Success and survival of various types of all-ceramic single crowns. A critical review and analysis of studies with a mean follow-up of 5 years or more

Alhanoof Aldegheishem[1], George Ioannidis[2], Wael Att[3], Haralampos Petridis[4*]

[1] Postgraduate Student, Department of Prosthodontics, School of Dentistry, University Hospital, Freiburg, Germany

Demonstrator, Department of Prosthodontics, School of Dentistry, Princess Nourah bint Abdulrahman University, Riyadh, Saudi Arabia.

[2] Clinical Fellow, Aristotle University of Thessaloniki, Thessaloniki, Greece

[3] Professor, Director of postgraduate program, Department of Prosthodontics, School of Dentistry, University Hospital, Freiburg, Germany

[4] Senior Clinical Lecturer, Prosthodontic Unit, Department of Restorative Dentistry, UCL Eastman Dental Institute, London, UK

Corresponding author:

Dr. Haralampos Petridis
Prosthodontic Unit, Department of Restorative Dentistry
UCL Eastman Dental Institute
256 Gray's Inn Road, London WC1X 8LD, UK
Tel: 0044(0)2034561250
e-mail: c.petridis@ucl.ac.uk

Abstract:

Aims: The objective of this critical review was to assess the survival and success rates of all ceramic single crowns manufactured from different ceramic materials with a mean follow-up time of 5 years or more.

Methods: An electronic search from 1980 to 2014 complemented by manual searching was conducted in Medline and Scopus libraries to identify relevant studies. The terms ceramic, crown, survival, success, longevity and complications were selected as keywords. Pre-determined inclusion and exclusion criteria guided the search. Data were assessed and extracted by two independent reviewers. The results were statistically analyzed according to the type of material, and survival/success rate was calculated by assuming a Poisson-distributed number of events.

Results: The initial search yielded 972 titles. After a subsequent filtering process, 14 studies were finally selected. The inter-reviewer agreement was rated as 'good' (k=0.65) and 'very high agreement' (k=0.93) during the identification and screening phases respectively. No studies on densely sintered zirconia or feldspathic crowns satisfied the minimum follow-up time. Only 1 study of each of the following materials satisfied the inclusion criteria: lithium disilicate, leucite reinforced, pressed Al_2O_3 and sintered Al_2O_3. Meta-analysis of the included studies of other materials resulted in the following estimated survival and success rates: for densely sintered alumina crowns 93.8% and 92.75% respectively, for fluoromica-reinforced 87.7% and 87.7% respectively, and for glass infiltrated alumina core 94.4% and 92% respectively.

Crown fracture was considered as the most frequent complication.

Conclusion: Based on the present critical review, there was no evidence to support the superior application of a single ceramic system or material, further prospective long-term studies are required.

Key words: all-ceramic, single crowns, success, survival, complication

Introduction

Due to the constant increase in esthetic demand in dentistry, progress has been made in the development of several types of all ceramic systems. The first major dental breakthrough was the fabrication of feldspathic porcelain crowns made by Land in 1886 (1). The high coefficient of thermal expansion of feldspathic ceramics led to the development of ceramic fillers in the form of a crystalline mineral called leucite in 1962 to make the material compatible with metal-ceramic fabrication (2, 3). Leucite has proven to be a suitable strengthening filler, whereby moderate strengthening can be achieved without severely increasing opacity, and furthermore, it can be easily etched to create micromechanical features for resin bonding (4). At the same time, McLean and Hughes introduced alumina oxide ceramics (5). Further developments in ceramic technology led to the introduction of polycrystalline ceramics, the most recent being transformation-toughened zirconia (6, 7).

Currently, dental ceramics are categorized into three main groups, according to the glass and filler content: predominantly glass, particle filled glass and polycrystalline (4). Dental ceramics, which are predominantly glass, such as feldspathic porcelains, imitate the optical properties of both enamel and dentine. Unfortunately, they have the disadvantage of low flexural strengths and fracture toughness, and therefore must be reinforced by a core substructure or adhesively bonded to tooth structure in order to prevent catastrophic bulk fractures under occlusal loads (8). Therefore, feldspathic ceramics are more suitable as veneering layers on a core substructure (ceramic or metallic), which provides the support and strength to the bi-layered system. Ceramic cores in bi-layered all-ceramic restorations are either particle-filled glasses or polycrystalline ceramics. Particle filled glasses contain filler particles, which are added to the base glass composition to enhance compatibility with the core structure. These fillers are usually crystalline, and are dissolved during etching to create micromechanical retentive features enabling bonding. The major difference between particle-

filled glasses and polycrystalline is that the latter contain no glass. Polycrystalline ceramics tend to be relatively opaque compared to glassy ceramics, thus these stronger materials are esthetically unsuitable as monolithic materials (4, 9, 10).

Typical survival rates for all-ceramic restorations range from 88-100% after 2-5 years in service and 84-97% after 5-14 years in service (11). A meta-analysis of all-ceramic restorations fabricated from various types of materials showed that for all positions in the mouth, densely sintered alumina crowns had a five-year survival rate of 96.4%, which was quite similar to the survival of leucite-reinforced glass ceramics (95.4%) and infiltrated glass ceramics (94.5%), but significantly different from that of tetrasilicic fluormica glass ceramic (87.5%) (12) . That study reported only on the survival rates of all-ceramic crowns, using both prospective and retrospective studies, with a mean follow-up of 3 years and published up until December 2005 (12) . Although the luting procedure was not factored in, all types of all-ceramic crowns performed better in the anterior part of the dentition (12). Another systematic review (13) , evaluated the survival rates of single-tooth restorations fabricated by computer-aided design and manufacturing (CAD/CAM) systems, by analyzing both prospective and retrospective studies published up to 2007, with a mean follow-up time of at least 3 years and reported an overall survival rate of 91.6%. A previous systematic review (14) reported on fracture of single all-ceramic crowns by analyzing prospective and retrospective studies published up to 2011 with a mean follow-up time of at least 3 years. The authors did not analyze the data according to material type, due to low number of studies, and reported an overall 5-year fracture rate of 4.4%.

A recent systematic review (15) evaluated the survival and complication rates of single crowns. It reported a survival rate of 94.7% for metal-ceramic SCs. This was considered almost similar to those of other ceramic materials investigated in the study including leucite or lithium-disilicate reinforced glass ceramic SCs (96.6%), glass infiltrated alumina SCs (94.6%)

and densely sintered alumina and zirconia SCs (96%; 92.1% respectively) in both the anterior and posterior regions. However, this study (15) used both prospective and retrospective studies with a mean follow-up period of at least 3 years and only the survival rate was reported.

Although all ceramic restorations seem to be a highly reliable form of esthetic treatment for anterior teeth, their success rates in posterior teeth still remain unpredictable (12, 16). Moreover, all ceramic restorations still have lower clinical longevity compared to metal ceramic restorations(12, 17). The clinical behavior of dental ceramics is affected by their microstructure and, for some systems, by the mode of cementation, both factors strongly affecting the mechanical properties and survival rate for each ceramic system (11, 12). Mechanical failures are time dependent due to slow crack growth and it is therefore important to assess these materials after long-term (>5 years) service. From a patient and practice management point of view, it is also important to distinguish between success and survival rates, a distinction that has been lacking in previous published reviews.

The objective of this review was to assess the survival and success rates of all ceramic single crowns manufactured from different ceramic materials, and to investigate the frequency of various complication types reported in studies with a mean follow-up of 5 years or more. The position in the mouth (anterior vs. posterior) and the properties of material were evaluated as confounding variables.

Materials and Methods

Search strategy:

The initial literature search was conducted independently by 2 reviewers (AA and GI). A search in Medline and Scopus libraries was conducted from 1980 up to and including December 2014. Keywords and Keywords combinations were as follows: ((ceramic OR

"dental porcelain") AND crown) AND (survival OR success OR longevity OR complications) AND (Humans[Mesh]).

