TITLE PAGE

Full title: Accuracy of Original vs. Non-original Abutments Using Various Connection Geometries for Single Unit Restorations: A Systematic Review

Running title: Non-original Abutments and Connection Geometry

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The authors declare there are no conflicts of interest.

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ABSTRACT

Purpose: To ascertain whether the compatibility of non-original abutments (NOAs) with dental implants is influenced by the type of implant connection i.e. internal or external, and whether certain combinations of componentry may be as compatible as the original components.

Methods: A structured literature search was conducted using 3 electronic databases (MEDLINE®, The Cochrane Library, and Web of Science Core Collection) for studies reporting on the use of non-original abutments published between 1995 and 2020. This was supplemented with hand searching in relevant journals and references, as well as searching grey literature. Relevant studies were selected according to specific inclusion criteria. Data was collected for the following parameters: precision of fit, microleakage, micromorphological differences, micromotion, rotational misfit, screw loosening, maximum load capacity, fracture resistance, tensile strength, compressive strength and in-vivo implant and prosthesis outcomes.

Results: The electronic searching and hand search yielded titles and abstracts of 5617 studies following de-duplication; 40 studies were finally selected. Overall, original abutments showed better precision of fit, ability to resist microleakage, prevention of rotational misfit and micromotion, and fatigue strength compared with non-original abutments. Some non-original abutments on external connections were comparable with original abutments in terms of precision of fit and resistance to screw loosening and may be associated with less catastrophic failures than those on internal connections.

Conclusion: Original abutments present more predictable outcomes than non-original abutments with regards to the parameters investigated. However, it seems that external connections can provide some level of compatibility in terms of precision of fit and may also exhibit less catastrophic failures than NOAs on internal connections. This may be due to increased rotational freedom external connections provide. There is a lack of information regarding the influence of connection geometry on many aspects of compatibility and therefore the current clinical recommendation should be to use original abutments. More laboratory studies comparing non-original abutments on different implant connections are required. In addition, there is a need for long-term in vivo studies providing data on the clinical performance of non-original abutments.

Keywords: Dental implants, components, Compatible, Non-original abutments, Interchangeable, Connection geometry

Clinicians and dental technicians may use 'non-original' abutments produced by a manufacturer different to that of the implant system, in order to reduce costs, to implement digital computer aided-design and computer-aided manufacturing (CAD-CAM) workflows, or due to the lack of availability of original abutments (OAs) from the same manufacturer as the implant. Non-original abutments (NOAs) can also be referred to as interchangeable, after-market, third-party, look-alike, copy, clone or compatible abutments. Although often less expensive, the problem with NOAs is that they are not an exact replica due to differences in the manufacturing process and dimensional inaccuracies, leaving uncertainty with regards to the actual degree of compatibility.[1, 2]

A precise fit at the implant-abutment interface (IAI) is crucial in order to minimise the risk of mechanical and biological complications. Microgaps at the implant-abutment interface can serve as a bacterial reservoir, causing inflammatory changes in the soft tissues and possible bone loss. [3, 4]

Studies, including a systematic review by Tallarico et al,[5] demonstrate that the fit between NOAs and dental implants is less precise compared with that of OAs, creating microgaps at the implant-abutment interface. The assumption is that this in turn increases the incidence of mechanical complications and microleakage.[1,2,3,5,6] In other studies, NOA combinations have been shown to produce results comparable with OAs. NOAs on implants with external connections appeared to result in less misfit and severe failures than combinations utilising deeper internal connections.[7,8,9,10]

The aim of this study was to ascertain whether the compatibility of non-original abutments with dental implants is influenced by the connection geometry and whether certain combinations may be as compatible as the original components and potentially reduce the risk of complications. The focussed PICOS question formulated was 'when non-original abutments are connected to dental implants for single-unit prostheses, does the implant connection type i.e., internal or external, influence the compatibility?'. 'P' denotes the population (single implants), 'I' is the intervention (use of non-original abutments), 'C' is the comparison (between different connection geometries), 'O' is the outcome (effect on compatibility) and 'S' is the study design (in vitro and in vivo studies). Specific parameters investigated as a measure of compatibility included: precision of fit, microleakage, micromorphological differences, micromotion, rotational misfit, screw loosening, maximum load capacity, fracture resistance, tensile strength, compressive strength and in vivo implant and prosthesis outcomes.

METHODS

This systematic review followed the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) Statement guidelines.[11]

Search strategy

A structured literature search was conducted by two reviewers (NR and AR) in July 2020, using three different electronic databases (MEDLINE®, The Cochrane Library, and Web of Science Core Collection) for laboratory and clinical studies reporting on the use of non-original abutments for dental implants.

Search terms were identified using MeSH terms relevant to the focus area of the study and keywords found during a preliminary review of the literature. A medical librarian was consulted regarding the structuring of the search strategy. A representation of the search strategy is depicted in Table 1. The MEDLINE® database was searched first, followed by The Cochrane Library and Web of Science Core Collection. The same search strategy terms were used, with symbols changed according to the format for each database. ProQuest Dissertations & Theses Global and Open Grey databases were used for identification of grey literature, with search terms being input individually.

The electronic search covered January 1995 to July 2020 and was supplemented by hand-searching of the following journals from January 2010 to July 2020: *Clinical Implant Dentistry and Related Research*, *Clinical Oral Implants Research*, *European Journal of Oral Implantology*, *Implant Dentistry*, *International Journal of Oral and Maxillofacial Implants*, *International Journal of Prosthodontics*, *Journal of Prosthetic Dentistry*, *Journal of Prosthodontic Research*, and *Journal of Prosthodontics*. Articles obtained were scanned to find further studies.

Study selection

The first screening phase of the articles returned via searching involved review of the title, abstracts and/ or full texts by the reviewers based on inclusion and exclusion criteria.

The criteria for inclusion were: studies published between January 1995 and July 2020 (including e-publications ahead of print), abstracts and full texts in English, in vitro and in vivo prospective, retrospective, observational or interventional case control and cohort studies. These studies would be testing non-original abutments for single-unit implant restorations, comparing NOAs to OAs and/or variations in connection geometry.

The exclusion criteria were: publications dated prior to January 1995, studies published in languages other than English, studies involving only multi-unit fixed or removable restorations or frameworks, author opinions, case reports on individual patients, studies where abutments are only connected to implants from the same manufacturer and studies testing abutments not connected to dental implants.

The full texts of all studies returned from the first phase of screening and hand searching were obtained for further eligibility analysis and screened independently. The results were then compiled, and a Kappa Score was calculated to indicate agreement regarding inclusion/ exclusion between the two reviewers for phase 2 screening. Bias within the studies was assessed according to indication of conflicts of interest, sponsorships or provision of components used.

Data extraction and statistical analysis

Data from the studies finally selected was extracted and tabulated for the following parameters: precision of fit at the implant-abutment interface, microleakage, micro-morphological differences, micromotion and displacement, rotational misfit, screw loosening (removal torque values), maximum load capacity and fracture resistance, tensile and compressive strengths and in vivo implant and prosthesis outcomes. Statistical analysis was not possible due to the heterogeneity of the studies.

RESULTS

Searching of the electronic databases yielded 7606 studies and hand searching yielded 88 titles, which, following removal of duplicates, gave 5617 studies. No studies were identified via searching of the ProQuest Dissertations & Theses Global and Open Grey databases. During Phase 1 screening, 203 studies were obtained for full-text screening. One hundred and sixty-three studies were excluded during Phase 2, with the most common reason for exclusion being that the implant-abutment combinations were original only. Based on the eligibility criteria, 40 studies were finally selected. (Supplementary Figure 1 depicts the process of selection of the final articles). (Supplementary Table 1 details the finally selected articles).

The inter-reviewer agreement regarding eligibility of studies during Phase 2 was ‘substantial’ (Cohen’s Kappa value: 0.740).

Twenty-five in vitro studies [2, 3, 6, 8,12-32] connected NOAs to implants with internal connections, whilst 12 studies involved testing of NOAs on implants with external connections. [1, 7, 9, 10, 33-40] Three studies connected NOAs onto implants with both kinds of connection (internal and external).[41, 42, 43]

Risk of bias

A number of studies acknowledged sponsorship either by funding or provision of components, as well as affiliations with implant companies. Twelve studies acknowledged university or state grants, 15 studies acknowledged receiving implants and components from companies and 1 study declared a co-author was employed by one of the implant companies providing components. Five studies declared they had no conflicts of interest without further details, and 13 studies did not state any details with regards to conflicts of interest or support.

Precision of fit at the implant-abutment interface

Tables 2 summarizes details of the studies testing precision of fit at the implant-abutment interface in terms of mean gap widths or areas of tight contact, implant/abutment hexagon dimensions and scratches/ wear, respectively.

