

A Comparison between published clinical success of direct resin composite restorations in vital posterior teeth in 1995-2005 and 2006-2016 periods.

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ABSTRACT:

Background: Composites are increasing in popularity as restorative materials. This growing role indicates the necessity of studies on their clinical outcome.

Methods: Clinical studies published on the performance of posterior composite restorations were included except those of less than a 24-month assessment period. Results of non-vital, anterior or primary teeth and cervical-single-surface restorations were also excluded. Records about composite type, number of final recall restorations, failure/survival rate, and assessment period and failure reasons were analyzed for each decade.

Results: Overall survival/failure rates for studies in 1995-2005 were 89.41%/10.59% and for 2006-2016 were 86.87%/13.13% respectively. In 1995-2005 the reasons for failure were secondary caries (29.47%) and composite-fracture (28.84%) with low tooth-fracture (3.45%) compared to reasons of failure in 2006-2016, which were secondary caries (25.68%), composite-fracture (39.07%), and tooth-fracture (23.76%). An increase in incidence of composite-fracture, tooth-fracture and need for endodontic treatment as failure reasons was noted in latter decade in addition to a decrease in secondary caries, post-operative sensitivity, unsatisfactory marginal adaptation and wear.

Conclusion: The overall rates of failure showed little difference, but the causes showed a notable change. This is believed to be a reflection of increased use of composites for larger restorations and possibly changes of material characteristics.

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i) Abstract

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Key words: Clinical success; composite restoration; failure reason; Posterior restoration; Vital teeth

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ii) Main test:

1. Introduction

Posterior resin composite restorations have established an important place in clinical practice and have continued to gain popularity. Resin composite use has almost superseded the previous posterior restorative material, namely silver amalgam (1). Compared to other posterior restorative materials tooth-coloured resin composite is preferred by patients as a result of their increased desire for aesthetic restoration. In addition, patients have questioned the biocompatibility of the mercury in amalgam (2). The advances of minimal intervention dentistry to conserve tooth structure have led to modified cavity preparations in association with improved bonding.

Any restorative material has a limited working life and replacing any restoration will cause further loss of tooth structure (3). Many factors affect longevity and success of a restoration such as: the material, patient and dentist factors and cavity type (2). Since resin composites were introduced, there has been an ongoing challenge to improve their clinical performance, particularly for use in posterior teeth. This has seen the introduction of hybrid, packable, nano-filled, low-shrinkage, and bulk-fill composites (4-8), but still the clinical effectiveness of posterior composite is questioned by many. Patient factors such as caries risk and occlusal stress can influence the long-term clinical success of a restoration (9). Also a significantly higher failure rate for multi-surface and complex restorations compared to occlusal single-surface restorations has been demonstrated(2).

According to Beck et al. (10), who reviewed studies on composite performance conducted during 19 years (1996-2015) the main reason for failure in the first 4 years of a composite restoration's life was fracture followed by marginal defects and secondary caries. In contrast, for older restorations (≥ 5 years) secondary caries and fracture were the predominant reasons for failure. However, in the last 20 years there have been substantial advancements and changes in composite materials and adhesive systems, which may have influenced failure reasons and rates. The aim of this systematic literature review was to evaluate papers that assessed clinical performance of posterior composite restorations. Only papers published since

1995 that determined failure reasons and rates were evaluated in two periods, 1995-2005 and 2006-2016.

2. Materials and methods

In order to collect the related articles two separate search engines, PubMed and Medline Ovid were used.

The search terms used for this review were:

[("clinical evaluation" or "clinical trial" or "clinical success") and ("Class I restoration" or "Class II restoration" or "posterior composite") and ("composite" or "resin composite")]

The same search terms were used for two time periods: 1995-2005 and 2006-2016. (Figure 1)

After eliminating duplicate papers for the different search engines several excluding factors were also applied:

1. Laboratory-based,
2. Conducted entirely on non-vital teeth or results were not separable for vital teeth,
3. Conducted entirely on primary teeth or results were not separable for permanent teeth,
4. Conducted entirely on anterior teeth or results were not separable for posterior teeth,
5. Of a duration less than 24 months,
6. Evaluating restored teeth with open laminate, tunnel preparation or cervical single surface (class V) restorations, and
7. In a language other than English.

Exclusion of studies less than 24 months was based on the fact that failures increase significantly as study length increases and a short follow-up can overestimate the clinical effectiveness/success of restorations. (11, 12)

After excluding unrelated papers and any previous articles to follow-up clinical trials, 64 papers remained. In addition, six papers were cited in these articles that fitted the search criteria. They were added by hand search. Out of these 70 articles, 30 belonged to the 1995-2005 period and 40 belonged to 2006-2016 period.

Extracted data from the contents of these papers were: composite brand and type, number of restorations placed at baseline and available at the final recall in each study, type of restoration (Occlusal single-surface / multi-surface), observation period and numbers, reasons and rates of failure or overall success. All of this information was extracted from the texts and tables in the published papers and collated in 2 tables for each specified period. (Table 2, 3)

Various types of composite were evaluated in these 70 papers.

Only studies that used the manufacturers' instructions for handling the materials and the accepted method of incremental insertion for non-bulk-fill composites regardless of use of lining such as glass ionomer cement with or without calcium hydroxide were included. No excluding factor was applied regarding cavity preparation, which varied from single occlusal surface to cusp build-ups and complex multi-surface cavities.

In articles that included a combination of either primary, non-vital or anterior teeth only the results related to vital permanent posterior teeth were extracted and used. A similar procedure was followed with studies where direct and indirect composite restorations were placed by excluding the results related to indirect composite restorations.

Some papers aimed to compare the performance of composites with another direct restorative material such as, amalgam or calcium aluminate cement. In these cases, only the results related to composites were extracted and used.

In a few papers failure rates for each reason were presented as a percentage rather than actual numbers, therefore when a total number for failures was specified, reported percentages were converted to number of failed restorations.