The option of “related articles” was also used. Moreover, manual searching was performed the following journals for the years 2001–2014: Dental Materials, International Journal of Prosthodontics, Journal of Esthetic and Restorative Dentistry, Journal of Prosthetic Dentistry, Journal of Prosthodontics, International Journal of Computerized Dentistry, Journal of Oral Rehabilitation and Quintessence International.

Selection of studies

The review process consisted of four phases (Figure 1). During the identification phase, duplicate records were removed. During the first screening phase, titles and abstracts were screened for relevance by the two reviewers independently. Disagreement was resolved by discussion amongst the reviewers or by consulting the third reviewer (HP), and in case of doubt the full text article was obtained. The screening during the first phase was performed, according to the following inclusion criteria: Clinical studies on humans, published in the English language, reporting on the survival, success and/or complications of tooth supported, all ceramic, single crowns. Case reports, laboratory studies, technical articles, and non-peer reviewed journals were excluded, whereas reviews were studied for reference purposes.

The full text of all studies of possible relevance was obtained. At this point, searching the references of the selected studies and hand searching of the selected journals was also implemented.

The selected full text studies were further screened by the two reviewers independently using the following inclusion criteria:

- Prospective studies.
- A mean follow-up time of 5 years or more.

- Studies incorporating a clinical exam of patients at follow-up visits. Publications based only on patient records, questionnaires or interviews were excluded.
- Studies reporting details on the ceramic materials and systems used, and providing results on survival or success, or complications.

Any disagreement was resolved by discussion amongst the reviewers and the third reviewer (HP). Finally, all included studies were analyzed to determine suitability for either meta-analysis or only for qualitative analysis.

The final included studies that passed the second screening phase in the review process were classified according to the strength of evidence into 4 categories according to Jökstad et al (18) :

1. A1, controlled clinical trial with patient randomization (RCT).
2. A2, controlled clinical trial with split-mouth randomization (split-RCT).
3. B, prospective controlled trial without randomization (CCT).
4. C, clinical studies with different designs than categories A and B. (prospective uncontrolled)

Data Extraction

Publications which combined findings of various prosthetic restorations were included only if they provided data for at least 10 single crowns (SC) per publication. In cases of multiple publications following the same cohort of patients, only the study with the longest follow-up was taken into account. Various demographic and clinical data was extracted from the included studies. The data were extracted using a data extraction sheet by two reviewers independently. Any disagreement was resolved by discussion amongst the reviewers and the

third reviewer (HP). Factors such as study setting, patient's age and number of dropouts, presence of parafunctional habits, restoration location, mode of cementation and occlusal scheme were recorded.

Also, the number and type of complications during the observation period of the study were recorded, in order to calculate the survival and success rates. Success was defined as the crown remaining in situ without modifications or changes. Survival was defined as the crown remaining in situ with or without modification during the entire observation period.

Information on the survival proportions of the reconstructions was extracted from the final studies. Where US Public Health Service (USPHS) criteria were used to evaluate the restorations, a 'Charlie' score was considered as an irreversible complication affecting both survival and success rates, while a 'Bravo' score was considered as a reversible complication affecting only the success rate. The number of events and the corresponding total exposure time of the reconstructions were calculated and tabulated from the studies included.

Statistical analysis

Inter-reviewer agreement during both screening phases was determined using Cohen's Kappa coefficients.

Annual failure rates were calculated by dividing the total number of events (failures or complications), by the total exposure time in years multiplied by 100 to convert it as per 100 crown years, this can be translated into the following formula:

$$\text{Failure rate (for material X)} = \frac{(\text{Number of complications (within X)} * 100)}{\text{Time exposure for X}}$$

The total number of events was extracted directly from the publications. The total exposure time was calculated by multiplying the mean follow-up time by the number of crowns available for analysis. The mean follow-up time was extracted directly from the publications. Poisson distribution was considered for the number of events. Five-year survival and success

percentages (with the corresponding 95% Confidence intervals) were calculated assuming a constant event rate with the following formula:

$$S(t)_X = Exp.\left(-t \times failure\ rate(X)\right), t = 5\ years$$

Two-sample T test was used to compare whether there were differences between the mean values of survivals within densely sintered alumina locations (Anterior and Posterior) at a significance level of 0.05.

Moreover, the I^2 in forest plots was used as a summary indicator to measure heterogeneity between studies, with large percentages indicating large heterogeneity between studies. The Cochran Q test was also used to evaluate heterogeneity, with p values < 0.1 indicating heterogeneity and leading to the use of a random effects model, rather than a fixed effects model for the meta-analysis.

The statistical package STATA 13.0 (IBM, New York, USA) was utilized to perform the meta analysis.

Results

The initial electronic database search yielded 972 titles. After screening of duplicate titles, 597 abstracts were obtained and reviewed according to identification inclusion criteria, and 73 studies were selected for full text review. Five studies were retrieved from references of identified studies, and nine studies were retrieved from journal hand searching. Therefore, a total of 87 full texts (17, 19-104), were obtained and screened against inclusion/exclusion criteria during the screening phase. Sixty-nine studies (17, 19-35, 37-42, 44-49, 51-53, 57-61, 67-70, 73-75, 77-85, 87-93, 95-99, 102-104) were excluded during the screening phase, and the most frequent reason for exclusion was a mean observation period of less than five years (Table 1).

Eighteen studies (36, 43, 50, 54-56, 62-66, 71, 72, 76, 86, 94, 100, 101) met the criteria of the screening phase. By exclusion of studies reporting on the same cohort (62, 63, 65, 66) 14 were finally selected for analysis (Figure 1). The inter-reviewer agreement was calculated as 'good' (k=0.65) and 'very high agreement' (k=0.93) during the identification and screening phases respectively.

The publication date of the studies included in this meta-analysis ranged between 1998 and 2013. Most included studies were classified as category C except for two studies, one (50) as A2, and the other (76) as A1 according to strength of evidence (18) (Table 3).

Survival and Success

All of the 14 included studies reported on the survival and success of all ceramic single crowns. In three of the included studies, the complication type was not specified (64, 76, 100), and in another study (50), the complications for both all ceramic single crowns and metal ceramic crowns were pooled. Therefore, these 4 studies were not included in the meta-analysis but were included in the descriptive tables (Tables 2&3).

The estimated survival rate and success rate for each study is shown in Table 4.

Most of the included studies reported on some confounding variables possibly influencing the survival and success of all ceramic single crowns, such as type of material and location of the crowns. The 14 articles were categorized with respect to their context on both factors. A detailed description of the studies related to each factor is provided below:

Material Type

The studies were pooled according to material type in order to calculate the corresponding cumulative survival and success rates, as this was more meaningful (Table 4) (Figures 2-7). It was interesting to note that no studies evaluating crowns based on densely sintered zirconia

were included, as none passed the minimum mean 5-year follow-up inclusion criterion. The same held true for studies which reported on feldspathic ceramics which were also excluded as they either had a follow-up period of less than 5 years or were retrospective studies.

Only 1 study (43) reporting on lithium disilicate crowns satisfied the inclusion criteria and showed a survival rate of (97.6%). Lower survival rates were reported for other materials: glass infiltrated alumina (94.4%) (Fig 5), densely sintered alumina (93.8%)(Fig. 2), leucite reinforced glass ceramic (90.8%), sintered alumina (89.5%), fluoromica reinforced glass ceramic (87.7%) (Fig. 4), and pressed Al_2O_3, $MgAl_2O_4$ (84.5%).

Regarding the success rates, the single study of lithium disilicate showed a success rate of (93%), followed by densely sintered alumina (92.75%), glass infiltrated alumina (92%)(Fig. 6), leucite reinforced glass ceramic (90.8%), fluoromica reinforced ceramic (87.7%), pressed Al_2O_3, $MgAl_2O_4$ (80.5%), and sintered Al_2O_3 (80.1%) (Fig.3.

Types of complications

Due to the low number of complications, it was not possible to statistically correlate individual complication types with material types. However, descriptive analysis of the data revealed that the complications were mostly technical, with crown fracture being the most frequent within all ceramic materials (Figure 7).