Of the 12 studies measuring gap widths between OAs/NOAs and implants with an external connection, 4 studies found better precision of fit with OAs compared with NOAs.[1, 38, 39, 40] One study found that although the OAs statistically fit better than NOAs, both were within acceptable limits[33]; 5 studies reported no differences between OAs and NOAs.[7,9,10,42,43] Two studies reported better fit when the NOAs were connected to the implants, compared with the OAs. [34, 35]

When OAs and NOAs were connected to implants with internal connections, 7 studies found OAs had better precision of fit compared with NOAs. [2, 13, 14, 15, 18, 26, 43] Two studies reported that although OAs had a statistically better fit than NOAs, both were within limits deemed acceptable [12, 17] and 1 study reported no difference between OAs and NOAs. [19]

In studies directly measuring components, Karl and Irastorza-Landa indicated NOAs were less compatible with implant systems with an internal connection compared with OAs due to discrepancies in dimensions.[22] Lang et al deemed original and non-original abutments compatible with implants with an external hexagon.[37] One study reported more wear and scratches with NOAs,[40] whereas another found less wear with NOAs and no correlation between wear at the IAI and precision of fit.[39]

Of the studies which allowed comparison of NOAs on internal and external connections, Siadat et al, found the horizontal gaps were significantly less on external connections abutments than on internal connections[43] whereas Park et al found the connection type did not influence the gap discrepancies.[42]

Microleakage to indicate degree of misfit

The study testing OAs and NOAs on implants with internal double hexagon connection found that the percentage volume of microleakage was significantly higher with NOAs compared to OAs,[3] however another study utilising internal conical connections found no correlation between the type of abutment and amount of microleakage.[22] The results of these are summarised in Table 3. No studies were found investigating microleakage at the IAI when NOAs are connected to implants with an external connection.

Micromorphological differences

Scrutiny of the micromorphological differences between OAs and NOAs highlighted the irregularities leading to altered fit when NOAs are connected to implants with internal and external connections, although there were no studies which compared the connection types directly. Photomicrographs from the study by Da Cunha et al illustrated misfit, lack of uniformity, and the presence of horizontal over and under-contouring when NOAs were connected to implants with an external hexagon; in contrast to the micro-gap being evenly distributed among all measured sites in the original abutment connection.[1]

Mattheos et al and Fokas et al tested on internal connections and found more marked micromorphological differences in NOAs, which also displayed tapering.[18,26] On the internal conical connection, differences were not significant with titanium abutments and minor with gold abutments.

Premature contacts between the abutment and the inner implant surface hindered seating for zirconia abutments. [18]

Micromotion after loading and displacement after torqueing

Four studies investigated micromotion of abutments connected on dental implants, the results of which are summarised in Table 4.

Berberi et al found that NOAs displayed more movement than OAs when they were placed on implants with an internal double hexagon.[15] Karl and Taylor found no significant difference in micromotion overall between NOAs and OAs when they were placed on conical connections.[21] A later study by Karl and Irastorza-Landa also generally reported no significant differences in micromotion between NOAs and OAs on internal conical connections.[22]

When placed on implants with an internal hexagon in another study,[30] no correlation was found between the amount of displacement after torqueing and whether the abutments were NOAs or OAs. [30] There were no studies investigating micromotion or displacement of NOAs connected to implants with external connections (Table 4).

Measure of rotational misfit

OAs and NOAs were connected to implants with an external connection in 3 studies,[33, 36, 43] and 2 studies connected abutments to implants with internal connections. [8, 43] The details of these studies are given in Table 5.

All of the studies showed increased rotational misfit (measured by degrees of freedom) with NOAs compared with OAs. Siadat et al allowed direct comparison of the values for rotational freedom in external and internal connections. The degree of rotational freedom with NOAs on implants with external connections appeared to reach higher values than when NOAs are connected to implants with an internal connection.

Removal torque values as a measure of residual abutment screw preload (screw-loosening)

Five studies, all of which connected abutments to implants with internal connections, found that removal torque values were higher, i.e. there was less screw loosening with OAs compared with NOAs.[6, 13, 16, 23, 28] Four studies reported differences in removal torques between OAs and NOAs were not significant. One of these tested on internal connections only,[27] 1 study tested on external connections [34] and two studies tested on both internal and external connections.[42, 43] Table 6 details the findings.

The type of implant-abutment connection did not influence removal torque values. In one study, the removal torque value for NOAs post-loading was higher on the external connection than on the internal connection,[42] whilst another found that there was greater loss of torque when NOAs were connected to external connection[43] – these differences were not statistically significant.

Maximum load capacity and fracture resistance, tensile and compressive strengths

Five of 10 studies testing OAs and NOAs on implants with an internal connection found no statistical significant differences between the groups, in general.[12, 13, 24, 29, 32] Two types of zirconia NOAs were found to have higher load to failure values than their original counterparts, however these observations were attributed to the incorporation of titanium.[24, 32] Four studies reported better outcomes with OAs compared to NOAs.[22, 25, 31, 41] One study unexpectedly found higher load to deformity and failure in NOAs compared with OAs.[8]

Jarman et al conducted the only study which placed an NOA on internal and external connections and found no statistically significant differences between outcomes on different connection types. [41] Table 7 summarizes the findings.

In vivo implant and prosthesis outcomes

No clinical studies allowing comparison of OAs and NOAs on different connections were available at the time this systematic review was conducted.

One retrospective clinical study with a mean follow up period of 7.2 years allowed comparison of posterior implant supported restorations on original prefabricated and compatible CAD-CAM titanium abutments on implants with an internal connection.[20] No implant failures were reported in either group. The only statistically significant differences were for decementation, which was greater in OAs (14.1%) than NOAs (3.1%) and abutment screw loosening which was seen more frequently in NOAs (11%) than OAs (0%).

DISCUSSION

This study is the first to specifically investigate the influence of connection geometry on compatibility of NOAs. The rigorous searching process enabled detection of a number of additional studies previously not included and provides the most recent evidence on the subject.

Strengths and limitations

The PRISMA guidelines [11] were followed, providing a methodical and transparent approach to reviewing the literature. Further effort to minimize bias was exercised by the two reviewers, who assessed the studies independently, and a third reviewer (HP) was consulted where required. Selection bias was reduced by hand searching all volumes of relevant journals between January 2010 and July 2020. The Cohen's Kappa score for inter-reviewer agreement regarding eligibility of studies was 'substantial', which indicated reviewers were generally following the same criteria and consistent with each other.

With 15 studies declaring directly receiving sponsorship (either funding or provision of components) from the manufacturers of the very same implant systems/ components being tested and 1 study stating a co-author was employed by one of these companies – there is a potential risk of reporting bias in over a third of the studies included in this review. Around one third did not state whether there were any conflicts of interest of sponsorships to be acknowledged, hence the risk of bias may be even greater.

Most of the studies included in this review were conducted in vitro, therefore results observed may not resemble clinical behaviour. There was a high degree of heterogeneity in the studies i.e. abutments tested varied according to brand, fabrication method, material and assembly. There were also differences in the testing methods, e.g. the studies that measured gap widths with scanning electron microscopy (SEM) measured the widths at different points of the implant-abutment interface, thus the results could not be pooled together for quantitative analysis.

Implications of the review

The findings of this study were generally in agreement with a previous systematic review,[5] which concluded a lower incidence of mechanical failure and higher marginal accuracy overall for original abutments compared to non-original abutments.[5] Although most studies recommend original abutments based on these findings, the results show that in some instances, NOAs are comparable to OAs with regards to precision of fit and resulted in less severe mechanical failures.[7, 9, 10, 34, 35, 42, 43] Most of these studies tested NOAs on external connections.

Some observations could be made based on the few studies which allowed direct comparison of NOAs on internal and external connections. Mechanical failures appeared to be less catastrophic when NOAs were placed on external connections compared with on internal connections[41] and this may be due to increased rotational freedom this connection provides. The rotational freedom was greater when NOAs were placed on external connections compared with internal connections.[43] Connection type did not influence abutment screw loosening.[42, 43] With regards to precision of fit, Park et al reported no significant differences between NOAs on internal and external connections, [42] whereas Siadat et al found NOAs showed significantly more intimate marginal fit on external connections compared with on internal connection.[43]

Recommendations for further research

Reporting on long term in vivo outcomes with the use of original versus non-original abutments would give a more accurate representation of the outcomes of clinical use in patients. There is also need for more in vitro studies comparing NOAs and OAs on a variety of internal and external connections, as well as in vivo studies involving NOAs. Study designs for future in vitro studies should focus on the influence of connection geometry on the influence of parameters such as precision of fit, microleakage etc, with attempt to standardise all variables other than connection type, e.g. abutment materials, manufacturing methods, brands and testing methods.

Clinical recommendations for consideration

Complications associated with NOAs on external connections may be easier to manage than those seen with NOAs on internal connections.[41] For the other parameters discussed, e.g. microleakage, micromovement and *in vivo* outcomes – there is a lack of evidence and therefore the recommendation should still be to use OAs where possible, regardless of the connection geometry.

A commonly encountered issue when NOAs are used is the fact that original screws cannot be used because they usually do not match,[18, 37] and this may have implications for the component connection. As for OAs,[44] the abutment screw for NOAs should be retightened after 10 minutes to prevent abutment screw loosening. [21, 30]

There is also a need for transparency in clinical practice regarding the use of NOAs, for example keeping accurate records, imaging and reporting their outcomes – for the benefit of the wider profession.