Articles with periods of assessment greater than 5 years are displayed in Table-1. This table includes the publication date, assessment duration, overall success and failure rate and depending on availability the annual failure rate. In several papers these rates were calculated specifically for each composite brand or type, which are demonstrated as two separate results in one study

3. Results

In the last two decades numerous studies have been undertaken to evaluate performance of composites. However, the more recent studies showed that the clinical studies and methods of data collection have become more detailed and robust in the information provided. In the 1995-2005 period an annual failure rate was rarely calculated and the rate of unknown failure reason was high, on the other hand in the 2006-2016 period more reports provided annual failure rates, case selection was more detailed and unknown causes of failure were reduced considerably (13.17% to 4.31%) (Fig-2). The number of studies has increased by 33% (30 to 40) in 2006-2016 period, which indicates the increase in relevance of composite for restoring posterior teeth as well as the need to improve the evidence base.

Twenty-eight different brands in period 1995-2005 and thirty-eight in period 2006-2016. Several types of composites were included such as: mini-hybrid, micro-hybrid, nano-hybrid, nano-filled, micro-filled, mini-filled, midi-filled, fiber-reinforced, low-shrinkage (Silorane-base), Giomer, bulk-fill, flowable, packable, conventional, universal or posterior.

Most papers placed restorations in a combination of permanent molars and premolars. However, some only used molars, but no study solely used premolars. Recall durations varied from 2 to 22 years, with just over half of the papers identified being three years or less in duration. Overall, 3012 restorations were assessed at the final recalls in 1995-2005 and 4327 in 2006-2016. Respectively 319 and 568 restorations were recorded as having failed. (Fig-2) Reasons for failure included: restoration fracture, tooth fracture, secondary caries, postoperative sensitivity / pain, endodontic treatment, clinically unacceptable marginal adaptation, wear, unknown factors and finally the operator, however occasionally a combination of two factors was considered. The sum of failure reasons for 1995-2016 period was 942, which included 110 teeth with two reasons for failure. (100: tooth and restoration fracture, 4: secondary caries combined with restoration fracture, 3: marginal and anatomical failure, 2: marginal adaptation failure and secondary caries and 1: secondary caries with tooth fracture). Failure reasons and their percentages for each time period are shown in Fig -3.

Overall failure rates showed a slight increase for the 2006-2016 period (Fig-2), this was accompanied with a notable difference between principle failure reasons. In 1995-2005 there were two key causes for failure, secondary caries (29.47%) and composite fracture (28.84%), in

comparison with 2006-2016 where composite fracture (39.26%) had increased markedly compared to secondary caries (25.80%). In addition, there was an obvious difference between the rate of tooth fracture, post-operative sensitivity, wear and endodontic treatments: a notable increase in tooth fracture, a slight increase in endodontic treatment, a dramatic decrease in post-operative sensitivity as well as a noteworthy decrease in wear for the more recent studies (Fig-3).

4. Discussion

This is a systematic review of research on clinical evaluations of posterior composite restorations of more than 24 months duration that were published since 1995. Laboratory based work and studies that used open laminate or tunnel techniques were excluded. Articles were categorized into two time periods, namely 1995-2005 and 2006-2016 to reflect some of the technological changes that have occurred during the last 20 years. A change was obvious in number of articles in these two periods. An increase of 33.33% in 2006-2016 reflects the increasing placement of composite materials and the improvement in techniques.

A couple of different methods have been used for assessment of restorations: usually USPHS criteria and in some cases in the 2006-2016 period the FDI criteria (16, 50, 81). The overall trend in clinical evaluations has become more detailed, such as calculation of annual failure rates. Unknown causes of failure were overall listed at a rate of 13.17% in 1995-2005 but this had reduced to 4.31% in 2006-2016, which shows improved reporting and more detail of the recording of outcomes. (Fig-3)

Most studies the search identified were short term, of less than 2 years duration. Typically, the short study outcomes varied from the long-term results for composite restorations. More than half of the studies were 3 years or less in length, with 59.5% being in the 2006-2016 period. This is in line with the reported trend by Beck et al. (10), who indicated an increase in short-term clinical studies and lack of long term reports. In a few studies of longer duration (from 10 to 22 years) the annual failure rates ranged between 1.5% and 2.2%. This range is slightly lower than

that reported by Opdam et al. in their systematic review of 2014, that stated a failure rate of 2.4% at 10 years. (12)

Regarding overall success rates, the report for the least successful material belongs to a packable composite, which is no longer commercially available. The best overall survival rates typically appeared in short-term studies. A total of 11 studies with different assessment durations had 100% success rate (Seven 2 year, two 3 year, one 2.5 year and one 6 year). Lower failure rates in the early years following composite restoration placement are expected (annual failure rate: at 5 years: 1.8% and 10 years: 2.4% (12)). It is interesting to note that failure patterns tend to change during the lifespan of a restoration and do not have linear progression. Failure rate due to caries increases significantly as study length increases, whereas failure due to restoration fracture does not change markedly with time (12).

According to overall failure rates for all studied restorations, which were 10.59% for 1995-2005 and 13.13% for 2006-2016, little difference was noted between these two periods, but the reasons for failure changed. (Fig-3) In 1995-2005, secondary caries and composite fracture were the predominant reason at rates of 29.47% and 28.84% respectively, whereas in 2006-2016 although caries and fracture remained the main reasons for failure (25.68% and 39.07%). It was evident that fracture had increased. Both secondary caries and restoration fracture showed similar ratios of change but in different directions i.e., a decrease in secondary caries and increase in restoration fracture. (Fig-4) The third most common reason for failure in 2006-2016 was tooth fracture, which changed from 3.45% in 1995-2005 to 23.76% in 2006-2016. Restoration fracture, secondary caries and tooth fracture are responsible for 88.51 % of failures in 2006-2016 period compared with 61.76% in 1995-2005 period. This indicates that other factors such as wear, post-operative sensitivity and unacceptable marginal adaptation are becoming less important as failure reasons in more recent studies. Restoration fracture and tooth fracture together represent 62.83% of failures in the 2006-2016 compared with 32.29% in 1995-2005 period. This change may be due to the increased and wider use of composite material in complex and multi-surface cavities, which are known to be more prone to tooth and restoration fracture(13, 16). Including an extra surface in a restoration can be associated with a 30-40% increase in risk of failure (12). As a result of this trend an increase in endodontic

treatments was also noted. Unfortunately, the specific distribution of the occlusal single-surface and multi-surface restorations in failed restorations was not always provided, therefore was not possible to determine clearer outcomes for failure of restoration types. In a few of papers this information was listed as the number of restoration surfaces but more specific descriptions of restorations were unclear. The difference in failure of restoration type was calculated in a few papers with higher failure rates for multi-surface restorations being evident. For example, Van de Sande et al. showed a 78% and 22% distribution of overall failure rates respectively for multi-surface and occlusal single-surface restorations after 18 years (13). Shimizu et al. showed 55.5% and 44.1% distribution of overall failure rates respectively for multi-surface and occlusal single-surface restorations after 10 years (22).