Crown location

The effect of crown location on survival and success rate of each individual material type was investigated. Due to the lack of studies, statistical analysis was possible only for densely sintered alumina and glass infiltrated alumina. Detailed calculations for failure, survival and success rates within each study are listed in tables 5 and 6.

A higher survival rate for crowns located anteriorly was noticed for densely sintered alumina with a five years survival summary estimate of (100%) compared to (92.6%), 95%CI (90.37%-94.77%) for posteriorly located crowns (P=0.046) (Table 5).

While for glass infiltrated alumina crowns the results showed that no statistically significant difference in survival rates was found between those located anteriorly and posteriorly, with rate values of 97.5% and 97.7% respectively (p=0.560) (Table 5).

Regarding success rates, no statistically significant difference was found between anterior and posterior crowns for both densely sintered alumina (P=0.108) and glass infiltrated alumina core (P=0.089) (Table 6).

Discussion

Ceramic materials can affect complication rates due to variability in mechanical properties and failure modes (4). The aim of this critical review was to assess the survival and success rates of all ceramic single crowns manufactured from different ceramic materials after a true clinical mean follow-up time of 5 years or more, a time that constitutes mid-term follow-up. The effect of various confounding variables, such as material and position were also analyzed.

The validity of reviews depends mainly on the search methodology, and the quality of included studies. In this study, 2 reviewers completed independent searches, utilizing an electronic database, related articles, citations, and hand searching of selected journals. Non-English and non-peer reviewed articles were excluded, and this fact may have led to the omission of some papers, however, there are problems related to translation and data extraction from non-English journals, as well as validating non-peer reviewed articles. Moreover, grey literature was not sought and this could have increased the risk of publication bias.

The included studies presented clinical and statistical heterogeneity, due to different study designs, different materials, operator experience, and patient characteristics. In order to develop meaningful aggregations and comparisons during the meta-analysis, "success" and "survival" were strictly defined in the current study and the relevant criteria were used during data extraction. Nevertheless, the degree of heterogeneity meant that all meta-analyses results should be viewed under this prism of caution.

All studies included in this review were prospective cohort studies except two (50, 76), which were randomized controlled clinical trials. However, in one study (50) the complications for both all ceramic single crowns and metal ceramic crown were pooled, whereas in the other study (76), the authors didn't specify the complications, which made it impossible to extract relevant data. A recent publication showed that there has been no increase in published RCTs in prosthodontics during the past decade compared to previous years (105). In the current study, no RCTs were available directly comparing different materials of all ceramic crowns. Only 1 prospective study (86) compared four different materials (Cerestore, Dicor, In-Ceram, Hi-Ceram). However, the strength of the included studies in this review was the fact that they were all prospective in design.

Survival and success

Descriptive analysis of the data showed that the highest survival (97.6%) rate was demonstrated for lithium disilicate crowns. However, this result should be interpreted with caution, since it was derived from only one study which met the inclusion criteria. Other studies were excluded either because they were retrospective in nature or they had an observation period of less than 5 years. This result is in line with 2 recent systematic reviews, which reported similar 5-year survival rates of 97% for lithium disilicate restorations (15, 106). In one of these systematic reviews (106), most of the included studies evaluated the

outcome of tooth-retained lithium disilicate restorations and a cumulative survival rate of 100% and 97.8% for single crowns after 2 and 5 years respectively, was reported. The cumulative survival rate over a 10-year period, primarily owing to data from 1 retrospective study, was 96.7% for single crowns. However, this systematic review (106) failed to show the true survival rates for both single crowns and FDPs due to insufficient data, the loss of patients to follow-up, and the inconsistent manner of reporting. In the other systematic review (15), an estimated survival rate of 96.6% after 5 years for leucite- or lithium disilicate-resinforced glass ceramic was reported. This was based on several studies including the single study (43) included in this review.

Despite the large number of studies available in the literature, there was a scarcity of studies, which directly compared different types of materials. Only 1 prospective study (86) , that met the inclusion criteria, compared four different materials (Cerestore, Dicor, In-Ceram, Hi-Ceram). In this study, the survival rate was 69% for Cerestore at 8 yrs, 86% for Dicor at 7 yrs, 81% for Hi-Ceram at 6 yrs, 92% for In-Ceram at 5 years. Different types of luting agents were used in this study (86) . The results for In-Ceram demonstrated a survival rate of 98% at 3 years which decreased to 92% after 5 years due to a series of failures that occurred during the third and fourth year (86). Another study (56), reported a survival rate of 91.2% for In-Ceram after 5 years. Here, it should be stressed that the time of clinical service is very important for ceramic materials. In this context, the initial failure rate of all ceramic crowns may not be indicative for long-term performance of the material (86). For this reason, clinicians need to be cautious with marketing of different ceramic materials and systems depending on short-term studies. The use of ceramic materials with less than 5 years true follow-up studies should be done with caution.

Clinical follow-up studies for ceramic crowns have demonstrated varying results. In regards to All-Ceram material, a study (54) reported a survival rate of 90.2% after 5 years, whereas in

another study (101), All-Ceram demonstrated a survival rate of 94.3% of all crowns (96.7% anterior, 91.3% posterior). This rate was lower than the results reported in other clinical studies on All-Ceram crowns, which reported survival rates of around 97% (71),(72). This may be partly explained by the heterogeneity of various clinical studies. However, it is important to mention that the included studies differed in the clinical techniques employed, the operator experience, the use of various clinical assessment tools, and the technical laboratory support.

Interestingly, studies on densely sintered zirconia crowns fulfilling the minimum 5-year follow-up were also lacking, despite the widespread use of this material. A recent review (15) reported that single crowns made of densely sintered zirconia presented with lower survival rates compared to other materials, even looking at studies with a mean follow-up of at least 3 years. This study (15) also reported a lower survival rate of single crowns made of feldspathic ceramics in comparison to other ceramic materials (90.7%). However, the feldspathic/silica-based ceramic was considered as one group, whereas the current review considered them as subgroups. Moreover, in this current study, all studies which reported on feldspathic ceramic crowns were excluded either due to not fulfilling the minimum mean observation period of 5 years, or because of their retrospective design. This explains the difference in number of included studies of this ceramic group compared to other published reviews (12, 15).

Types of complications

One of the aims of this review was to assess how different materials performed not only regarding their survival and success rates, but also considering the frequency of various complication types. However, due to low complication numbers this form of data analysis was not possible. Descriptive analysis, however, showed that the complications were mostly

technical, with crown fracture being the most frequent. Biologic complications, such as caries, pain to percussion, and loss due to periodontitis were uncommon. The high incidence of crown fracture explains the small discrepancy between survival and success rate, as it affects both.

Similarly, crown fracture has been reported as the most frequent complication in previous studies (11, 12, 40, 74). In contrast, porcelain chipping was considered a minor complication as the restorations were either polished or repaired.

Descriptive analysis showed that for specific material types (Fluoromica-reinforced, Leucite-reinforced, Pressed Al_2O_3, $MgAl_2O_4$ and Sintered Al_2O_3) the sole complication type within the observation time was fracture. Other materials (Densely sintered alumina, Glass infiltrated alumina core, Lithium disilicate) also exhibited a range of complication types. This finding may be due the latter materials being less prone to fracture, thus allowing time for complications other than fracture to occur. However, Scherrer (86) reported that the lifetime prediction for Dicor implied that 63% of the restorations would have failed at 35 years due to fracture. This explains why the material was withdrawn from the market and emphasizes the importance of long-term, well-designed clinical studies.

Once again, all these results should be viewed with caution due to the heterogeneity and the effect of some non-controlled confounding factors such as the occlusal force (107), shape of the prepared tooth (108), thickness of the coping (109), thickness of the veneered porcelain (109), cement film thickness (110), type of cement used (108) and mechanical strength of the coping itself (111).

Location

Analysis based on the material was attempted to compare between all ceramic crowns located anteriorly and those located posteriorly in terms of survival and success rates.