CONCLUSION

The use of non-original abutments has generally been shown to lead to fit discrepancies, greater micro-leakage, micromotion, rotational misfit and lower load to failure in several studies, which discourages the use of components from other manufacturers. Within the limitations of this study, it appears that external connections for NOAs can provide some level of compatibility in terms of precision of fit and may also exhibit less catastrophic failures than NOAs on internal connections. NOAs on internal connections were found to exhibit less rotational freedom than those on external connections, albeit this did not affect other properties. For other parameters such as microleakage, micromovement and in vivo outcomes – there is still a lack of studies providing evidence and therefore the overall recommendation should still be to use OAs where possible regardless of the type of connection.

More in vivo studies investigating multiple parameters on different connection types are needed to expand the evidence base and enable conclusions on the influence of varying connection geometry on the compatibility of NOAs. Long-term clinical trials are needed to investigate the effect of use of non-original abutments on patient outcomes and inform quality control of components in the future.

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TABLES

Table 1. MEDLINE® search strategy

Input no.	Search entry
1	exp Dental Implants/
2	(dental adj3 (implant* or abutment* or prosthe*)).mp. [mp=title, abstract, original title, name of substance word, subject heading word, floating sub-heading word, keyword heading word, organism supplementary concept word, protocol supplementary concept word, rare disease supplementary concept word, unique identifier, synonyms]
3	1 or 2
4	exp Dental Prosthesis, Implant-Supported/
5	(single-unit adj3 implant).mp. [mp=title, abstract, original title, name of substance word, subject heading word, floating sub-heading word, keyword heading word, organism supplementary concept word, protocol supplementary concept word, rare disease supplementary concept word, unique identifier, synonyms]
6	4 or 5
7	exp Dental Implant-Abutment Design/

8	(implant* adj3 abutment* adj3 connection*).mp. [mp=title, abstract, original title, name of substance word, subject heading word, floating sub-heading word, keyword heading word, organism supplementary concept word, protocol supplementary concept word, rare disease supplementary concept word, unique identifier, synonyms]
9	(implant* adj3 abutment* adj3 compatib*).mp. [mp=title, abstract, original title, name of substance word, subject heading word, floating sub-heading word, keyword heading word, organism supplementary concept word, protocol supplementary concept word, rare disease supplementary concept word, unique identifier, synonyms]
10	(implant* adj3 abutment* adj3 interface*).mp. [mp=title, abstract, original title, name of substance word, subject heading word, floating sub-heading word, keyword heading word, organism supplementary concept word, protocol supplementary concept word, rare disease supplementary concept word, unique identifier, synonyms]
11	(implant* adj5 connect* adj3 geometr*).mp. [mp=title, abstract, original title, name of substance word, subject heading word, floating sub-heading word, keyword heading word, organism supplementary concept word, protocol supplementary concept word, rare disease supplementary concept word, unique identifier, synonyms]
12	(implant* adj5 internal adj3 connection*).mp. [mp=title, abstract, original title, name of substance word, subject heading word, floating sub-heading word, keyword heading word, organism supplementary concept word, protocol supplementary concept word, rare disease supplementary concept word, unique identifier, synonyms]
13	(implant* adj5 external adj3 connection*).mp. [mp=title, abstract, original title, name of substance word, subject heading word, floating sub-heading word, keyword heading word, organism supplementary concept word, protocol supplementary concept word, rare disease supplementary concept word, unique identifier, synonyms]
14	7 or 8 or 9 or 10 or 11 or 12 or 13
15	compatib*.mp. [mp=title, abstract, original title, name of substance word, subject heading word, floating sub-heading word, keyword heading word, organism supplementary concept word, protocol supplementary concept word, rare disease supplementary concept word, unique identifier, synonyms]
16	(fit* or (fit* adj3 (accuracy* or precis* or vertical* or horizontal* or margin*))).mp. [mp=title, abstract, original title, name of substance word, subject heading word, floating sub-heading word, keyword heading word, organism supplementary concept word, protocol supplementary concept word, rare disease supplementary concept word, unique identifier, synonyms]
17	toleran*.mp. [mp=title, abstract, original title, name of substance word, subject heading word, floating sub-heading word, keyword heading word, organism supplementary concept word, protocol supplementary concept word, rare disease supplementary concept word, unique identifier, synonyms]
18	15 or 16 or 17

19	3 or 6
20	18 and 19
21	exp Dental Abutments/
22	(dental adj3 implant* adj3 abutment*).mp. [mp=title, abstract, original title, name of substance word, subject heading word, floating sub-heading word, keyword heading word, organism supplementary concept word, protocol supplementary concept word, rare disease supplementary concept word, unique identifier, synonyms]
23	(original adj3 abutment*).mp. [mp=title, abstract, original title, name of substance word, subject heading word, floating sub-heading word, keyword heading word, organism supplementary concept word, protocol supplementary concept word, rare disease supplementary concept word, unique identifier, synonyms]
24	(stock adj3 abutment*).mp. [mp=title, abstract, original title, name of substance word, subject heading word, floating sub-heading word, keyword heading word, organism supplementary concept word, protocol supplementary concept word, rare disease supplementary concept word, unique identifier, synonyms]
25	(pre-fabricated adj3 abutment*).mp. [mp=title, abstract, original title, name of substance word, subject heading word, floating sub-heading word, keyword heading word, organism supplementary concept word, protocol supplementary concept word, rare disease supplementary concept word, unique identifier, synonyms]
26	(non-original adj3 abutment*).mp. [mp=title, abstract, original title, name of substance word, subject heading word, floating sub-heading word, keyword heading word, organism supplementary concept word, protocol supplementary concept word, rare disease supplementary concept word, unique identifier, synonyms]
27	(abutment* adj3 (certified* or compatib* or lookalike or after-market or cop* or interchang*)).mp. [mp=title, abstract, original title, name of substance word, subject heading word, floating sub-heading word, keyword heading word, organism supplementary concept word, protocol supplementary concept word, rare disease supplementary concept word, unique identifier, synonyms]
28	21 or 22 or 23 or 24 or 25 or 26 or 27
29	exp Computer-Aided Design/
30	(implant* adj3 abutment*).mp. [mp=title, abstract, original title, name of substance word, subject heading word, floating sub-heading word, keyword heading word, organism supplementary concept word, protocol supplementary concept word, rare disease supplementary concept word, unique identifier, synonyms]
31	29 and 30
32	((implant* adj7 discrepanc*) or (geometr* adj3 discrepancy)).mp. [mp=title, abstract, original title, name of substance word, subject heading word, floating sub-heading word, keyword heading word, organism supplementary concept word, protocol

	supplementary concept word, rare disease supplementary concept word, unique identifier, synonyms]
33	(implant* adj3 abutment* adj3 microleakage*).mp. [mp=title, abstract, original title, name of substance word, subject heading word, floating sub-heading word, keyword heading word, organism supplementary concept word, protocol supplementary concept word, rare disease supplementary concept word, unique identifier, synonyms]
34	(implant* adj3 microgap*).mp. [mp=title, abstract, original title, name of substance word, subject heading word, floating sub-heading word, keyword heading word, organism supplementary concept word, protocol supplementary concept word, rare disease supplementary concept word, unique identifier, synonyms]
35	(implant* adj3 micromotion*).mp. [mp=title, abstract, original title, name of substance word, subject heading word, floating sub-heading word, keyword heading word, organism supplementary concept word, protocol supplementary concept word, rare disease supplementary concept word, unique identifier, synonyms]
36	(implant adj7 (misfit* or (rotational adj misfit))).mp. [mp=title, abstract, original title, name of substance word, subject heading word, floating sub-heading word, keyword heading word, organism supplementary concept word, protocol supplementary concept word, rare disease supplementary concept word, unique identifier, synonyms]
37	(implant adj3 (remov* adj3 torque*)).mp. [mp=title, abstract, original title, name of substance word, subject heading word, floating sub-heading word, keyword heading word, organism supplementary concept word, protocol supplementary concept word, rare disease supplementary concept word, unique identifier, synonyms]
38	(implant* adj fracture adj resistance).mp. [mp=title, abstract, original title, name of substance word, subject heading word, floating sub-heading word, keyword heading word, organism supplementary concept word, protocol supplementary concept word, rare disease supplementary concept word, unique identifier, synonyms]
39	((abutment* or implant*) adj3 (screw* adj3 loose*)).mp. [mp=title, abstract, original title, name of substance word, subject heading word, floating sub-heading word, keyword heading word, organism supplementary concept word, protocol supplementary concept word, rare disease supplementary concept word, unique identifier, synonyms]
40	32 or 33 or 34 or 35 or 36 or 37 or 38 or 39
41	20 and 28
42	41 or 14 or 31 or 40
43	limit 42 to yr="1995 -Current"
44	limit 43 to english language