One of the theories for cause of post-operative pain is formation of gaps between the cavity surface and restorative material allowing microleakage and fluid flow within dentinal tubules that is responsible for stimulating pulpal pain receptors. Consequently, an appropriate adhesive system that can seal dentinal tubules more effectively and can reduce post-operative pain, in addition to improving the marginal integrity of restorations is important (90). The significant change in post-operative sensitivity, which fell from 11.60% to 0.96% (Fig-3&4) and slight decrease in clinically unacceptable marginal adaptation (3.13% to 2.71%) (Fig-3) is most likely a result of improvements in adhesive systems during the last 20 years. Recent adhesive systems often show a reduction in technique sensitivity leading to less post-operative sensitivity (91), and an associated improvement in durability and sealing qualities (92).

Methods for measuring restoration wear either used a die cast at each recall session or a 3D-scanning method. The mean wear value varied from 2.72 μm per year (15) to 16 μm per year(25) in the studies reviewed. Wear of composite materials is largely dependent on filler particle size, volume and resin matrix of the composite (90, 93). Sarrett mentioned in his review that as a result of improvements in composite materials, wear and surface roughness are no longer significant clinical problems in posterior composite restoration longevity (90) , the current review confirms this statement as failure due to wear and loss of anatomical form was reduced from 9.40 % in 1995-2005 to 1.43% in 2006-2016. (Fig-4)

In the second period no failure or analysis of failure was reported due to operator influence. As described in previous reviews on clinical outcomes of posterior composites, this factor was not identified as an influencing factor on restoration survival. (10, 2) The reason this is that many of these studies are undertaken in controlled clinical settings and therefore do not reflect a typical private practice scenario.

Another factor that has been suggested to affect the life expectancy of a restoration is type of tooth i.e., molars compared with premolars. Some reviews showed that molars have a higher risk of failure (12) whereas others showed no difference (2, 10). In the current review, several studies evaluated this aspect and found that the risk of failure was higher in molars (13, 16) where others reported no difference (8, 19). It seems that a larger sample size and longer assessment period provides much better evidence for effect of tooth type on restoration survival.

A further factor that also has an effect on failure rates is the patient. In this category the more influential factors are: poor oral hygiene or high caries risk (10, 12) and high occlusal stress (9, 10). Both of these factors can effect failure rates of restorations and reduce clinical longevity. In a meta-analysis, Opdam et al. (12) showed that restoration failure rates in patients with high, medium and low risk of caries after 10 years were 4.6%, 4.1% and 1.6% respectively, which shows the influencing effect of caries risk on survival. In addition, Van de Sande et al. (9) investigated the influence of patient risk factors on survival of posterior restorations. They reported a higher failure rate due to restoration fracture in patients with bruxism. Both factors must therefore be considered with respect to restoration success. Many of the papers included in this review considered these as excluding factors in patient selection, which means restoration success is not applicable to all patients. Another element that makes a difference is the evaluation of restorations on teeth with adjacent teeth and in a functioning occlusion. These conditions change the nature of the patient population, in view of the fact that some restorations are placed in absence of a neighbouring or opposing tooth.

As an established posterior restorative material, amalgam has been compared to posterior composite in several studies, where some showed better performance for amalgam (50, 94) and other similar to each other (95, 96). Moraschini et al. in a review on the clinical

performance and longevity of amalgam and composite as posterior restorative materials reported a mean success rate of 86.2% and 92.8% respectively for composite and amalgam in a mean 55-month assessment duration. As well as a shorter clinical life and greater degree of secondary caries for composites compared to amalgam, there was no significant difference between fracture rates.(97) This review showed similar survival rates with an average assessment duration of 5.17 Years for 1995-2005 and 5.23 years for 2006-2016.(Fig-2)

The overall success of posterior composite restorations showed satisfactory rates, with overall success rate of 89.41% for 1995-2005 and 86.87% for 2006-2016 for all studied restorations. (Fig-2) The range of the reported overall success rates for long term studies (Table-1) improved in the 2006-2016 (minimum:64%-Maximum:96.9%) compared to the 1995-2005 (minimum:50%-Maximum:83%). This trend indicates that although composite materials are being used in multi-surface and more complex cavities, which are likely to show higher failure rates, the overall clinical performance seems to have improved in the last two decades. However, the necessity of longer assessment times for future studies is obvious, since as Opdam et al. (12), Beck et al. (10), Brunthaler et al. (2) and many other authors have reported with longer assessment periods there is a tendency of an increase in failure rates. Having this information will allow better case selection compared to what is currently known.

In conclusion, within the limitations of this review, comparing failure reasons in the last two decades has shown an important shift. Reducing the significance of secondary caries, post-operative sensitivity and wear as failure factors in contrast to an increasing role of tooth fracture, restoration fracture and endodontic treatment as reasons for failure. The greater level of fracture may relate to the increase in size of restorations now being placed, however more detailed data are needed. Further practice-based studies on posterior composite restorations are required with long assessment periods in combination with detailed failure reports on type and complexity of the studied restorations.