However, statistical analysis was possible only for densely sintered alumina and glass infiltrated alumina core crowns. The only significant difference noted was for the survival rate of densely sintered alumina crowns, which was higher for those located anteriorly. A recent study also found no statistical difference for the survival of single all-ceramic crowns depending on location, with the exception of feldspathic crowns (15).

Finally, crown location seemed to have a significant effect on the incidence of crown fracture, which was more frequent in posterior areas. This is a common finding in the literature (14, 54, 98, 101). Previous studies have shown that the strength of certain all ceramic materials is positively affected by adhesive cementation (65, 92). The intention of the authors was to assess the possible effect of this improvement in mechanical properties on survival and success rates, as well as in the incidence of certain complications such as fracture or secondary caries. This was not possible due to the limited data available. Similarly, not enough data existed to analyze the correlation between failure rate and the type of occlusion, i.e. canine guidance or group function. The studies included were not homogenous regarding these two factors, and this could have had an effect on the results presented in the study.

The results of this review have to be interpreted with caution due to the limitations of the study. These limitations included, exclusion of non-peer reviewed articles and those published in a language other than English, grey literature and low number of included studies in each group of material.

The included studies were categorized according to the criteria of Jokstad (18). The exclusion of retrospective studies, and the minimum true 5-year follow up time are factors that may have improved the robustness of the findings. However, the results have shown a lack of long-term prospective studies for various commonly used ceramic materials, as well as the lack of studies with direct clinical comparisons of different materials for single crowns.

Conclusion

Within the limitations of the study, survival and success rates for tooth-supported single crowns were affected by the type of material. However, no evidence was found to support the superior application of single ceramic system or material, due to the heterogeneity of studies. The most frequent major complication was fracture. The results of this review warrant the need for well-designed long-term randomized controlled studies, allowing for a direct prospective comparison between different types of ceramic materials.

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Table 1. Excluded studies and reason for exclusion

Studies	Reason for exclusion
Barnes et al 2006 (19), Beuer et al 2010 (21), Bindl et al 2002 (22), Bindl et al 2004 (23),Bindl et al 2005 (24), Bohlsen et al 2003 (26), Cehreli et al 2009 (28), Cehreli et al 2011 (29), Cheung et al 1991(30), Cortellini et al 2012 (31), Encke at al 2009 (35), Etman MK & Woolford MJ 2010 (37), Fradeani et al 1997 (38), Fradeani et al 2002 (39), Fradeani et al 2005 (40), Fyffe 1992 (42), Gemalmaz et al 2002 (44), Groten et al 2010 (45), Haselton 2000 (47), Kelsey 1995 (52), Lehner et al 1997 (58), Mansour et al 2008 (67), McLaren & White 2000 (68), Monticelli et al 2003 (69), Nothdurft & Pospiel 2006 (70), Ortorp et al 2009 (73), Pang 1995 (75), Paul & Werder 2004 (77), Probster 1993 (79), Probster et al 1996 (80), Rinke et al 2011 (83), Rinke et al 2013 (82), Sagirkaya et al 2012 (85), Schmitt et al 2010 (87), Scotti et al 1995 (88), Sorensen et al 1998 (91), Tartaglia et al 2011 (95), Taskonaka & Sertgoz 2006 (96), Toksavul &Toman 2007 (97), Vanoorbeek et al 2010 (99), Zitzmann et al 2007 (104).	Mean follow up time <5 years
Beier et al 2012 (20), Burke & Lucarotti 2009 (17), Black SM & Charlton G 1990 (25), De Backer et al 2007 (32), De Backer et al 2006 (33), Dhima et al. 2014 (34), Fradeani & Redemagni 2002 (41), Hawthorne & Smales 1997 (48), Hekland et al 2003 (49), Karlsson 2003 (51), Lockard 2002 (59), Lucarotti & Burke 2009 (60), Leempoel PJ et al 1985 (57), Lugassy AA et al 1986 (61) Ortorp et al 2012 (74), Poggio et al 2012 (78), Rinke et al 2011 (83), Reiss B et al 2011 (81), Segal 2001 (89), Sjogren et al 1999 (90), Hankinson & appetta 1994 (46), Sorrentino et al 2012 (92), Steeger 2010 (93), Valenti & Valenti 2009 (98), Wolleb et al 2012 (102), Zarone et al 2005 (103).	Not prospective studies
Brodbeck et al 1997 (27)	Non-peer reviewed journals
Keough et al 2011 (53)	Mean follow-up time not reported

Table 2. Study design and demographics of participants in the included studies.

Study	Year	Type of study	Category of evidence	Planned No. (sex) of patients	Actual No. of patients	Drop out	Drop out %	Age range	Mean age (Y)
Gehrt et al (43)	2013	Prospective	C	41 (15M, 26F)	37	4	10	NR	34±9.6
Kokubo et al (55)	2011	Prospective	C	39 (9M, 30F)	31	5	14.7	NR	50.9
Kokubo et al (54)	2009	Prospective	C	57 (6M, 51F)	46	11	19.2	20-70	46.4
Kokubo et al (56)	2006	Prospective	C	41 (10M, 31F)	33	8	24.2	NR	36
Walter et al (101)	2006	Prospective	C	70 (29M, 41F)	66	4	6.1	NR	38.8
Vigolo P & Mutinelli S (100)	2012	Prospective	C	40 (NR)	39 (NR)	1	2.5	19-55	32
Jokstad (18)	2004	RCT	A2	20 (10M, 10F)	NR	NR	NR	34-72	53
Odman P & Andersson B (72)	2001	Prospective	C	50 (14M, 36F)	41 (13M, 28F)	9	18	19-79	53
Scherrer et al (86)	2001	Prospective	C	18 (NR)	NR	NR	NA	NR	NR
		Prospective	C	15 (NR)	NR	NR	NA	NR	NR
		Prospective	C	15 (NR)	NR	NR	NA	NR	NR
		Prospective	C	47 (NR)	NR	NR	NA	NR	NR
Malament KA & Socransky SS(64)	2001	Prospective	C						
Erpenstein et al (36)	2000	Prospective	C	88 (NR)	87	2	1.1	NR	40.4±9.6
Oden et al (71)	1998	Prospective	C	58 (20M, 38F)	56	2	3	NR	NR
Studer et al (94)	1998	Prospective	C	71 (NR)	59 (19M, 40F)	12	17	NR	NR
Passia et al (76)	2013	RCT	A1	123 (NR)	77	46	37	24.7-72.8	42.7

F=Female, M=Male, Y=Year, NR= Not Reported

Table 3. Clinical data for the all-ceramic crowns in the included studies.