Table 2. Studies testing precision of fit at the implant-abutment interface

Author (s)	**Implant system(s)**	**Connection type**	**Original abutments**	**Non-original abutments**	**Mean gap widths (OAs) (µm)**	**Mean g widths (N (µm)**
Alikhasi et al. (2013)	Brånemark (Nobel Biocare, Göteborg, Sweden)	EC (EH)	Titanium Easy Abutment (Nobel Biocare, Gotëborg, Sweden)	Customised ICE zirconia abutment (Zirkonzahn, Gais, Italy)	Horizontal: 2 Vertical: 0	Horizont Vertical:
Assuncao et al. (2011)	Osseotite Implants (Biomet 3i Inc., Palm Beach Gardens, FL, USA)	EC (EH)	(I) Gold UCLA abutments (Biomet 3i Inc., Palm Beach Gardens, FL, USA) cast in gold alloy with ceramic veneering (II) Gold UCLA abutment (Biomet 3i Inc., Palm Beach Gardens, FL, USA) cast in gold alloy with resin veneering (III) titanium castable UCLA abutment (Biomet 3i Inc., Palm Beach Gardens, FL, USA) with ceramic veneering (IV) titanium castable UCLA abutment (Biomet 3i Inc., Palm Beach Gardens, FL, USA)	(V) Zirconia abutment obtained by CAD/CAM system (Nobel Biocare, Goteborg, Sweden) with ceramic veneering.	Vertical: Pre-loading/post-loading (I) 24.98/18.78 (II) 16.49/ 14.43 (III) 67.69/ 38.38 (IV) 77.56/ 26.77	Vertical: Pre loading/po loading (V) 4.86/ 2

Byrne et al. (1998)	(A) Nobel Pharma (Nobel Biocare, Göteborg, Sweden) (B) 3I (Implant innovations Inc., Palm Beach, FL)	EC (EH) EC (EH)	(I) CeraOne™ (Nobel Biocare AB, Gothenburg, Sweden) (II) STR (Implant innovations Inc., Palm Beach, FL) (III) Cast UCLA abutments (Implant Innovations Inc.) (IV) Premachined UCLA abutments (Implant Innovations Inc.) (V) Premachined UCLA abutments with metal coping (Implant Innovations Inc.)	(III) Cast UCLA abutments (Implant Innovations Inc.)	(A/I) Vertical: 86 (B/II) Vertical: 36 (B/III) Vertical: 74 (B/IV) Vertical: 45 (B/V) Vertical: 40 (means for greatest gap widths)	(A/III Vertical (means greatest widths
De Morais Alves da Cunha et al. (2012)	(A) MK III™ (Nobel Biocare™, Göteborg, Sweden) (B) Try On (Sistema de Implantes, São Paulo, Brazil)	EC (EH)	(I) NobelProcera® Zirconia CAD/CAM (Nobel Biocare, Göteborg, Sweden)	(I) NobelProcera® Zirconia CAD/CAM (Procera, Nobel Biocare Göteborg, Sweden)	Vertical: (A/I) 5.7	Vertica (B/I) 9. (C/I) 10

	(C) Master screw Conexão® (Sistema de Prótese, São Paulo, Brazil)					
Dellow et al. (1997)	(SI) Southern Implant system (Southern Implants, Irene, South Africa) (BR) Brånemark (Nobel Biocare, Göteborg, Sweden) (SV) Swede-vent Implant (Core-vent corporation, Encino, California) (SO) Steri-oss Implant (Denar, Anaheim, California)	EC (EH) EC (EH) EC (EH) EC (EH)	(SI) Southern Implant System (BR) Brånemark (SV) Swede-vent (SO) Steri-Oss	(SI) Southern Implant System (BR) Brånemark (SV) Swede-Vent (SO) Steri-Oss	Marginal: (SI/SI) 0.23 (BR/BR) 7.17 (SV/SV) 0.00 (SO/SO) <1.00	Margir (SI/BR) (SI/SV) < (SI/SO) (BR/SI) (BR/SV) (BR/SO) (SV/SI) < (SV/BR) (SV/SO) (SO/SI) (SO/BR) (SO/SV)
Markarian et al. (2018)	SIN implant system (SIN Implant System, São Paulo, São Paulo, Brazil)	EC (EH)	(I) Titanium computer numeric control (CNC) prefabricated (SIN Implant System, São Paulo, São Paulo, Brazil)	(II) Zirconia CNC Milling Machine – RODERS, RXD5 (III) Selective laser melting CoCr – CUBO milling centre	Marginal gap: Before loading/ post loading (I) 1.103/ 2.296	Marginal Before loa post loa (II) 11.7 10.42 (III) 24.7

				(IV) CNC CoCr abutment – Neoshape, Neodent (V) CoCr Milled abutment (Ceramill, Amann Girrbach AG, Koblach, Austria)		18.40 (IV) 2.609/ (V) 1.098/
Queiroz et al. (2019)	Titamax (Neodent-Straumann, Basel, Switzerland)	EC (EH)	(N) Neodent Antirotational cobalt-chromium custom dental implant abutment with Zirconia CAD/CAM (Neodent-Straumann, Basel, Switzerland)	(CC) NiCr Completely cast Anti-rotational custom dental implant abutment (Talmax, Curitiba, Paraná, Brazil) (OC) Overcast Antirotational cobalt-chromium custom dental implant abutment with Ni-Cr-Ti (Talmax, Curitiba, Paraná, Brazil) (Z) Zirkonzahn Antirotational cobalt-chromium custom dental implant abutment Zirconia CAD/CAM (Zirkonzahn, Gais, Italy)	Initial gap/ gap after loading: (N) 2/ 20	Initial gap loadin (CC) 37 (OC) 35 (Z) 4/
Sola-Ruiz et al. (2013)	(BF) Biofit Implant (Castemaggiore, Italy) (BN) Bioner S.A implant	EC (EH)	(BF) Biofit (Castemaggiore, Italy) (BN) Bioner S.A (Barcelona, Spain)	(BF) Biofit (Castemaggiore, Italy) (BN) Bioner S.A (Barcelona, Spain)	Implant/Abutment fit: (3i/3i): G (BN/BN): G	(3i/BN) (3i/BTI) (BTI/NB (NB/3i) (NB/BTI

	(Barcelona, Spain) (3i) 3i Biomet implant (Palm Beach, Florida, USA) (BTI) BTI implant (Alava, Spain) (NB) Nobel Biocare implant (Göteborg, Sweden)		(3i) 3i Biomet (Palm Beach, Florida, USA) (BTI) BTI (Alava, Spain) (NB) Nobel Biocare (Göteborg, Sweden)	(3i) 3i Biomet (Palm Beach, Florida, USA) (BTI) BTI (Alava, Spain) (NB) Nobel Biocare (Göteborg, Sweden)	(BTI/BTI): G (NB/NB): G (BF/BF): A Note: Authors denoted gap widths as: E= Excellent, G= Good or A= Acceptable	(BF/BN (BN/3i) (BN/BTI (BN/NB (BTI/3i) (BTI/BN (NB/BN (3i/BF) (BF/3i) (BF/NTI (BF/NB (BN/BF (BTI/BF (NB/BF
Zanardi et al. (2012)	(SIN) SIN implant system (SIN Implant System, São Paulo, São Paulo, Brazil) (NEO) NEO implant system (Neodent, Curitiba, Paraná, Brazil)	EC (EH)	(SIN) Rotational abutment SIN implant system (NEO) Rotational abutment NEO implant system (CON) Rotational abutment CON implant system (SIN) Non-rotational abutment SIN implant system	(SIN) Rotational abutment SIN implant system (NEO) Rotational abutment NEO implant system (CON) Rotational abutment CON implant system (MIC) MIC Rotational abutment (Microplant	Rotational: (SIN/SIN): 2.6 (NEO/NEO):2.87 (CON/CON):10.55 Non rotational: (SIN/SIN): 2.97 (NEO/NEO):1.87 (CON/CON):8.76	Rotatio (SIN/NEO (SIN/CO 9.09 (SIN/MIC) (NEO/SIN (NEO/CO 7.87 (NEO/MIC (CON/ S 4.94 (CON/N 6.33 (CON/M 6.22

	(CON) CON implant system (Conexão Sistemas de Próteses, Arujá, São Paulo, Brazil)		(NEO) Non-rotational abutment NEO implant system (CON) Non-rotational abutment CON implant system	Sistemas de Prótese, São Paulo, Brazil) (SIN) Non-rotational abutment SIN implant system (NEO) Non-rotational abutment NEO implant system (CON) Non-rotational abutment CON implant system (MIC) MIC Non-rotational abutment (Microplant Sistemas de Prótese, São Paulo, Brazil)		Non-rotat (SIN/NEO (SIN/ C 5.34 (SIN/ 2.73 (NEO/SIN (NEO/CON (NEO/M 2.52 (CON/SI (CON/NE 8 (CON/M 3.83
Alonso-Perez et al. (2017)	Tapered Screw-Vent (Zimmer Biomet, Warsaw, Indiana, USA)	IC (IH)	Titanium Zimmer Hex-lock contour abutment (Zimmer Biomet, Warsaw, Indiana, USA)	Titanium CAD/CAM, Laser-sintered (Philbo Dental Solutions)	Marginal: not detectable	Margina
Alonso-Perez et al. (2018)	Straumann® Standard Plus, (Straumann®, Basel, Switzerland)	IC (ICo)	(I) CoCr SynOcta® prosthetic system (Straumann®, Basel, Switzerland)	(II) CoCr Ebsynocta, LC® (Montcada i Reixac, Spain) (III) CoCr SynOcta type abutment,	Implant-abutment: (I) 0.7 Implant- crown: (I) 5.5	Implar abutme (II): appro (estimatec graph (III): 7