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iv) Tables:

| Table-1: Notable articles with long assessment period | | Publication date | Duration | Overall success rate | Overall failure rate | Annual failure rate |
|---|-----------------------------|------------------|----------|----------------------|----------------------|---------------------|
| (2006-2016) | Van de Sande, F. H.(13) | 2015 | 18 years | 70% | 30% | 1.9% |
| | | | | | | 2.1% |
| | Krämer et al.(14) | 2015 | 10 years | 96.9% | 3.1% | -- |
| | Van Dijken et al.(8) | 2015 | 15 years | 77% | 23% | 1.6% |
| | | | | | | 1.5% |
| | Dietz et al.(15) | 2014 | 15 years | 73.6% | 26.4% | 1.92% |
| | Van Dijken et al.(3) | 2014 | 10 years | 80.7% | 19.3% | 1.9% |
| | Da Rosa Rodolpho et al.(16) | 2011 | 22 years | 64% | 36% | 2.20% |
| | | | 74% | 26% | 1.50% | |
| Van Dijken, J. W.(17) | 2006 | 6 years | 75% | 25% | -- | |
| | | | 87.2% | 12.8% | | |
| (1995-2005) | Gaengler et al. (18) | 2004 | 10 years | 83 % | 17% | -- |
| | Gaengler et al.(19) | 2001 | 10 years | 74.2%-53.5% | 25.8%-46.5% | -- |
| | Lundin et al.(20) | 1999 | 10 years | 77% | 21.4% | -- |
| | Raskin et al.(21) | 1999 | 10 years | 50-60% | 40-50% | -- |
| | Shimizu et al.(22) | 1995 | 10 years | 74% | 26% | -- |

Table-2: summary of search results for 1995-2005.

| Article | Composite type | No. of recall restorations | Failure rate or Survival | Length | No. of recall restoration per type | | Failure reason | | | | | | | | | | | |
|---------|---|----------------------------|------------------------------------|----------|------------------------------------|----------------|-----------------------|-----------------|----------------------|------------|------|-----------|-------------|-------------------------------------|---------|----------|----|---|
| | | | | | M ⁺ | S ⁺ | fracture Secondary | caries tooth | fracture Marginal | adaptation | Wear | operative | sensitivity | and pain Endodontic treatment | Unknown | Operator | | |
| (18) | Visio-Molar Hybrid | 70 | 83% (s) [§] | 10 yrs. | 8 | 38 | 24 | | | | | | | | | | | |
| (23) | Prodigy Condensable | 111 | | 2 yrs. | 111 | 0 | 3 | 1 | | | | | | | | | | |
| (24) | Occlusin Hybrid | 37 | | 10 yrs. | 22 | 15 | 1 | 6 | 1 | 11 | 4 | | | | | | | |
| (20) | Occlusin (PC 4575) Highly filled +PC4502 Highly filled | 117 | 21.4%(f) [¶] , 77% (s) | 10 yrs. | 74 | 43 | | | | | | | | | | | 25 | |
| (25) | Estilux UV cure +Nuva-fil UV cure +Nuva-fil PA UV cure +Uvio-fil UV cure | 85 | | 17 yrs. | - | - | 2 | 3 | | 3 | 2 | | | | | | 9 | 1 |
| (26) | Tetric Ceram Hybrid | 71 | 7.5% (f) Annual f.: 1.9% | 4 yrs. | - | - | 2 | 2 | | | | | | | | | 1 | |
| (6) | Surefil Hybrid | 33 | 81.3% | 3.5 yrs. | 23 | 31 | 6 | 2 | | | | | | | | | | |

| | | | | | | | | | |
|------------------|---|-----|---------------|--------|-----|----|---|---|--------|
| | Packable +Spectrum Hybrid conventional | | -92.0% (s) | | | | | | |
| (27) (28) | Beutifil Universal | 39 | | 4 yrs. | 27 | 12 | | | 1 |
| (29) | Tetric Ceram Highly dispersed | 140 | 5% (f) | 2 yrs. | 121 | 27 | 1 | 1 | 5 |
| (30) | Solitaire 2 Packable +Solitaire 2 & flowline | 70 | 95%(s) | 2 yrs. | 70 | 0 | | 1 | 2 1 |

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Table-2: continued.

| | | | | | | | | | | |
|----------|---|-----|----------------|----------|------|-----|----|----|---|----|
| (31) | Z100 | 726 | | 1-4 yrs. | 466 | 260 | | | | |
| (28) | Solitaire Packable | 165 | 79.0% (s) | 3 yrs. | - | - | 23 | | | 12 |
| (32) | Superlux Molar Midway-filled fine +P-50 APC Compact filled ultra-fine | 82 | 8% +13 %(f) | 3 yrs. | 82 | 0 | 3 | 6 | 1 | 1 |
| (5) | Herculite Hybrid fine +Clearfil Compact fine +Visiomolar Hybrid | 68 | | 2 yrs. | 68 | 0 | | | | |
| (33) | Herculite XR hybrid | 234 | 87% (s) | 1-4 yrs. | 1100 | 109 | 21 | 13 | 7 | 4 |
| (34, 35) | Prodigy packable +Definite packable | 73 | 5%(f) | 2 yrs. | - | - | | | | 2 |
| (36, 37) | Z100 Compact-filled fine +Clearfil RP Compact- fill ultrafine +Prisma TPH midway- filled ultrafine | 70 | 5.7%(f) | 7 yrs. | - | - | | | 4 | |
| (38) | Z100 Compact-filled | 90 | | 6 yrs. | 23 | 67 | 5 | | | |

| | | | | | | | | |
|-------------|---|----|----------------------|---------|---|---|----|---|
| | fine +Tetric hybrid Compact-filled fine +Chrisma midway- filled ultrafine | | | | | | | |
| (19) | Visio-Molar hybrid | 46 | 74.2% - 53.5% (s) | 10 yrs. | - | - | 11 | 5 |

Table-2: continued.

| | | | | | | | | | | | |
|----------|--|-----|--------------------------------|------------|----|-----|---|---|---|----|--------|
| (39, 40) | Surefil high density posterior | 22 | | 2 yrs. | 22 | 0 | | | | | |
| (41-43) | Tetric hybrid +blend-a-lux hybrid +Pertac hybrid | 30 | | 3 yrs. | 23 | 7 | 4 | | | | |
| (44) | Superlux midway-filled fine +P-50 APC Compact-filled ultrafine | 51 | 27.6%(f) | 6-65 mths. | - | - | 1 | 7 | 1 | 6 | 1 |
| (21) | Occlusin hybrid | 37 | 40-50% | 10 yrs. | - | - | 1 | 2 | 1 | 15 | 4 |
| (45) | Heliomolar micro-filled +P-30 APC Hybrid +Herculite XR hybrid | 161 | 14.4% - 9.3% - 15.4% (f) | 8 yrs. | - | - | 8 | 7 | | | 1 4 |
| (46) | Z100 +Clearfil RP +Herculite XR +Heliomolar | 104 | | 2 yrs. | 0 | 104 | | | | | |
| (22) | Lite-Fil P micro-filled | 72 | S: 44.1% M: 55.5% | 10 yrs. | 9 | 34 | 8 | | | | 1 |

| (f) | | | | | | | |
|----------|--|----|--------|---------|----|---|---|
| (47) | Solitaire 2 packable posterior | 76 | 96%(s) | 2 yrs. | - | - | 2 |
| (48, 49) | Surefil packable posterior | 47 | 6% (f) | 3 yrs. | - | - | 2 |
| (50) | P-30 hybrid +Occlusin hybrid posterior +Clearfil compact-fill fine | 56 | | 10 yrs. | 56 | 0 | 4 |