Study	Year	All Ceramic material/Technique	Planned No. of crowns	Actual No. of crowns	Drop out %	Follow-up range (Y)	Mean follow-up (Y)	Evaluation method	Luting type	Luting agent	Location of crowns (Molar/Premolar/Anterior)
Gehrt et al (43)	2013	Lithium disilicate (IPS e.max Press)	104	94	9.6	2.8 -9.1	6.6	Clinical examination	both	Variolink II, Vivaglass	20 posterior / 24 anterior
Kokubo et al (55)	2011	Glass-infiltrated alumina core (In-Ceram)	101	95	6	5	5	Clinical examination (CDA)	both	Panavia F, GC Full Luting	10 / 27 / 64
Kokubo et al (54)	2009	Densely-sintered alumina (All-Ceram)	101	75	25.7	5	5	Clinical examination (CDA)	Adhesive	Panavia F, Clapearl Panavia 21	20 / 46 / 35
Kokubo et al (56)	2006	Glass-infiltrated alumina core (In-Ceram)	70	57	18.6	4.5 -5.3	5	Clinical examination (USPHS)	both	Panavia 21, Fuji I, C&B Metabond	20 / 20 / 30
Walter et al (101)	2006	Densely-sintered alumina (All-Ceram)	107	102	4.9	6	6	Clinical examination	non-adhesive	GI – Ketac Cem	20 / 26 / 61
Vigolo P & Mutinelli S (100)	2012	Zirconium-oxide core (Procera/Lava)	40	39	2.5	5	5	Clinical examination (USPHS)	non-adhesive	GI – Ketac Cem	40 all molars
Jokstad (18)	2004	Densely-sintered alumina (All-Ceram)	70	12	44	6 - 8	NR	NR	both	Resin-modified glass ionomer, ZP	NR
Odman P & Andersson B (72)	2001	Densely-sintered alumina (All-Ceram)	87	71	18.4	5 – 10.5	NR	Clinical examination (CDA)	non-adhesive	ZP,GI	64 /23
Scherrer et al (86)	2001	Pressed Al_2O_3, $MgAl_20_4$ (Cerostore)	30	26	13.4	NR	8	Clinical examination	non-adhesive	GI	8 / 8 / 14
		Fluoromica-reinforced glass ceramic (Dicor)	30	25	16.7	NR	7	Clinical examination	non-adhesive	ZP	9 / 15 / 06
		Sintered Al_2O_3 (Hi-Ceram)	22	15	31.8	NR	6	Clinical examination	non-adhesive	ZP	5 / 8 / 09
		Glass-infiltrated alumina core (In-Ceram)	68	63	7.4	NR	5	Clinical examination	both	ZP, GI, resin-based	10 / 13 / 45
Malament KA & Socransky SS (64)	2001	Fluoromica-reinforced glass ceramic (Dicor)	1444	NR	NR	14	NR	NR	NR	NR	NR
Erpenstein et al (36)	2000	Fluoromica-reinforced glass ceramic (Dicor)	173	172	0.6	? -11	7.02	Clinical examination	non-adhesive	Zinc phosphate	70 posterior / 95 anterior
Oden et al (71)	1998	Densely-sintered alumina (All-Ceram)	100	97	3	5 - ?	5.3	Clinical examination (CDA)	both	ZP, GI, resin	55 / 28 / 17
Studer et al (94)	1998	Leucite-reinforced (IPS Empress)	NR	142	NR	NR	5.1	Clinical examination (USPHS)	both	Panavia TC, Porcelite, VP 891, DeTrey	39 / 36 / 67
Passia et al (76)	2013	shrinkage-free ZrSiO4-ceramic	123	77	37	5	5	Clinical examination	non-adhesive	GI	110/13/0

Y=Year, NR= Not Reported

Table 4. Survival and success estimates for single crowns according to the type of material.

Type of material/Study	No. of failures (survival)	Total crown exposure time	Estimated failure rate (per 100 crown years)	Estimated survival after 5 years (%)	No. of failures (success)	Estimated failure rate (per 100 crown years)	Estimated Success after 5 years (%)
Densely sintered alumina	20	1517	1.29	93.84% (91.45 - 96.23)	24	1.54	92.75% (89.20-96.29)
Oden (72)	6	530	1.13	94.5%	7	1.32	93.6%
Odman* (73)	5	NA	NR	NR	31	NR	NR
Walter (102)	6	612	0.98	95.2%	6	0.98	95.2%
Kokubo (55)	8	375	2.13	89.9%	11	2.93	86.4%
Fluoromica reinforced	46	1385	2.30	87.7% (83.91 – 91.40)	46	2.30	87.7% (83.91 – 91.40)
Erpenstein (37)	42	1210	3.47	84.1%	42	3.47	84.1%
Scherrer (87)	4	175	2.29	89.2%	4	2.29	89.2%
Glass infiltrated alumina core	13	1075	1.13	94.4% (93.12 – 95.74)	25	2.19	92.02% (89.97 – 94.08)
Scherrer (87)	3	315	0.95	95.3%	4	1.27	93.8%
Kokubo (57)	4	285	1.40	93.2%	11	3.86	82.4%
Kokubo (56)	6	475	1.26	93.9%	10	2.11	90.0%
Leucite reinforced (Studer (95))	14	724.2	1.93	90.8%	14	1.93	90.8%
Lithium disilicate (Gehrt (44))	3	620.4	0.48	97.6%	9	1.45	93.0%
Pressed Al_2O_3, $MgAl_2O_4$ Scherrer (87)	7	208	3.37	84.5%	9	4.33	80.5%
Sintered Al2O3	2	90	2.22	89.5%	4	4.44	80.1%

Scherrer (87)							

* Odman 2001 was excluded from densely sintered alumina computations, since exposure time is not available

Table.5: **Survival** estimates of crowns placed anterior or posterior per study

Type of material/Study	Survival								P- Value
	Anterior				Posterior				
	Total no. of crowns	Total no. of failures	Estimated Annual failure rate	5 year survival summary estimate	Total no. of crowns	Total no. of failures	Estimated Annual failure rate	5 year survival summary estimate	
Densely sintered alumina	52	0	0.00	100.0%	149	15	1.67	92.6% (90.37 – 94.77)	0.046
Oden (72)	17	0	0.00	100.0%	83	7	1.32	93.6%	
Kokubo (55)	35	0	0.00	100.0%	66	8	2.13	89.9%	
Glass infiltrated alumina core	139	5	0.61	97.5% (96.72 – 98.25)	100	8	0.43	97.7% (97.07 – 98.27)	0.560
Scherrer (87)	45	0	0.00	100.0%	23	3	0.95	95.3%	
Kokubo (57)	30	3	1.05	94.9%	40	1	0.35	98.3%	
Kokubo (56)	64	2	0.42	97.9%	37	4	0.84	95.9%	
Fluoromica reinforced	6	0	0.00	100.0%	24	4	2.29	89.2%	
Leucite reinforced	67	8	1.10	94.6%	75	6	0.83	95.9%	
Lithium disilicate	74	2	0.32	98.4%	20	1	0.16	99.2%	
Pressed Al_2O_3, $MgAl_2O_4$	14	1	0.48	97.6%	16	6	2.88	86.6%	

Table.6: **Success** estimates of crowns placed anterior or posterior per study

Type of material/Study	Success							
	Anterior				Posterior			
	Total no. of crowns	Total no. of failures	Estimated Annual failure rate	Estimated Success after 5 years	Total no. of crowns	Total no. of failures	Estimated Annual failure rate	Estimated Success after 5 years
Densely sintered alumina	52	2	0.53	97.4% (96.36 – 98.45)	149	16	1.73	92.5% (90.20 - 94.73)
Oden (72)	17	0	0.00	100.0%	83	7	1.32	93.6%
Kokubo (55)	35	2	0.53	97.4%	66	9	2.40	88.7%
Glass infiltrated alumina core	109	4	0.35	98.1% (97.53 - 98.65)	60	10	1.03	94.6% (93.03 - 96.15)
Scherrer (87)	45	1	0.32	98.4%	23	3	0.95	95.3%
Kokubo (56)	64	3	0.63	96.9%	37	7	1.47	92.9%
Fluoromica reinforced	6	0	0.00	100.0%	24	4	2.29	89.2%
Leucite reinforced	67	8	1.10	94.6%	75	6	0.83	95.9%
Lithium disilicate	74	8	1.29	93.8%	20	1	0.16	99.2%
Pressed Al_2O_3, $MgAl_2O_4$	14	2	0.96	95.3%	16	7	3.37	84.5%
Sintered Al_2O_3	9	2	2.22	89.5%	13	2	2.22	89.5%

Figure legends:

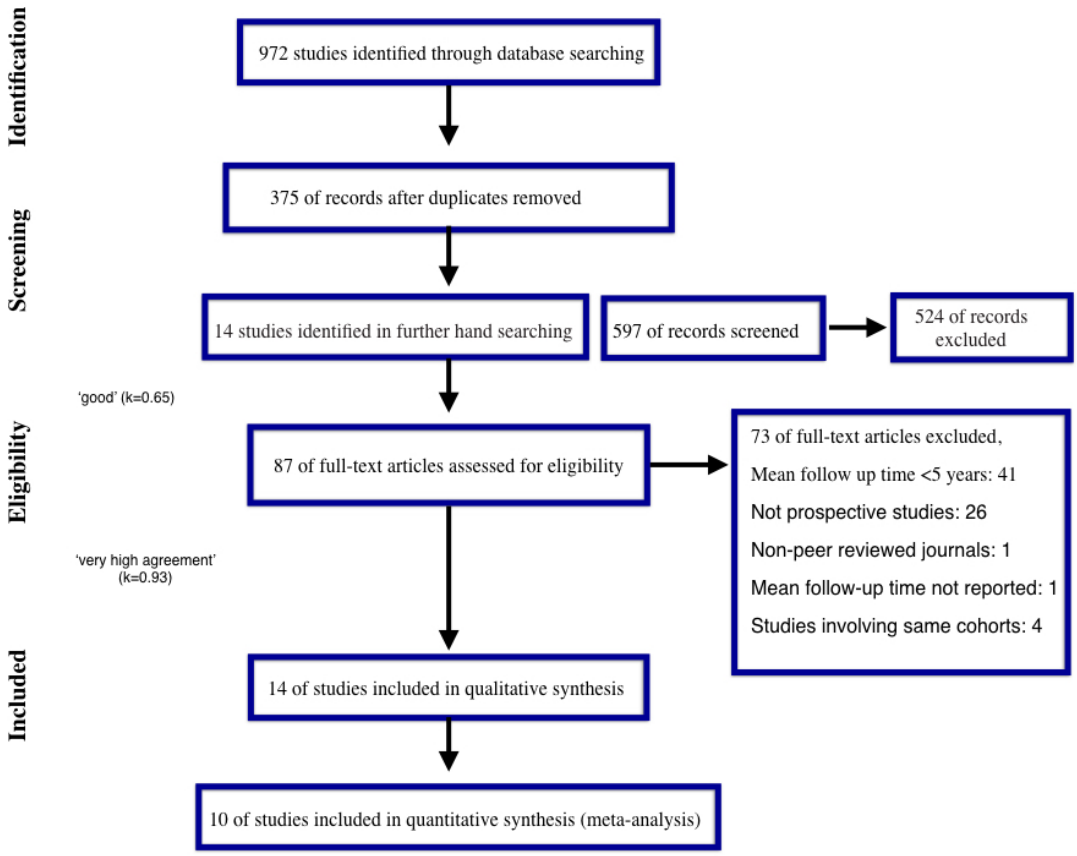

Fig.1: Search strategy

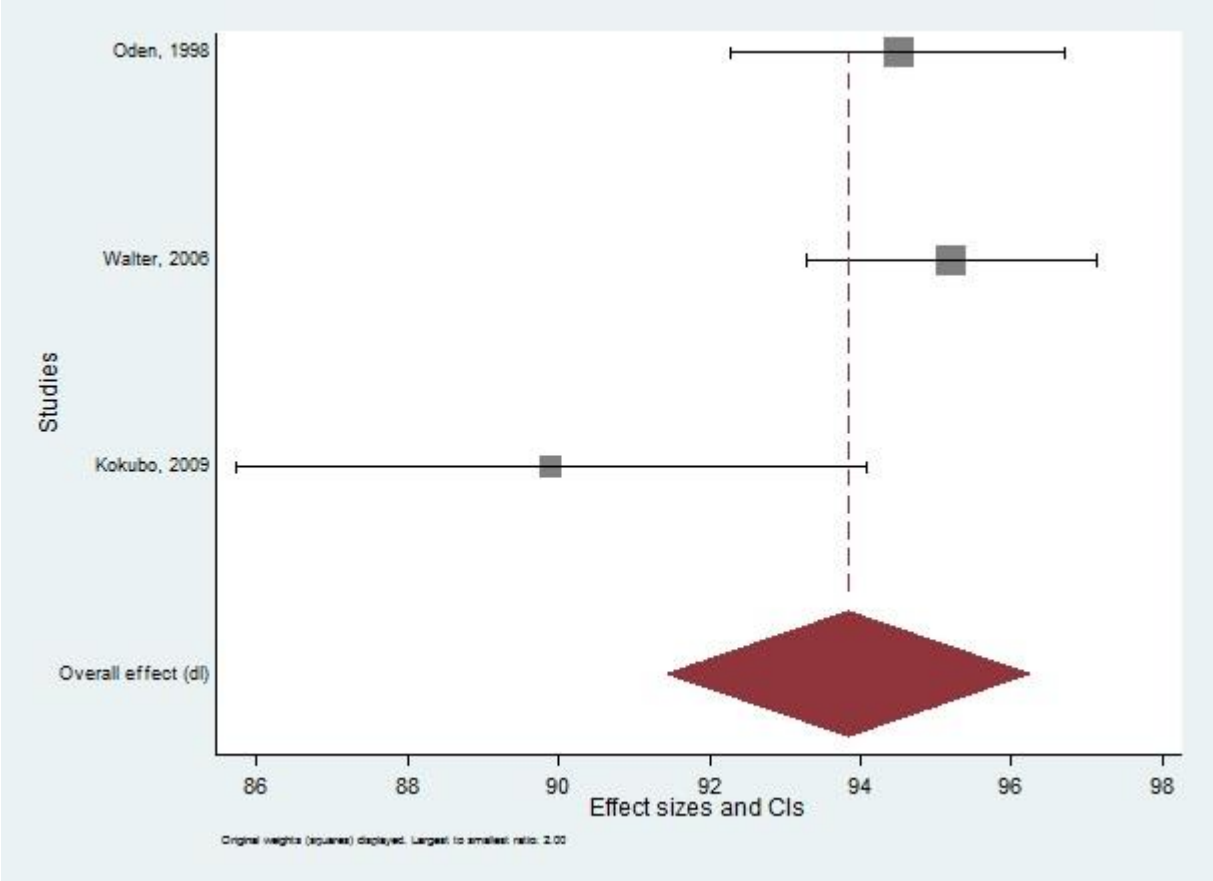

Fig.2 5 Estimated survival rate after 5 years for densely sintered alumina material (Cochrane Q test p=0.077-Random effects model)