				(Proclinic®, Zaragoza, Spain)		Implant-c (II): appro (estimated graph (III): 35
Baldassarri et al. (2012)	(A) Nobel Replace Select Tapered TiUnite (Nobel Biocare, Göteborg, Sweden) (B) NanoTite Tapered Certain Implants (Biomet 3i Inc., Palm Beach Gardens, FL, USA)	IC (IDH)	(I) NobelProcera® Zirconia CAD/CAM abutments on Ti base (Procera, Nobel Biocare Göteborg, Sweden) (II) Encode CAD/CAM zirconia abutments (Biomet 3i Inc., Palm Beach Gardens, FL, USA) (III) Encode custom titanium abutments (Biomet 3i Inc., Palm Beach Gardens, FL, USA)	(IV) Astra Tech Atlantis custom Zirconia Dentsply Implants, Mölndal, Sweden)	Marginal Gap: (A/I) – 8.4 (B/II) – 5.7 (B/III) – 1.6	(B/IV): 1
Berberi et al. (2016)	OsseoSpeed TX™ (AstraTech Implant Systems™, Dentsply Implants, Mölndal, Sweden)	IC (IDH)	(I) TiDesign™ (AstraTech Implant System™, Dentsply Implants, Mölndal, Sweden)	(II) Natea™ (Euroteknika™ Group, Sallanches, France) (III) Implanet™ (Derig LTDA, São Paulo, Brazil)	(I): 0	(II): 6. (III):
Duraisamy et al. (2019)	ADIN Dental Implants (ADIN, Israel)	IC (IH)	Pre-machined Standard Ti abutments (ADIN Dental Implants)	Pre- machined standard Ti abutments (MIS Implant Technologies, Ltd.)	External portion of interface: 1.597 Middle: 1.399 Internal: 1.831	External: Middle: 2 Internal:

Hamilton et al. (2013)	(SBL) Straumann Bone level (Straumann, Basel, Switzerland) (SSP) Straumann Standard Plus (Straumann, Basel, Switzerland) (NR) Nobel Replace (Nobel Biocare, Göteborg, Sweden) (OS) OsseoSpeed™, (Astra Tech Implant Systems, Dentsply Implants, Mölndal, Sweden) (BR) Brånemark RP (Nobel Biocare, Göteborg, Sweden)	IC (ICo) IC (ICo) IC (ITC) IC (IDH) EC (EH)	(I) RC Anatomic (Straumann, Basel, Switzerland) (II) RN synOcta® titanium (Straumann, Basel, Switzerland) (III) RN synOcta® + milling cylinder (Straumann, Basel, Switzerland) (IV) Esthetic (Nobel Biocare, Göteborg, Sweden) (V) NobelProcera CAD/CAM titanium (Nobel Biocare, Göteborg, Sweden) (VI) Tidesign™ (Astra Tech Implant Systems, Dentsply, Mölndal, Sweden)	(V) NobelProcera® CAD/CAM titanium (Nobel Biocare, Göteborg, Sweden)	(SBL/I) 28.0 (SSP/II) 14.2 (SSP/III) 4.0 (NR/IV) 47.7 (NR/V) 62.6 (OS/VI) 31.3 (BR/IV) 22.3 (BR/V) 21.2	(SBL/V) (SSP/V) (OS/V) 2

Park et al. (2014)	Brånemark Mark III implant system (Nobel biocare, USA) Replace Select implant system (Nobel biocare, USA)	EC (EH) IC (IH)	Gold UCLA abutment (Nobel biocare, USA)	Custom milled Ti abutment (ADDTECH, South Korea)	Branemark with UCLA: 35.0 Replace with UCLA: 31.3	Branemar Custom n 32.4 Replace Custom n 30.7
Siadat et al. (2017)	(A) Brånemark (Nobel Biocare AB, Göteborg, Sweden) (B) Noble Replace (Nobel Biocare AB, Göteborg, Sweden)	EC (EH) IC (IH)	(I) (Brånemark, Nobel Biocare AB, Göteborg, Sweden) (II) (Noble Replace, Nobel Biocare AB, Göteborg, Sweden)	(III) ICE Zirkon, Zirkonzahn GmbH)	(A/I) Horizontal gap: 2 Vertical gap: 0 (B/II) Horizontal gap: 59 Vertical gap: 63	(A/III Horizonta 4 Vertical g (B/III Horizonta 39 Vertical ga

Areas of Tight Contact

Author(s)	Implant system(s)	Connection type	Original abutments	Non-original abutments	Areas of tight contact	Areas of conta
Fokas et al. (2019)	Bone Level Implant; Straumann AG (Straumann, Basel,	IC (ICo)	(Zr1) Cares (Straumann, Basel, Switzerland) (Ti1) Variobase (Straumann, Basel,	(Zr2) Atlantis; (Dentsply Sirona, Sweden) (Zr3) Aadva Zr (GC Advanced Technologies Inc,	Length of tight contact at connection level (mm): left/right	Length o contac connectior (mm): left (Zr2) 0.69

	Switzerland)		Switzerland) (Gold1) Straumann Gold (Straumann, Basel, Switzerland)	Alsip, Illinois) (Ti2) KISS (Blue Sky Bio, Grayslake, Illinois, USA) (Gold2) Gold UCLA (Blue Sky Bio, Grayslake, Illinois, USA)	(Zr1) 0.91/ 0.92 (Ti1) 0.71/ 0.73 (Gold1) 0.71/ 0.75	(Zr3) 0.00 (Ti2) 0.85 (Gold2) 0 0.86
Mattheos et al. (2016)	Straumann AG (Straumann, Basel, Switzerland)	IC (ICo)	(I) Straumann SynOcta Gold	(II) Ostech Pro – Pack RN Eng II, CoCr Str (III) Medentika GmbH POC abutment, CoCr	Length of total tight contact as a percentage of max. possible contact area at IAI (%): left/ right (I) Shoulder: 82.57/ 82.06 Internal: 51.67/ 53.13	Length of tight conta a percenta max. pos contact ar IAI (%): right (II) Should 76.10/ 7 Internal: 12.40 (III) Should 46.55/ 7 Internal:0 0.00 Groups (I (III) show higher st and strain finite eler analysis group

Mattheos et al. (2017)	Straumann AG (Straumann, Basel, Switzerland)	IC (ICo)	(I) Straumann Variobase RN abutment	(II) Ebi best duo abutment (III) Implant direct titanium abutment	Length of total tight contact at IAI (mm): left/ right (I) Shoulder: 0.81/0.79 Internal: 0.39/1.39	Length of tight conta IAI (mm) right (II) Shoulde Internal: 1.43 (III) Shoulder: 0.40 Internal: 0.24
Component Dimensions						
Author(s)	**Implant system(s)**	**Connection type**	**Original abutments**	**Non-original abutments**	**Component dimensions**	**Compor dimensi**
Lang et al. (2003)	(A) Procera (Nobel Biocare, Göteborg, Sweden) (B) Brånemark (Nobel Biocare Göteborg, Sweden) (C) Lifecore Restore (Lifecore	EC (EH)	Procera CAD/CAM custom abutment (Nobel Biocare Göteborg, Sweden) Dimensions of flat-to-flat width and height for abutment Width= 2.73 mm Height= 0.9 mm	Procera CAD/CAM custom abutment (Nobel Biocare Göteborg, Sweden) Dimensions of flat-to-flat width and height for abutment Width= 2.73 mm Height= 0.9 mm	Dimensions of each implant hexagon (A) Width= 2.73 mm Height= 0.9 mm (B) Width= 2.69 mm Height= 0.70 mm	Dimensio each imp hexago (C) Width= 2.6 Height= mm (D) Width= 2.6 Height=

	Biomedical, Chaska, MN, U.S.A) (D) 3i (Palm Beach, FL, U.S.A.) (E) ImplaMed (ImplaMed, Attleboro, MA, U.S.A) (F) Paragon Taper-Lock (Encino, CA)					mm (E) Width= 2.6 Height= mm (F) Width= 2.6 Height= mm
Karl and Irastorza-Landa (2018)	NobelActive implants with a regular platform (Nobel Biocare)	IC (ICo)	(I) Snappy Abutment RP 5.5 mm (Nobel Biocare) – used as reference system. Dimensions not disclosed (II) NobelProcera Titanium Abutment (Nobel Biocare)	(III) ArgenIS Titanium Abutment F-Series (The Argen Corporation) (IV) Atlantis Titanium Abutment for cement-retained restorations (Dentsply Sirona Implants) (V) Inclusive Custom Titanium Abutments (Glidewell Laboratories) (VI) InterActive Straight Contoured Abutment (Implant Direct Sybron Manufacturing)	Flat-to-flat Dimensions % deviation from snappy abutment A: (II) -0.24	Flat-to- Dimensio deviation snapp abutmen (III) 0. (IV) 0. (V) -0. (VI) 0.