Table-2: continued.

| | | | | | |
|------|------------|----|--------|----|---|
| (51) | TPH hybrid | 29 | 2 yrs. | 29 | 0 |
|------|------------|----|--------|----|---|

[†] Multi-surface- [‡] Single-surface - [§] Survival rate - [¶] Failure rate-

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shrinkage

+Ceram X nano-hybrid

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Table-3: continued.

| | | | | | | | | | |
|------|--|-----|-----------------|--------|-----|----|----|---|---|
| (57) | Filtek Silorane low-shrinkage | 100 | | 2 yrs. | 70 | 30 | | | |
| (58) | Filtek P-60 packable +Prodigy packable | 39 | | 3 yrs. | 21 | 18 | 1 | | 1 |
| (59) | Tetric Ceram hybrid +Ceram X nano-hybrid | 54 | 3.7% - 7.4% (f) | 4 yrs. | - | - | | 1 | 2 |
| (60) | Filtek Supreme nano-filler | 91 | | 2 yrs. | - | - | | | |
| (61) | P-60 | 78 | | 4yrs. | 78 | 0 | 4 | 2 | 1 |
| (62) | Vit-L-essence micro-hybrid | 69 | | 2 yrs. | 69 | 0 | | | |
| (63) | Filtek Supreme nano-filler +Tetric Ceram fine hybrid | 112 | 98% (s) | 2 yrs. | 112 | 0 | 2 | | |
| (64) | Tetric Ceram hybrid & Tetric flow +Tetric ceram Hybrid | 114 | 85.3%(s) | 7 yrs. | 114 | 0 | 10 | 5 | 3 |

| | | | | | | | | | | | |
|----------------|---------------------------------|-----|------------------------------|---------|-----|-----|---|----|----|----|----|
| (13) | P-50 APC mini-filled hybrid | 632 | 30%(f) | | | | | 97 | 65 | 97 | 24 |
| | +Herculite XR mid-filled hybrid | | Annual f.: 1.9% - 2.1% | 18 yrs. | - | - | | | | | |
| (65) | Beautifil II S-PRG filler | 31 | | 3 yrs. | 65% | 45% | | | | | |
| (66-68) | Quixfil posterior | 62 | | | | | 1 | 3 | | | |
| | +Grandio Universal nano-hybrid | | 3 yrs. | 37 | 25 | | | | | | |

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Table-3: continued.

| | | | | | | | | | | | |
|-----------------|---|-----|----------------------|----------|-----|-----|----|----|----|---|---|
| (69) | Filtek Supreme nano-filled +Tetric Evo ceram nano-filled +Aelite Aesthetic nano-filled | 67 | Annual f.: 1.6% | 5 yrs. | 26 | 41 | 1 | | | | |
| (70) | Filtek Supreme universal nano-filled | 73 | 87.7% (s) 4.2%(f) | 3 yrs. | 74 | 0 | 6 | 2 | | | 1 |
| (16, 71) | P-50 APC hybrid midi-filled +Herculite XR hybrid mini-filled | 362 | 1.5% - 2.20% (f) | 22 yrs. | 241 | 121 | 51 | 27 | 19 | 3 | 7 |
| (72) | Tetric Ceram HB & Tetric-flow | 25 | 8% (f) | 3.5 yrs. | - | - | | | | 2 | 2 |
| (73-75) | Quixfil posterior +Tetric Ceram hybrid | 83 | 2.7%- 0.6% (f) | 4 yrs. | 70 | 13 | 3 | 1 | 4 | 1 | 1 |
| (76) | Prodigy packable +Heliomolar micro-filled | 432 | Annual f.: 1.7% | 3 yrs. | 153 | 279 | 4 | 15 | 2 | 2 | |
| (77, 78) | Alert packable +Surefil packable | 60 | | 5 yrs. | 34 | 26 | 1 | 1 | | | 1 |

| | | | | | | | | |
|-------------|---|----|--|----------|----|----|---|---|
| (79) | Filtek P-60 packable | 44 | | 6 yrs. | 44 | 0 | | |
| (80) | Esthet-X micro-hybrid +Point4 micro-hybrid | 51 | | 3 yrs. | 0 | 51 | 1 | |
| (81) | Vit-L-essence micro- hybrid | 25 | | 2.5 yrs. | 25 | 0 | | |
| (8) | InTen-S low-shrinkage +Point4 micro hybrid | 91 | 77% (s) Annual f.: 1.5% - 1.60% | 15 yrs. | 91 | 0 | 7 | 8 |

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Table-3: continued.

| | | | | | | | | | | | | | |
|-------------|---|-----|---|----------|-----|----|---|---|---|---|---|---|---|
| (82) | Filtek Silorane low-shrinkage +Ceram X | 107 | | 5 yrs. | 107 | 0 | 2 | 1 | 5 | 3 | | | |
| (7) | Filtek Z350 nano-filled +Esthet-X nano-hybrid +Filtek Z250 micro hybrid | 93 | Annual f.: 1.61% - 0.80% - 1.61% | 4.5 yrs. | 0 | 93 | | 1 | | 1 | 1 | 1 | 2 |
| (4) | SDR flowable bulk-filled & Ceram X mono +Ceram X mono | 104 | Annual f.: 0.00% - 1.30% | 3 yrs. | 76 | 28 | 1 | | 1 | | | | |
| (83) | Filtek LS Low-shrinkage +Tetric Evoceram nano-filled | 72 | | 3 yrs. | 72 | 0 | 4 | | | | | | |
| (84) | Filtek Supreme nano-filled +p60 packable +Filtek Silorane low-shrinkage | 60 | | 3 yrs. | 0 | 60 | | | | | | | |
| (1) | SDR flowable bulkfil&Ceram X +Ceram X mono | 196 | Annual f.: 1.2% - 1.0% | 3 yrs. | 122 | 74 | 2 | 2 | 3 | | | | |

| nano-hybrid | | | | | | | | | | |
|-------------|---|-----|----------------|-------------|-----|----|---|---|--|---|
| (85) | Filtek P90 | 156 | Annual f.: | | 156 | 0 | 5 | | | 2 |
| | +Quixfil posterior | | 1.7% - 1.2% | 3 yrs. | | | | | | |
| (86) | Filtek P60 posterior +Filtek Z250 posterior | 67 | 3% (f) | 56 mths. | 36 | 31 | | 1 | | 1 |
| (87) | TPH spectrum hybrid +Synergy Compact packable | 80 | | 3 yrs. | 0 | 80 | | 6 | | |

