusion: only 1 year follow-up.
- Andersson, B., Odman, P., Lindvall, A.M. & Branemark, P.I. (1998b) Five-year prospective study of prosthodontic and surgical single-tooth implant treatment in general practices and at a specialist clinic. *The International Journal of Prosthodontics* 11: 351–355. Reason for exclusion: abutment outcome not reported.
- Avivi-Arber, L. & Zarb, G.A. (1996) Clinical effectiveness of implant-supported single-tooth replacement: the Toronto study. *The International Journal of Oral & Maxillofacial Implants* 11: 311–321. Reason for exclusion: Lack of information regarding the abutment outcome.
- Bambini, F., Lo Muzio, L. & Procaccini, M. (2001) Retrospective analysis of the influence of abutment structure design on the success of implant unit. A 3-year controlled follow-up study. *Clinical Oral Implants Research* 12: 319–24. Reason for exclusion: no abutment survival data and very limited information on technical complications.
- Cannizzaro, G., Leone, M., Consolo, U., Ferri, V. & Esposito, M. (2008) Immediate functional loading of implants placed with flapless surgery versus conventional implants in partially edentulous patients: a 3-year randomized controlled clinical trial. *The International Journal of Oral & Maxillofacial Implants* 23: 867–75. Reason for exclusion: lack of information on abutment material.
- Crespi, R., Cappare, P. & Gherlone, E. (2010a) Fresh-socket implants in periapical infected sites in humans. *Journal of Periodontology* 81: 378–383. Reason for exclusion: lack of information on abutment material.
- Crespi, R., Cappare, P. & Gherlone, E. (2010b) A 4-year evaluation of the peri-implant parameters of immediately loaded implants placed in fresh extraction sockets. *Journal of Periodontology* 81: 1629–1634. Reason for exclusion: lack of information for abutment material.
- Crespi, R., Cappare, P., Gherlone, E. & Romanos, G.E. (2007) Immediate occlusal loading of implants placed in fresh sockets after tooth extraction. *The International Journal of Oral & Maxillofacial Implants* 22: 955–962. Reason for exclusion: lack of information for abutment material.
- Drago, C.J. (2003) A clinical study of the efficacy of gold-tite square abutment screws in cement-retained implant restorations. *The International Journal of Oral & Maxillofacial Implants* 18: 273–8. Reason for exclusion: mean follow-up less than 3 years.
- Duncan, J.P., Nazarova, E., Vogiatzi, T. & Taylor, T.D. (2003) Prosthodontic complications in a prospective clinical trial of single-stage implants at 36 months. *The International Journal of Oral & Maxillofacial Implants* 18: 561–5. Reason for exclusion: insufficient information on abutments and lack of survival data.
- Eckfeldt, A., Carlsson, G.E. & Borjesson, G. (1994) Clinical evaluation of single-tooth restorations supported by osseointegrated implants: a retrospective study. *The International Journal of Oral & Maxillofacial Implants* 9: 179–183. Reason for exclusion: less of 3 years' follow up.
- Eckfeldt, A., Fürst, B. & Carlsson, G.E. (2011) Zirconia abutments for single-tooth implant restorations: a retrospective and clinical follow-up study. *Clinical Oral Implants Research* 22: 1308–1314. Reason for exclusion: not enough data on patient population examined clinically.
- Engquist, B., Nilson, H. & Astrand, P. (1995) Single-tooth replacement by osseointegrated Brånemark implants. A retrospective study of 82 implants. *Clinical Oral Implants Research* 6: 238

- 245. Reason for exclusion: mean follow-up less than 3 years.
- Gallucci, G.O., Grütter, L., Nedir, R., Bischof, M. & Belser, U.C. (2011b) Esthetic outcomes with porcelain-fused-to-ceramic and all-ceramic single-implant crowns: a randomized clinical trial. *Clinical Oral Implants Research* **22**: 62–9. Reason for exclusion: mean follow-up less than 3 years.
- Johnson, R.H. & Persson, G.R. (2001) A 3-year prospective study of a single-tooth implant. *Prosthodontic complications. The International Journal of Prosthodontics* **14**: 183–89. Reason for exclusion: mixed one-piece abutments and “others”, lack of information on abutments.
- Jung, U.W., Choi, J.Y., Kim, C.S., Cho, K.S., Chai, J.K., Kim, C.K. & Choi, S.H. (2008b) Evaluation of mandibular posterior single implants with two different surfaces: a 5-year comparative study. *Journal of Periodontology* **79**: 1857–63. Reason for exclusion: technical complications not reported.
- Kemppainen, P., Eskola, S. & Ylipaavalniemi, P. (1997) A comparative prospective clinical study of two single-tooth implants: a preliminary report of 102 implants. *The Journal of Prosthetic Dentistry* **77**: 382–7. Reason for exclusion: only 1 year follow-up.
- Kim, S.-S., Yeo, I.-S., Lee, S.-J., Kim, D.-J., Jang, B. M., Kim, S.-H. & Han, J.-S. (2012) Clinical use of alumina-toughened zirconia abutments for implant-supported restoration: prospective cohort study of survival analysis. *Clinical Oral Implants Research*. Accepted for publication. Reason for exclusion: not enough data on abutment population.
- Krennmair, G., Schmidinger, S. & Waldenberger, O. (2002) Single-tooth replacement with the Frialit-2 system: a retrospective clinical analysis of 146 implants. *The International Journal of Oral & Maxillofacial Implants* **17**: 78–85. Reasons for exclusion: not enough information on the incidence of complications related to time of function of the restorations and wide variability of crown fixation methods.
- Levine, R.A., Clem, D.S., Wilson, T.G., Higginbottom, F. & Solnit, G. (1999) Multicenter retrospective analysis of the ITI implant system used for single-tooth replacements: results of loading for 2 or more years. *The International Journal of Oral & Maxillofacial Implants* **14**: 516–20. Reason for exclusion: mean follow-up less than 3 years.
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- Moberg, L.E., Köndell, P.A., Sagulin, G.B., Bolin, A., Heimdahl, A. & Gynther, G.W. (2001) Brånemark System and ITI Dental Implant System for treatment of mandibular edentulism. A comparative randomized study: 3-year follow-up. *Clinical Oral Implants Research* **12**: 450–61. Reason for exclusion: full-arch implant bridges for fully edentulous jaws.
- Norton, M.R. (2006) Multiple single-tooth implant restorations in the posterior jaws: maintenance of marginal bone levels with reference to the implant-abutment microgap. *The International Journal of Oral & Maxillofacial Implants* **21**: 777–84. Reason for exclusion: insufficient information and data on abutments.
- Palmer, R.M., Palmer, P.J. & Smith, B.J. (2000) A 5-year prospective study of Astra single tooth implants. *Clinical Oral Implants Research* **11**: 179–82. Reason for exclusion: insufficient information and data on abutments.
- Romanos, G.E. & Nentwig, G.H. (2000) Single molar replacement with a progressive thread design implant system: a retrospective clinical report. *The International Journal of Oral & Maxillofacial Implants* **15**: 831–6. Reason for exclusion: mean follow-up less than 3 years.
- Scholander, S. (1999) A retrospective evaluation of 259 single-tooth replacements by the use of Brånemark implants. *The International Journal of Prosthodontics* **12**: 483–91. Reason for exclusion: insufficient information and data on abutments.