Scratches and Wear						
Author(s)	**Implant system(s)**	**Connection type**	**Original abutments**	**Non-original abutments**	**Scratches/wear (OAs)**	**Scratch wear (NO**
Tannure et al. (2017)	Titamax (Neodent-Straumann, Basel, Switzerland)	EC (EH)	(I) CAD/CAM Zirconia (Neodent) (II) Zirconia abutments on Titanium base (Neodent, Curitiba, Paraná, Brazil)	(III) CAD/CAM Zirconia (Amann Girrbach AG, Koblach, Austria) (IV) CAD/ CAM Zirconia (Zirkonzahn, Gais, Italy)	Less scratches in (II) than (I) Values not given in study.	(IV) Had scratch indicated a fit and hex mismat
Queiroz et al. (2019)	Titamax (Neodent-Straumann, Basel, Switzerland)	EC (EH)	(N) Neodent Antirotational cobalt-chromium custom dental implant abutment with Zirconia CAD/CAM (Neodent-Straumann, Basel, Switzerland)	(CC) NiCr Completely cast Anti-rotational custom dental implant abutment (Talmax, Curitiba, Paraná, Brazil) (OC) Overcast Antirotational cobalt-chromium custom dental implant abutment with Ni-Cr-Ti (Talmax, Curitiba, Paraná, Brazil) (Z) Zirkonzahn Antirotational cobalt-chromium custom dental implant abutment Zirconia CAD/CAM (Zirkonzahn, Gais, Italy)	Worn surface area (mm^2) (N) 1313	Worn surfa area (mm^2 (CC) 2 (OC) 2 (Z) 73

Legend: EC=External connection, IC=Internal connection, (EH)=External hexagon, (IH)=Internal hexagon, (IDH)=Internal double hexagon, (ICo)=Internal conical, (MT)=Morse Taper, (ITC)=Internal Tri-channel. Implant-abutment combinations denoted with letters and roman numerals in brackets.

Table 3. Studies investigating microleakage to indicate degree of misfit

Author(s)	Implant system	Connection type	Original abutments	Non-original abutments	Microleakage (OAs)	M
Berberi et al. (2014)	OsseoSpeed™ (Astra Tech Implant Systems, Dentsply Implants, Mölndal, Sweden)	IC (IDH)	TiDesign™ (AstraTech Implant System™, Dentsply Implants, Mölndal, Sweden)	Natea™ (Euroteknika™ Group, Sallanches, France) Dual™ (Implantium, Dentium Implant System, Seoul, South Korea) Implanet™ (Derig LTDA, São Paulo, Brazil)	At 1hr/ at 48hrs 1.48%/ 5.56%	At 1 Nate 39.8 Dua 10.5 Imp 51.0
Karl and Irastorza-Landa (2018)	NobelActive implants with a regular platform (Nobel Biocare)	IC (ICo)	(I) Snappy Abutment RP 5.5 mm (Nobel Biocare) (II) NobelProcera Titanium Abutment (Nobel Biocare)	(III) ArgenIS Titanium Abutment F-Series (The Argen Corporation) (IV) Atlantis Titanium Abutment for cement-retained restorations (Dentsply Sirona Implants) (V) Inclusive Custom Titanium Abutments (Glidewell Laboratories) (VI) InterActive Straight Contoured Abutment (Implant Direct Sybron Manufacturing)	After 6 days: (I) 28.57% (II) 30.95%	Afte (III) (IV) (V) (VI)

Legend: IC = Internal connection, (IDH) = Internal Double Hexagon, (ICo) = Internal conical

Table 4. Studies testing micromotion and displacement of abutments

Authors	Implant system	Connection type	Original abutments	Non-original abutments	Mean gap widths/ micromotion/ displacement (OAs) Pre-/post loading (µm)	Me widths/ / disp (N Pre-/p
Berberi et al. (2016)	OsseoSpeed TX™ (AstraTech Implant Systems™, Dentsply Implants, Mölndal, Sweden)	IC (IDH)	TiDesign™ (AstraTech Implant System™, Dentsply Implants, Mölndal, Sweden)	Natea™ (Euroteknika™ Group, Sallanches, France) Implanet™ (Derig LTDA, São Paulo, Brazil)	Gap widths: TiDesign™: 0/ 8.4	Gap wid Natea™ Implanet
Karl and Irastorza-Landa (2018)	NobelActive implants with a regular platform (Nobel Biocare)	IC (ICo)	(I) Snappy Abutment RP 5.5 mm (Nobel Biocare) (II) NobelProcera Titanium Abutment (Nobel Biocare)	(III) ArgenIS Titanium Abutment F-Series (The Argen Corporation) (IV) Atlantis Titanium Abutment for cement-retained restorations (Dentsply Sirona Implants) (V) Inclusive Custom Titanium Abutments (Glidewell Laboratories)	Post-loading micromotion (I) 65.14 (II) 75.74	Post-loa micromo (III) 63.1 (IV) 61.6 (V) 75.6 (VI) 79.6

				(VI) InterActive Straight Contoured Abutment (Implant Direct Sybron Manufacturing)		
Karl and Taylor (2016)	Straumann Tissue-level (Straumann, Basel, Switzerland)	IC (ICo)	Two-piece cementable (Straumann, Basel, Switzerland) CAD/CAM titanium abutment (Straumann, Basel, Switzerland) CAD/CAM zirconia abutment (Straumann, Basel, Switzerland)	Two-piece cementable abutment (Dr. Ihde Dental AG, Gommiswald, Switzerland) Two-piece cementable abutment (Medentika GmbH, Hügelsheim, Germany) NobelProcera® CAD/CAM titanium (Nobel Biocare, Göteborg, Sweden)	Mean micromotion: Straumann two-piece: 55.33/40.16 CAD/CAM titanium: 47.64/ 37.18 CAD/CAM zirconia:44.11/ 35.30	Mean m Dr. Ihde 42.40 Medentil 34.76 NobelPr 33.15 / 3
Yilmaz et al. (2015a)	Tapered Screw-Vent Implant (Zimmer Inc, Warsaw, Indiana, USA)	IC (IH)	(I) Hex-lock Contour stock abutment (Zimmer, Inc, Warsaw, Indiana, USA) (II) Zimmer Contour Zirconia stock Abutment (Zimmer, Inc, Warsaw, Indiana,	(IV) Atlantis custom Titanium (Dentsply Implants, Mölndal, Sweden) (V) Atlantis custom Zirconia (Dentsply Implants, Mölndal,	3D - Displacement after 1st Torque/ 2nd Torque (I) 5/ 1 (II) 7.5/ 4 (III) 6.5/ 3	3D - Dis after 1st Torque (IV) (V) (VI) (VII) (VIII

			USA) (III) Zimmer Patient Specific Abutment custom Titanium (Zimmer, Inc, Warsaw, Indiana, USA)	Sweden) (VI) Inclusive Custom Implant Abutment Titanium (Glidewell Laboratories, Frankfurt, Germany) (VII) Inclusive Custom Implant Abutment All-zirconia (Glidewell Laboratories, Frankfurt am main, Germany) (VIII) Legacy Straight Contoured stock Abutment (Implant Direct, Kloten, Switzerland) (IX) Legacy Zirconia Straight Contoured stock Abutment (Implant Direct, Kloten, Switzerland)		(IX)

Legend: IC=Internal connection, (IH)=Internal hexagon, (IDH)=Internal double hexagon, (ICo)=Internal conical

Table 5. Studies testing rotational misfit of abutments

Author(s)	Implant system(s)	Connection type	Original abutments	Non-original abutments	Mean rotational freedom (degrees) OAs	ro fr (d
Alikhasi et al. (2013)	Brånemark (Nobel Biocare, Göteborg, Sweden)	EC (EH)	Titanium Easy Abutment (Nobel Biocare, Gotëborg, Sweden)	Customised ICE zirconia abutment (Zirkonzahn, Gais, Italy)	0.99	
Binon (1995)	(NP) Nobelpharma USA (Chicago IL) (STR) Stryker (Kalamazoo, MI) (SO) Steri-Oss (Anaheim, CA) (3i) Implant innovations Inc. (West Palm Beach, FL) (OTC) Osseodent (Palo Alto, CA) (ISS) Implant Support Systems (Irvine, CA) (IMTEC) IMTEC	EC (EH) EC (EH) EC (EH) EC (EH) EC (EH)	(3ia) Implant innovations Inc. (West Palm Beach, FL) (Xmarka) Crossmark (Belmont, CA) (IMPa) Impla-Med (Sunrise, FL) (ISSa) Implant Support Systems (Irvine, CA) (IMTECa) IMTEC (Ardmore, OK)	(NPa) Nobelpharma USA (Chicago IL) (STRa) Stryker (Kalamazoo, MI) (SOa) Steri-Oss (Anaheim, CA) (3ia) Implant innovations Inc. (West Palm Beach, FL) (OTCa) Osseodent (Palo Alto, CA) (ISSa) Implant Support Systems (Irvine, CA)	(Xmark/Xmarka): 4.0 (3i/3ia): 4.6 (IMP/IMPa): 5.0 (ISS/ISSa): 6.7 (NP/NPa): 6.7	(NP/ 3.5 (NP/ (NP/ (NP/ 7.9 (3i/I (3i/IS (3i/N (3i/C (ISS