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Table-3: continued.

| | | | | | | | | | | |
|-------------|--|-----|-----------|--------|----|----|---|---|---|---|
| (17) | Nulite F fiber reinforced packable + Alert fiber reinforced packable | 72 | 25% (f) | 6 yrs. | 72 | 0 | 5 | 5 | 4 | |
| (88) | Beatifil universal giomer | 108 | 5% (f) | 3 yrs. | 72 | 36 | 2 | 1 | 1 | 1 |
| (89) | Solitaire packable porous +Alert fiber reinforced packable +Surefil hybrid packable +Filtek P60 packable +TPH spectrum hybrid packable | 75 | 12.5% (f) | 3 yrs. | 66 | 9 | 2 | | | 1 |

[†] Multi-surface - [‡] Single-surface - [§] Survival rate - [¶] Failure rate-

v) Figure legends.

Figure-1: Search

Figure-2: Overall results

Figure-3: Failure cause per period

Figure-4: Change of failure rates from 1995-2005 to 2006-2016

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| Table-1: Notable articles with long assessment period | | Publication date | Duration | Overall success rate | Overall failure rate | Annual failure rate | |
|---|-----------------------------|------------------|----------|----------------------|----------------------|---------------------|-------|
| (2006-2016) | Van de Sande, F. H.(11) | 2015 | 18 years | 70% | 30% | 1.9% | |
| | | | | | | 2.1% | |
| | Krämer et al.(12) | 2015 | 10 years | 96.9% | 3.1% | -- | |
| | Van Dijken et al.(8) | 2015 | 15 years | 77% | 23% | 1.6% | |
| | | | | | | 1.5% | |
| | Dietz et al.(13) | 2014 | 15 years | 73.6% | 26.4% | 1.92% | |
| | Van Dijken et al.(3) | 2014 | 10 years | 80.7% | 19.3% | 1.9% | |
| | Da Rosa Rodolpho et al.(14) | 2011 | 22 years | 64% | 36% | 2.20% | |
| | | | | | 74% | 26% | 1.50% |
| Van Dijken, J. W.(15) | 2006 | 6 years | 75% | 25% | -- | | |
| | | | | | 87.2% | 12.8% | |
| (1995-2005) | Gaengler et al. (16) | 2004 | 10 years | 83 % | 17% | -- | |
| | Gaengler et al.(17) | 2001 | 10 years | 74.2%-53.5% | 25.8%-46.5% | -- | |
| | Lundin et al.(18) | 1999 | 10 years | 77% | 21.4% | -- | |
| | Raskin et al.(19) | 1999 | 10 years | 50-60% | 40-50% | -- | |
| | Shimizu et al.(20) | 1995 | 10 years | 74% | 26% | -- | |

Table-2: summary of search results for 1995-2005.

| Article | Composite type | No. of recall restorations | Failure rate or Survival | Length | No. of recall restoration per type | | Failure reason | | | | | | | | | | | | | | | |
|---------|---|----------------------------|--------------------------|---------|------------------------------------|----------------|----------------|--------------------|--------|----------------|---------------------|------|----------------------------|----------|-------------|---------|----------|--|--|--|----|---|
| | | | | | M ⁺ | S [#] | fracture | Secondary fracture | caries | Tooth fracture | Marginal adaptation | Wear | Post-operative sensitivity | and pain | C treatment | Unknown | Operator | | | | | |
| (16) | Visio-Molar Hybrid | 70 | 83% (s) | 10 yrs. | 8 | 38 | 24 | | | | | | | | | | | | | | | |
| (21) | Prodigy Condensable | 111 | | 2 yrs. | 111 | 0 | 3 | 1 | | | | | | | | | | | | | | |
| (22) | Occlusin Hybrid | 37 | | 10 yrs. | 22 | 15 | 1 | 6 | 1 | 11 | 4 | | | | | | | | | | | |
| (18) | Occlusin (PC 4575) Highly filled +PC4502 Highly filled | 117 | 21.4%(f) 77% (s) | 10 yrs. | 74 | 43 | | | | | | | | | | | | | | | 25 | |
| (23) | Estilux UV cure +Nuva-fil UV cure +Nuva-fil PA UV cure +Uvio-fil UV cure | 85 | | 17 yrs. | - | - | 2 | 3 | | 3 | 2 | | | | | | | | | | 9 | 1 |

| | | | | | | | | | |
|-----------|--|-----|--------------------------------|----------|-----|----|---|---|---|
| (24) | Tetric Ceram Hybrid | 71 | 7.5% (f) Annual f.: 1.9% | 4 yrs. | - | - | 2 | 2 | 1 |
| (6) | Surefil Hybrid Packable +Spectrum Hybrid conventional | 33 | 81.3% -92.0% (s) | 3.5 yrs. | 23 | 31 | 6 | 2 | |
| (25) (26) | Beutifil Universal | 39 | | 4 yrs. | 27 | 12 | | 1 | |
| (27) | Tetric Ceram Highly dispersed | 140 | 5% (f) | 2 yrs. | 121 | 27 | 1 | 1 | 5 |
| (28) | Solitaire 2 Packable +Solitaire 2 & flowline | 70 | 95%(s) | 2 yrs. | 70 | 0 | 1 | 2 | 1 |

Table-2: continued.