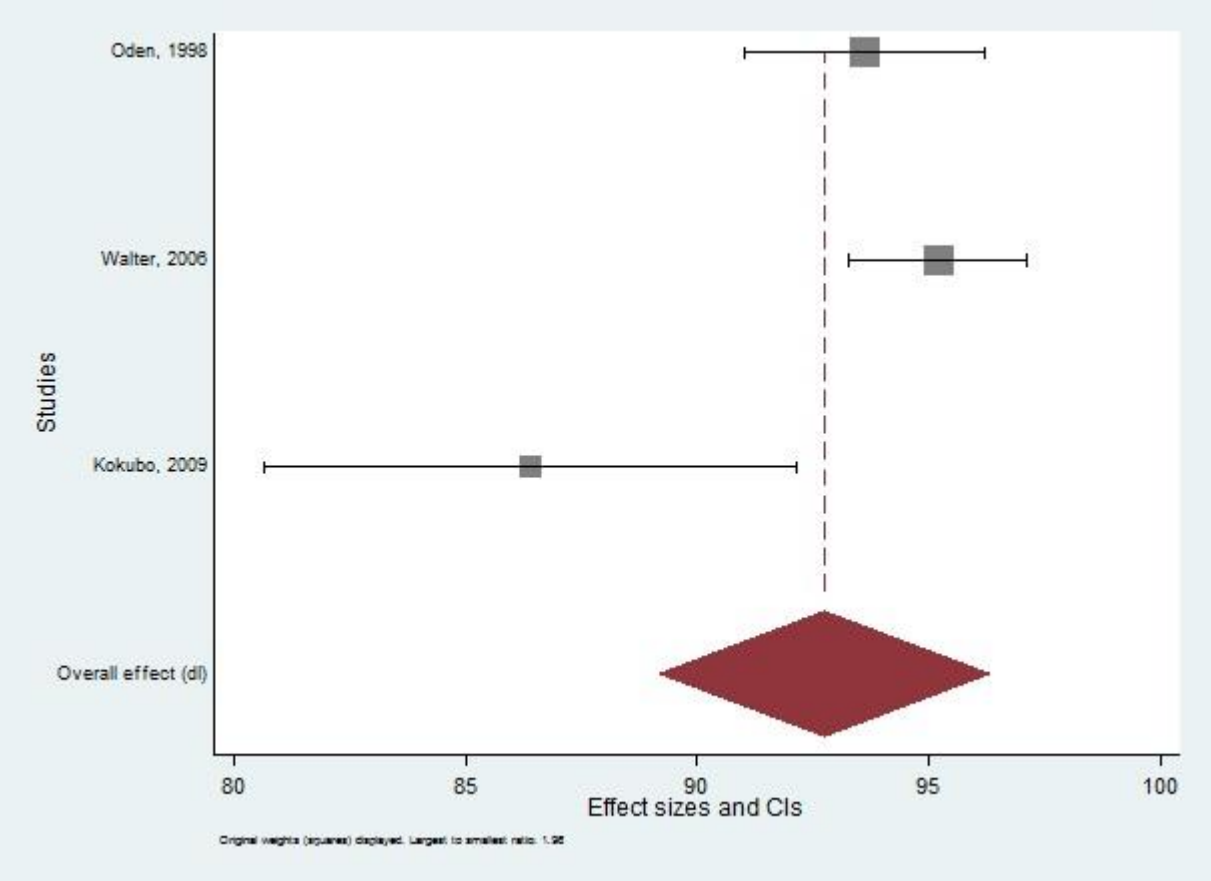

Fig.3 5 Estimated success rate after 5 years for densely sintered alumina material (Cochrane Q test p=0.016-Random effects model)

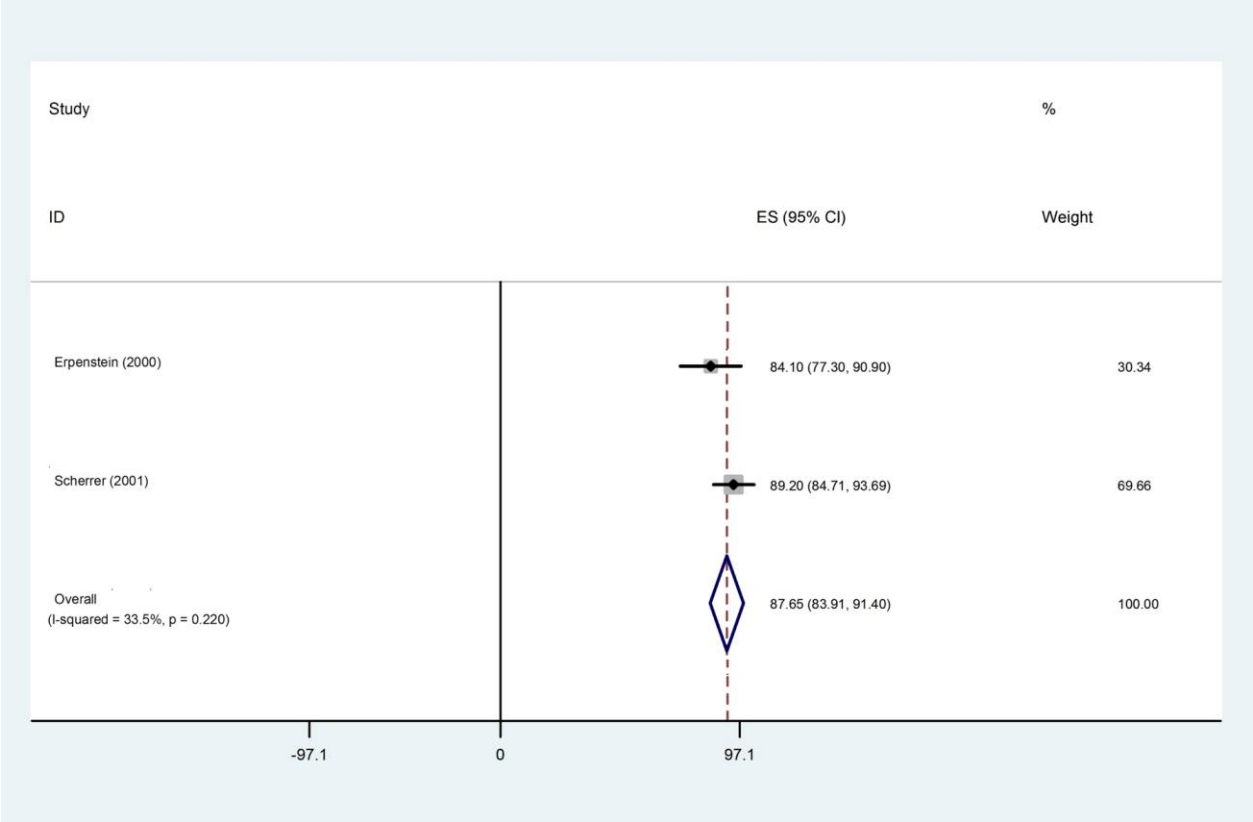

Fig.4 Estimated survival rate after 5 years for Fluoromica reinforced material (Fixed effects model)

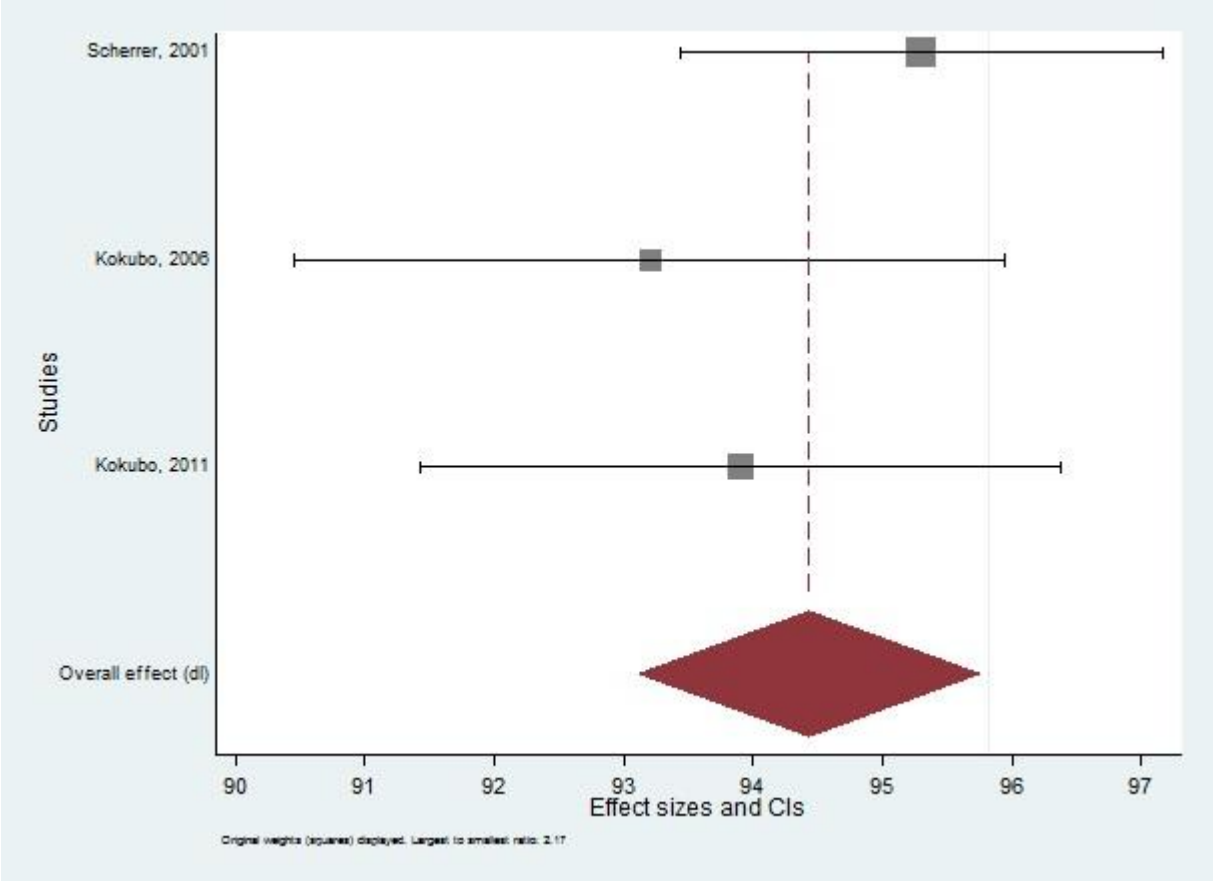

Fig.5 5 Estimated survival rate after 5 years for Glass infiltrated alumina core material (Cochrane Q test p=0.016-Fixed effects model)