	(Ardmore, OK) (SV) Dentsply-Core-Vent Div. (Encino, CA) (IMP) Impla-Med (Sunrise, FL) (Bud) Bud Ind. (East Aurora, NY) (Xmark) Crossmark (Belmont, CA) (IMZ) Interpore Int. (Irvine, CA)	EC (EH) EC (EH) EC (EH) EC (EH) EC (EH) EC (EH) EC (EH)	(NPa) Nobelpharma USA (Chicago IL)	(IMTECa) IMTEC (Ardmore, OK) (SVa) Dentsply-Core-Vent Div. (Encino, CA) (IMPa) Impla-Med (Sunrise, FL) (Buda) Bud Ind. (East Aurora, NY) (Xmarka) Crossmark (Belmont, CA) (IMZa) Interpore Int. (Irvine, CA)		4.2 (ISS (ISS (ISS 8.9 (IMF 7.9 (IMF (IMF (IMF 9.5 (SO 5.7 (SO (SO (SO 8.6 (SO

						(STF 8.8 (STF (STF 9.3 (STF 10.1
Gigandet et al. (2014)	(A) Straumann Roxolid® (Straumann, Basel, Switzerland) (B) Nobel Biocare Replace/Select Straight (Nobel Biocare™, Kloten, Switzerland) (C) Astra Tech OsseoSpeed TX™ (Astra Tech, Lausanne Switzerland)	IC (ICo) IC (ITC) IC (IDH)	(I) CARES® titanium CAD/CAM (Straumann, Basel, Switzerland) (II) NobelProcera® titanium CAD/CAM (Nobel Biocare Kloten, Switzerland) (III) Atlantis® titanium CAD/CAM (Astra Tech, Lausanne Switzerland)	(IV) NobelProcera® titanium CAD/CAM (Nobel Biocare Kloten, Switzerland) (V) Atlantis® titanium CAD/CAM (Astra Tech, Lausanne Switzerland)	(A/I) 1.21 (B/II) 3.50 (C/III) 2.50	(A/IV mea poss abut over (A/V

Siadat et al. (2017)	(A) Brånemark (Nobel Biocare AB, Göteborg, Sweden) (B) Noble Replace (Nobel Biocare AB, Göteborg, Sweden)	EC (EH) IC (IH)	(I) Brånemark (Nobel Biocare AB, Göteborg, Sweden) (II) Noble Replace (Nobel Biocare AB, Göteborg, Sweden)	(III) ICE Zirkon, Zirkonzahn GmbH)	(A/I): 0.97 (B/II): 0.000	(A/II (B/II

Legend: EC=External connection, IC=Internal connection, (EH)=External hexagon, (IH)=Internal hexagon, (IDH)=Internal double hexagon, (ICo)=Internal conical, (ITC)=Internal Tri-channel.

Table 6. Studies testing removal torque values

r(s)	Implant system(s)	Connection type	Original abutments	Non-original abutments	Mean post-loading removal torque values (RTVs) - OAs	Mean post-loading removal torque values (RTVs) - NOAs	Differ betwee and N signifi
o- t al. 3)	Straumann Standard Plus (Straumann, Basel, Switzerland)	IC (ICo)	(I) SynOcta® prosthetic system (Straumann, Basel, Switzerland)	(II) Ebsynocta, LC®, Montcada i Reixac, Spain (III)SynOcta type abutment, Proclinic®, Zaragoza, Spain	(I) 30.4Ncm (13.1% loss)	(II) 26.4Ncm (24.6% loss) (III) 23.8Ncm (32.1% loss)	Yes, in f OA
an . l)	Straumann tissue-level (Straumann USA, Andover, MA)	IC (ICo)	Straumann regular neck solid abutment (Straumann USA, Andover, MA)	Titan Implant Inc. abutment (Titan Implant, Bergenfield, New Jersey)	42.65N	36.25N	Yes, in f OA

al. 2)	Straumann SLA (Straumann, Basel, Switzerland)	IC (ICo)	Straumann® Solid abutment (Straumann, Basel, Switzerland)	Restore RDS COC (Lifecore Biomedical Inc, USA) Neoplant solid abutment (Niobiotech®) AVANA solid abutment (Osstem Co, Busana, Korea)	32.74Ncm	Restore: 22.79 Ncm Neoplant: 12.00 Ncm (6 screws fractured) AVANA: 18.67 Ncm (4 implants fractured)	Yes, in f OA
nd n 3)	GS II Fixture (Osstem Co., Seoul, Korea)	IC (IH)	Ti stock abutment (Osstem Co., Seoul, Korea) GoldCast abutment (Osstem Co., Seoul, Korea)	CAD/CAM Ti MYPLANT (Raphabio, Seoul, Korea)	Ti stock: 17.67Ncm Goldcast: 16.10Ncm	Myplant: 15.20Ncm	Yes, in f OAs.
t al. 6)	Implantium (Dentium, Seoul, Korea) GS (Osstem Co., Seoul, Korea) Straumann Bone level (Straumann, Basel, Switzerland)	IC (IH) IC (IH) IC (ICo)	Stock Abutment (Dentium, Seoul, Korea) Stock Abutment (Osstem Co., Seoul, Korea) Straumann Bone level (Straumann, Basel, Switzerland)	Myplant (Raphabio, Seoul, Korea)	(first loading/ second loading) Dentium/ Dentium: 27.17Ncm/ 23Ncm Osstem/ Ossteum: 26.17Ncm/ 22.5Ncm Straumann/ Straumann: 37.33Ncm/	(first loading/ second loading) Dentium/ Raphabio: 26.67Ncm/ 23.5Ncm Ossteum/ Raphabio: 26.33Ncm/ 22.33Ncm Straumann/ Raphabio:	No diffe between and NO

					32.67Ncm	36.67Ncm/ 32.5Ncm	
t al. 7)	Straumann SLA tissue level (Straumann, Basel, Switzerland)	IC (ICo)	Solid abutment (Straumann, Basel, Switzerland)	Solid abutment (Southern Implants, Irene, South Africa) Straight abutment (Implant Direct Sybron International, Valencia, USA) Regular Platform abutment (Blue Sky Bio, Grayslake, Illinois, USA)	Solid: 34Ncm	Southern Implants: 25Ncm Implant Direct: 23.9Ncm Blue Sky Bio: 27.9Ncm	Yes, in f OAs.
cao . 1)	Osseotite Implants (Biomet 3i Inc., Palm Beach Gardens, FL, USA)	EC (EH)	(I) Gold UCLA abutments (Biomet 3i Inc., Palm Beach Gardens, FL, USA) cast in gold alloy with ceramic veneering (II) Gold UCLA abutment (Biomet 3i Inc., Palm Beach Gardens, FL, USA) cast in gold alloy with resin veneering (III) Titanium castable UCLA abutment (Biomet 3i Inc., Palm Beach Gardens, FL, USA) with	(V) Zirconia abutment obtained by CAD/CAM system (Nobel Biocare, Goteborg, Sweden) with ceramic veneering.	(I) 23.2Ncm (II) 23.8Ncm (III) 22.1Ncm (IV) 23.6Ncm	Vertical: Pre-loading/post-loading (V) 21.7Ncm	No statis differenc between and NO.

			ceramic veneering (IV) Titanium castable UCLA abutment (Biomet 3i Inc., Palm Beach Gardens, FL, USA)				
t al. 4)	Brånemark Mark III implant system (Nobel biocare, USA) Replace Select implant system (Nobel biocare, USA)	EC (EH) IC (IH)	Gold UCLA abutment (Nobel biocare, USA)	Custom milled Ti abutment (ADDTECH, South Korea)	Branemark with UCLA: 23.3 N Replace with UCLA:23.9 N	Branemark with Custom milled: 21.9 N Replace with Custom milled : 21.7N	No diffe betwee and N **Typ conne no signifi**
t et 17)	(A) Brånemark (Nobel Biocare AB, Göteborg, Sweden) (B) Noble Replace (Nobel Biocare AB, Göteborg, Sweden)	EC (EH) IC (IH)	(I) (Brånemark, Nobel Biocare AB, Göteborg, Sweden) (II) (Noble Replace, Nobel Biocare AB, Göteborg, Sweden)	(III) ICE Zirkon, Zirkonzahn GmbH)	Loss of torque values (A/I) - 13.42 Ncm (B/II) - 11.43 Ncm	Loss of torque values: (A/III) - 14.20Ncm (B/III) - 11.86Ncm	Altho greater loss se NO compare OAs, exte compare inter connec not stati signifi