| | | | | | | | | | | | |
|----------|---|-----|-----------------|----------|------|-----|----|----|---|---|----|
| (29) | Z100 | 726 | | 1-4 yrs. | 466 | 260 | | | | | |
| (26) | Solitaire Packable | 165 | 79.0% (s) | 3 yrs. | - | - | 23 | | | | 12 |
| (30) | Superlux Molar Midway-filled fine +P-50 APC Compact filled ultra-fine | 82 | 8% +13 % (f) | 3 yrs. | 82 | 0 | 3 | 6 | 1 | | 1 |
| (5) | Herculite Hybrid fine +Clearfil Compact fine +Visiomolar Hybrid | 68 | | 2 yrs. | 68 | 0 | | | | | |
| (31) | Herculite XR hybrid | 234 | 87% (s) | 1-4 yrs. | 1100 | 109 | 21 | 13 | 7 | | 4 |
| (32, 33) | Prodigy packable +Definite packable | 73 | 5% (f) | 2 yrs. | - | - | | | | 2 | |
| (34, 35) | Z100 Compact-filled fine | 70 | 5.7% (f) | 7 yrs. | - | - | | 4 | | | |

| | | | | | | | | |
|------|--|----|-------------------------|---------|----|----|----|---|
| | +Clearfil RP Compact-fill ultrafine +Prisma TPH midway-filled ultrafine | | | | | | | |
| (36) | Z100 Compact-filled fine +Tetric hybrid Compact-filled fine +Chrisma midway- filled ultrafine | 90 | | 6 yrs. | 23 | 67 | 5 | |
| (17) | Visio-Molar hybrid | 46 | 74.2% - 53.5% (s) | 10 yrs. | - | - | 11 | 5 |

Table-2: continued.

| | | | | | | | | | | | | |
|----------|--|-----|-----------------------------------|---------------|----|-----|---|---|---|----|---|---|
| (37, 38) | Surefil high density posterior | 22 | | 2 yrs. | 22 | 0 | | | | | | |
| (39-41) | Tetric hybrid +blend-a-lux hybrid +Pertac hybrid | 30 | | 3 yrs. | 23 | 7 | 4 | | | | | |
| (42) | Superlux midway-filled fine +P-50 APC Compact- filled ultrafine | 51 | 27.6%(f) | 6-65 mths. | - | - | 1 | 7 | 1 | 6 | 1 | |
| (19) | Occlusin hybrid | 37 | 40-50% | 10 yrs. | - | - | 1 | 2 | 1 | 15 | 4 | |
| (43) | Heliomolar micro-filled +P-30 APC Hybrid +Herculite XR hybrid | 161 | 14.4% - 9.3% - 15.4% (f) | 8 yrs. | - | - | 8 | 7 | | | 1 | 4 |
| (44) | Z100 +Clearfil RP +Herculite XR +Heliomolar | 104 | | 2 yrs. | 0 | 104 | | | | | | |
| (20) | Lite-Fil P micro-filled | 72 | S: 44.1% | 10 yrs. | 9 | 34 | 8 | | | | 1 | |

| | | M: 55.5% (f) | | | | | |
|----------|--|--------------------|--------|---------|----|---|---|
| (45) | Solitaire 2 packable posterior | 76 | 96%(s) | 2 yrs. | - | - | 2 |
| (46, 47) | Surefil packable posterior | 47 | 6% (f) | 3 yrs. | - | - | 2 |
| (48) | P-30 hybrid +Occlusin hybrid posterior +Clearfil compact-fill fine | 56 | | 10 yrs. | 56 | 0 | 4 |

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Table-2: continued.

| | | | | | |
|------|------------|----|--------|----|---|
| (49) | TPH hybrid | 29 | 2 yrs. | 29 | 0 |
|------|------------|----|--------|----|---|

† Multi-surface- ‡ Single-surface -§ Survival rate - ¶ Failure rate-

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Table-3: summary of search results for 2006-2016.

| Article | Composite type | No. of recall restorations | Failure rate or Survival | Length | No. of recall restoration per type | | Failure reason | | | | | | | | | | | | | | | | | |
|----------|---|----------------------------|--|---------|------------------------------------|----------------|--------------------|------------------|----------------|---------------------|------|----------------------------|----------|---|-------------------|----------|--|--|--|--|--|--|--|--|
| | | | | | M [#] | S [#] | Composite fracture | Secondary caries | Tooth fracture | Marginal adaptation | Wear | Post-operative sensitivity | and pain | c | treatment Unknown | operator | | | | | | | | |
| (50) | Estelite +G-aenial highly-filled flowable | 40 | | 3 yrs. | 30 | 10 | | | | | | | 1 | 1 | | | | | | | | | | |
| (13) | Visio-Molar hybrid | 37 | 73.6%(s ^s) Annual f ^l : 1.92% | 15 yrs. | - | - | 13 | 7 | | | | | | | | | | | | | | | | |
| (51) | TPH | 86 | S: (s) :96.0% M:72.1% | 3 yrs. | 61 | 25 | 10 | | | | | | 4 | 4 | | | | | | | | | | |
| (12, 52) | Grandio nano-hybrid +Tetric Ceram hybrid | 65 | 96.9% (s) | 10 yrs. | 65 | 0 | | | | | | | 1 | 1 | | | | | | | | | | |

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| | | | | | | | | | | |
|---------|---|-----|-------------------------|---------|-----|---------|---|----|---|---|
| (3, 53) | Tetric evoceram | 114 | 80.7%(s | 10 yrs. | 114 | 0 | 7 | 11 | 5 | 3 |
| | nano-filled +Tetric Ceram hybrid | |) Annual f.: 1.9% | | | | | | | |
| (54) | Filtek Silorane Low-shrinkage +Ceram X nano-hybrid | 100 | | 2 yrs. | 0 | 10 0 | | | | |

Table-3: continued.