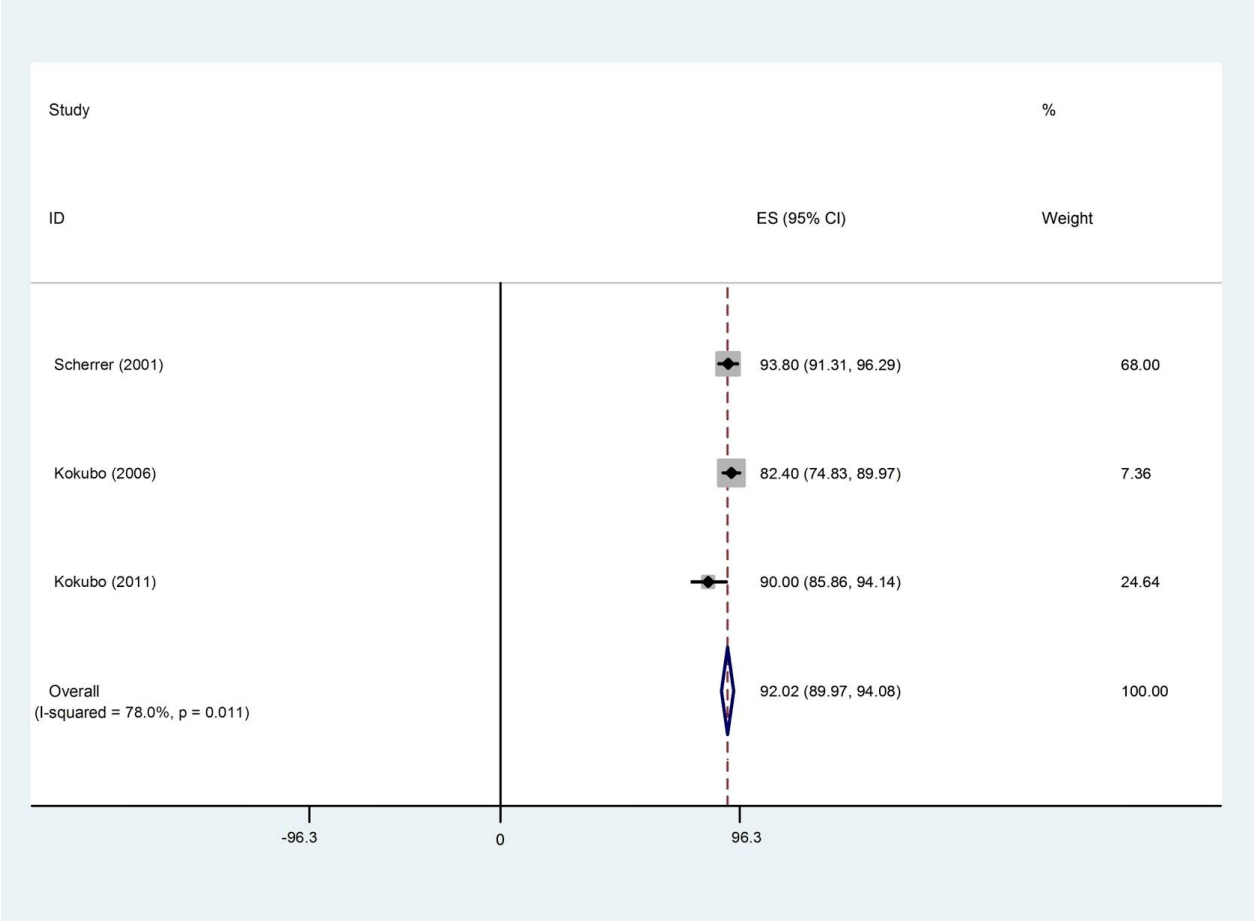

Fig.6 Estimated success rate after 5 years for Glass infiltrated alumina core material (Fixed effects model)

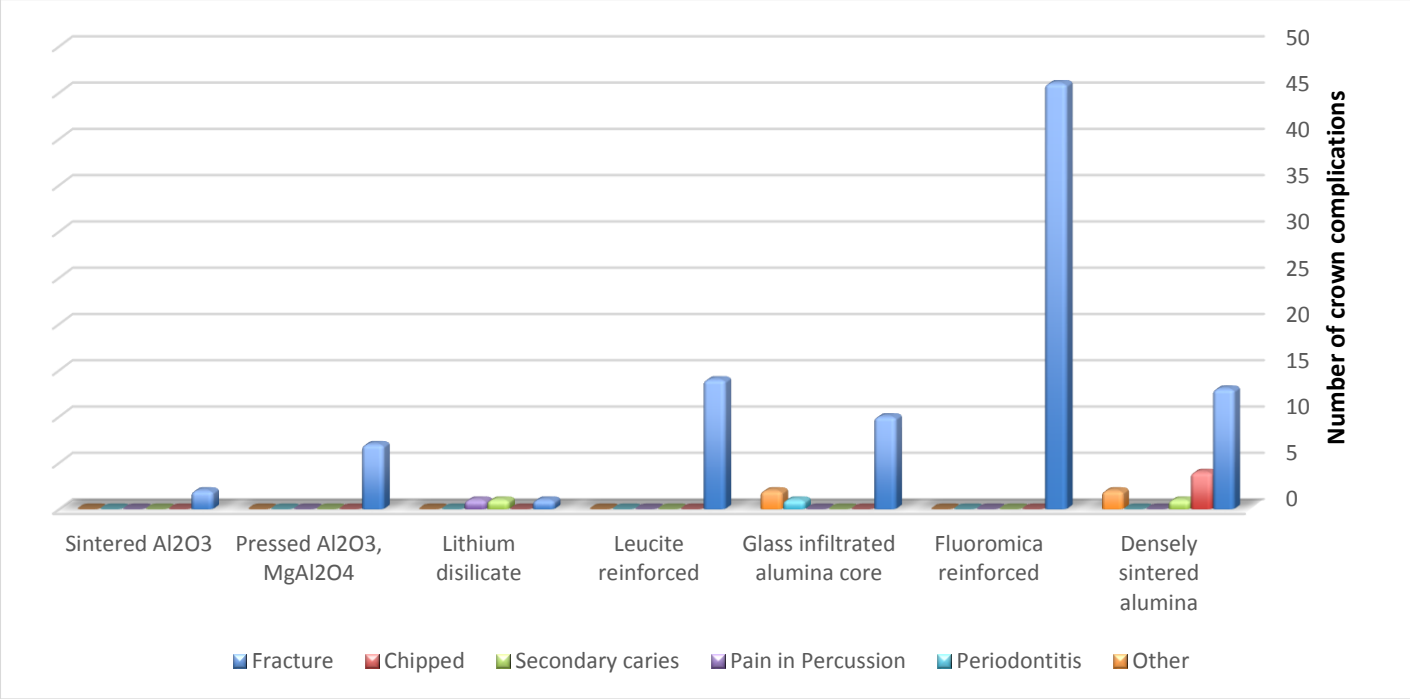

Fig.7: The distribution and comparison of crown complications between materials and within each material

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