Legend: EC=External connection, IC=Internal connection, (EH)=External hexagon, (IH)=Internal hexagon, (ICo)=Internal conical

Table 7. Studies investigating mechanical properties e.g. load/ cycles to failure, fracture resistance, tensile and compressive strengths

Author(s)	**Implant system(s)**	**Connection type**	**Original abutments**	**Non-original abutments**	**Load/Cycles to failure (OAs)**	**Load/Cycles t failure (NOAs**
Alonso-Perez et al. (2017)	Tapered Screw-Vent (Zimmer Biomet, Warsaw, Indiana, USA)	IC (IH)	Zimmer Hex-lock contour abutment (Zimmer Biomet, Warsaw, Indiana, USA)	CAD/CAM, Laser-sintered (Philbo Dental Solutions)	Load-bearing capacity: ~ 750N Mean cycles to failure: 423.225 ± 69.220	Load-bearing capacity: ~ 800N Mean cycles to failure: 416.069 ± 85.392
Alonso-Perez et al. (2018)	Straumann® (Standard Plus, Straumann, Basel, Switzerland)	IC (ICo)	(I) (SynOcta® prosthetic system, Straumann, Basel, Switzerland)	(II) Ebsynocta, LC®, Montcada i Reixac, Spain (III) SynOcta type abutment, Proclinic®, Zaragoza, Spain	Static load bearing capacity: (I) 1098N Load to deformation: (I) 842N	Static load bearin capacity: (II)1057N (III) 973N Load to deformat (II) 736N (III) 760N
Gigandet et al. (2014)	Straumann Roxolid® (Straumann, Basel, Switzerland) Nobel Biocare Replace/Selec t Straight (Nobel Biocare™,	IC (ICo) IC (ITC)	CARES® titanium CAD/CAM (Straumann, Basel, Switzerland) NobelProcera ® titanium CAD/CAM (Nobel Biocare	NobelProcera® titanium CAD/CAM (Nobel Biocare Kloten, Switzerland) Atlantis® titanium CAD/CAM (Astra Tech,	Straumann/ Straumann Force to fracture = 553N Force to deformation = 487N Nobel/ Nobel: Force to fracture =	Straumann/ Nob Biocare Force to fracture 700N Force to deforma = 538N Straumann/ Astra

	Kloten, Switzerland) Astra Tech OsseoSpeed TX™ (Astra Tech, Lausanne Switzerland)	IC (IDH)	Kloten, Switzerland) Atlantis® titanium CAD/CAM (Astra Tech, Lausanne Switzerland)	Lausanne Switzerland)	555 N Force to deformation = 453N Astra/ Astra: Force to fracture = 508N Force to deformation = 439N	Tech: Force to fracture 690N Force to deforma = 587N
Karl and Irastorza-Landa (2018)	NobelActive implants with a regular platform (Nobel Biocare)	IC (ICo)	(I) Snappy Abutment RP 5.5 mm (Nobel Biocare) – used as reference system. Dimensions not disclosed (II) NobelProcera Titanium Abutment (Nobel Biocare)	(III) ArgenIS Titanium Abutment F-Series (The Argen Corporation) (IV) Atlantis Titanium Abutment for cement-retained restorations (Dentsply Sirona Implants) (V) Inclusive Custom Titanium Abutments (Glidewell Laboratories) (VI) InterActive Straight Contoured Abutment (Implant Direct Sybron Manufacturing)	Median fatigue limit (N) (I) 326 (II) 326	Median Fatigue l (N) (III) 344 (IV) 246 (V) 296 (VI) 279
Kim et al. (2013)	NobelReplace (Noble Biocare, Yorba Linda,	IC (ITC)	NobelProcera, Ti insert frictional fit to zirconia abutment	Aadva all zirconia CAD/CAM abutment (GC Advanced	Maximum load capacity: NobelProcera: 484.6	Maximum load capacity: Aadva: 503.9 N

	California)		(Noble Biocare, Yorba Linda, California)	Technologies Inc, Alsip, Illinois) Lava CAD/CAM zirconia abutment bonded to Ti insert (3M ESPE, St Paul, Minnesota)	N	Lava: 729.2 N
Leutert et al. (2012)	Straumann Bone level (Straumann, Basel, Switzerland) Astra Micro Thread OsseoSpeed ™, (Astra Tech Implant Systems, Dentsply Implants, Mölndal, Sweden) Straumann Standard Plus (Straumann, Basel, Switzerland)	IC (ICo) IC (IDH) IC (ICo)	CARES® RC zirconia CAD/CAM (Straumann, Basel, Switzerland) zirconia ZirDesign® (Dentsply Implants, Mölndal, Sweden) CARES® RC titanium CAD/CAM (Straumann, Basel, Switzerland)	Zirabut zirconia abutments (Wohlwend AG)	Mean bending moments: Straumann/CARES Zi: restored = 224.8Ncm unrestored = 344.8Ncm Astra/ZirDesign Zi: restored = 292.8Ncm unrestored = 324.8Ncm Straumann/CARES Ti: restored = 419.4Ncm unrestored = 678.2Ncm	Straumann/ Zirab Zi: restored = 117.9Ncm unrestored = 158.2Ncm
Salaita et al. (2017)	Tapered Screw-Vent (Zimmer Inc, Warsaw,	IC (IH)	Zimmer Patient Specific Abutment	Atlantis titanium (AtlTi) Dentsply Sirona	No differences among the abutments for compression strain values AtlZr and PSA abutments had highest ter	

	Indiana, USA)		(PSA) custom Titanium (Zimmer, Inc, Warsaw, Indiana, USA)	Atlantis zirconia (AtlZr) Dentsply Sirona Inclusive custom implant abutment titanium (GlTi) Glidewell Laboratories Inclusive custom implant abutment zirconia (GlZr) Glidewell Laboratories Legacy straight contoured abutment (IDTi) Implant Direct Legacy zirconia straight contoured abutment (IDZr) Implant Direct AstraTech ZirDesign abutment (AstZr) AstraTech AstraTech TiDesign abutment (AstTi) AstraTech	strain around the implants.	
Yilmaz et al. (2015b)	Tapered Screw-Vent (Zimmer Inc, Warsaw, Indiana, USA)	IC (IH)	Zimmer Patient Specific Abutment custom Titanium (Zimmer, Inc, Warsaw, Indiana, USA)	Atlantis custom Titanium (Dentsply Implants, Mölndal, Sweden) Inclusive	Did not fracture	Atlantis: Screw fracture 506.62 N Inclusive: Screw fracture 524.09 N

				Custom Implant Abutment Titanium (Glidewell Laboratories, Frankfurt am main, Germany) TiDesign™ stock (AstraTech Implant System™, Dentsply Implants, Mölndal, Sweden) Legacy Straight Contoured stock Abutment (Implant Direct, Kloten, Switzerland)		TiDesign: Screw fracture 661.64 N Legacy: Screw fracture 1104.96
Yilmaz et al. (2015c)	Tapered Screw-vent implants (Zimmer Inc, Warsaw, Indiana, USA)	IC (IH)	Zimmer Contour Zirconia stock Abutment (Zimmer, Inc, Warsaw, Indiana, USA)	Atlantis custom Zirconia (Dentsply Implants, Mölndal, Sweden) Inclusive Custom Implant Abutment All-zirconia (Glidewell Laboratories, Frankfurt am main, Germany) AstraTech ZirDesign®	Abutment (hex) fracture 668 N	Atlantis Abutmen fracture 465N Inclusive abutme fracture 124N Astratech abutme fracture 236N Legacy screw fracture 1017 N

				(Dentsply Implants, Mölndal, Sweden) Legacy Zirconia Straight Contoured stock Abutment (Implant Direct, Kloten, Switzerland)		
Jarman et al. (2017)	(A) Straumann Bone level (Straumann, Basel, Switzerland) (B) Nobel Biocare RP (Nobel Biocare, Göteborg, Sweden) (C) Nobel Replace/ Select (Nobel Biocare, Göteborg, Swed	IC (ICo) EC (EH) IC (ITC)	(I) Straumann IPS e.max ZrO2 abutment (II) Procera Straight Aesthetic abutment Control (III) Nobel Procera Straight Aesthetic Abutment (IV) Biomet 3i ZiReal abutment	(V) CAD/CAM milled Atlantis Zr abutments	Load to failure: (A/I) Straumann:387N (B/II) Nobel Biocare: 408 N (C/III) Nobel Replace 430 N (D/IV) Biomet 3i: 448 N	Load to failure: (A/V) Straumann 211 N (B/V) Nobel Bioc 218 N (C/V) Nobel Replace: 260 N (D/V) Biomet 3i: N

	en)					
	(D) Biomet 3i Certain (Biomet 3i Inc., Palm Beach Gardens, FL, USA)	IC (IH)				

Legend: EC=External connection, IC=Internal connection, (EH)=External hexagon, (IH)=Internal hexagon, (IDH)=Internal double hexagon, (ICo)=Internal conical, (ITC)=Internal Tri-channel.