| | | | | | | | | | |
|------|--|-----|-----------------|--------|-----|----|----|---|---|
| (55) | Filtek Silorane low-shrinkage | 100 | | 2 yrs. | 70 | 30 | | | |
| (56) | Filtek P-60 packable +Prodigy packable | 39 | | 3 yrs. | 21 | 18 | 1 | | 1 |
| (57) | Tetric Ceram hybrid +Ceram X nano-hybrid | 54 | 3.7% - 7.4% (f) | 4 yrs. | - | - | | 1 | 2 |
| (58) | Filtek Supreme nano-filler | 91 | | 2 yrs. | - | - | | | |
| (59) | P-60 | 78 | | 4yrs. | 78 | 0 | 4 | 2 | 1 |
| (60) | Vit-L-essence micro-hybrid | 69 | | 2 yrs. | 69 | 0 | | | |
| (61) | Filtek Supreme nano-filler +Tetric Ceram fine hybrid | 112 | 98% (s) | 2 yrs. | 112 | 0 | 2 | | |
| (62) | Tetric Ceram hybrid & Tetric flow +Tetric ceram Hybrid | 114 | 85.3%(s) | 7 yrs. | 114 | 0 | 10 | 5 | 3 |

| | | | | | | | | | | |
|---------|--|-----|--|---------|---|---|---------|---------|----|----|
| (11) | P-50 APC mini-filled hybrid +Herculite XR mid-filled hybrid | 632 | 30%(f) Annual f: 1.9% - 2.1% S: 22% M: 78%(f) | 18 yrs. | - | - | 97 | 65 | 97 | 24 |
| (63) | Beautifil II S-PRG filler | 31 | | 3 yrs. | | | 65 % | 45 % | | |
| (64-66) | Quixfil posterior +Grandio Universal nano-hybrid | 62 | | 3 yrs. | | | 37 | 25 | 1 | 3 |

Table-3: continued.

| | | | | | | | | | | | |
|----------|---|-----|-------------------------|----------|-----|-----|----|----|----|---|---|
| (67) | Filtek Supreme nano-filled +Tetric Evo ceram nano-filled +Aelite Aesthetic nano-filled | 67 | Annual f.: 1.6% | 5 yrs. | 26 | 41 | | 1 | | | |
| (68) | Filtek Supreme universal nano-filled | 73 | 87.7% (s) 4.2%(f) | 3 yrs. | 74 | 0 | 6 | 2 | | 1 | |
| (14, 69) | P-50 APC hybrid midi-filled +Herculite XR hybrid mini-filled | 362 | 1.5% - 2.20% (f) | 22 yrs. | 241 | 121 | 51 | 27 | 19 | 3 | 7 |
| (70) | Tetric Ceram HB & Tetric-flow | 25 | 8% (f) | 3.5 yrs. | - | - | | | 2 | 2 | |
| (71-73) | Quixfil posterior +Tetric Ceram hybrid | 83 | 2.7%- 0.6% (f) | 4 yrs. | 70 | 13 | 3 | 1 | 4 | 1 | 1 |
| (74) | Prodigy packable +Heliomolar | 432 | Annual f.: 1.7% | 3 yrs. | 153 | 279 | 4 | 15 | 2 | 2 | |

| micro-filled | | | | | | | | | |
|--------------|---|----|---|----------|----|----|---|---|---|
| (75, 76) | Alert packable +Surefil packable | 60 | | 5 yrs. | 34 | 26 | 1 | 1 | 1 |
| (77) | Filtek P-60 packable | 44 | | 6 yrs. | 44 | 0 | | | |
| (78) | Esthet-X micro-hybrid +Point4 micro-hybrid | 51 | | 3 yrs. | 0 | 51 | | 1 | |
| (79) | Vit-L-essence micro- hybrid | 25 | | 2.5 yrs. | 25 | 0 | | | |
| (8) | InTen-S low- shrinkage +Point4 micro hybrid | 91 | 77% (s) Annual f.: 1.5% - 1.60% | 15 yrs. | 91 | 0 | 7 | 8 | |

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Table-3: continued.

| | | | | | | | | | | | | | |
|------|--|-----|--|----------|-----|----|---|---|---|---|---|---|---|
| (80) | Filtek Silorane low-shrinkage +Ceram X | 107 | | 5 yrs. | 107 | 0 | 2 | 1 | 5 | 3 | | | |
| (7) | Filtek Z350 nano-filled +Esthet- X nano-hybrid +Filtek Z250 micro hybrid | 93 | Annual f.: 1.61% -0.80% - 1.61% | 4.5 yrs. | 0 | 93 | | 1 | | 1 | 1 | 1 | 2 |
| (4) | SDR flowable bulk-filled & Ceram X mono +Ceram X mono | 104 | Annual f.: 0.00% - 1.30% | 3 yrs. | 76 | 28 | 1 | | 1 | | | | |
| (81) | Filtek LS Low-shrinkage +Tetric Evoceram nano-filled | 72 | | 3 yrs. | 72 | 0 | 4 | | | | | | |

| | | | | | | | | | |
|------|--|-----|---------------------------------|-------------|-----|----|---|---|---|
| (82) | Filtek Supreme nano-filled +p60 packable +Filtek Silorane low- shrinkage | 60 | | 3 yrs. | 0 | 60 | | | |
| (1) | SDR flowable bulkfil&Ceram X +Ceram X mono nano-hybrid | 196 | Annual f.: 1.2% - 1.0% | 3 yrs. | 122 | 74 | 2 | 2 | 3 |
| (83) | Filtek P90 +Quixfil posterior | 156 | Annual f.: 1.7% - 1.2% | 3 yrs. | 156 | 0 | 5 | | 2 |
| (84) | Filtek P60 posterior +Filtek Z250 posterior | 67 | 3% (f) | 56 mths. | 36 | 31 | 1 | | 1 |
| (85) | TPH spectrum hybrid +Synergy Compact packable | 80 | | 3 yrs. | 0 | 80 | 6 | | |

Table-3: continued.

| | | | | | | | | | | |
|------|--|-----|-----------|--------|----|----|---|---|---|---|
| (15) | Nulite F fiber reinforced packable + Alert fiber reinforced packable | 72 | 25% (f) | 6 yrs. | 72 | 0 | 5 | 5 | 4 | |
| (86) | Beatifil universal giomer | 108 | 5% (f) | 3 yrs. | 72 | 36 | 2 | 1 | 1 | 1 |
| (87) | Solitaire packable porous +Alert fiber reinforced packable +Surefil hybrid packable +Filtek P60 packable +TPH spectrum hybrid packable | 75 | 12.5% (f) | 3 yrs. | 66 | 9 | 2 | | | 1 |

† Multi-surface- ‡ Single-surface -§ Survival rate - ¶ Failure rate-

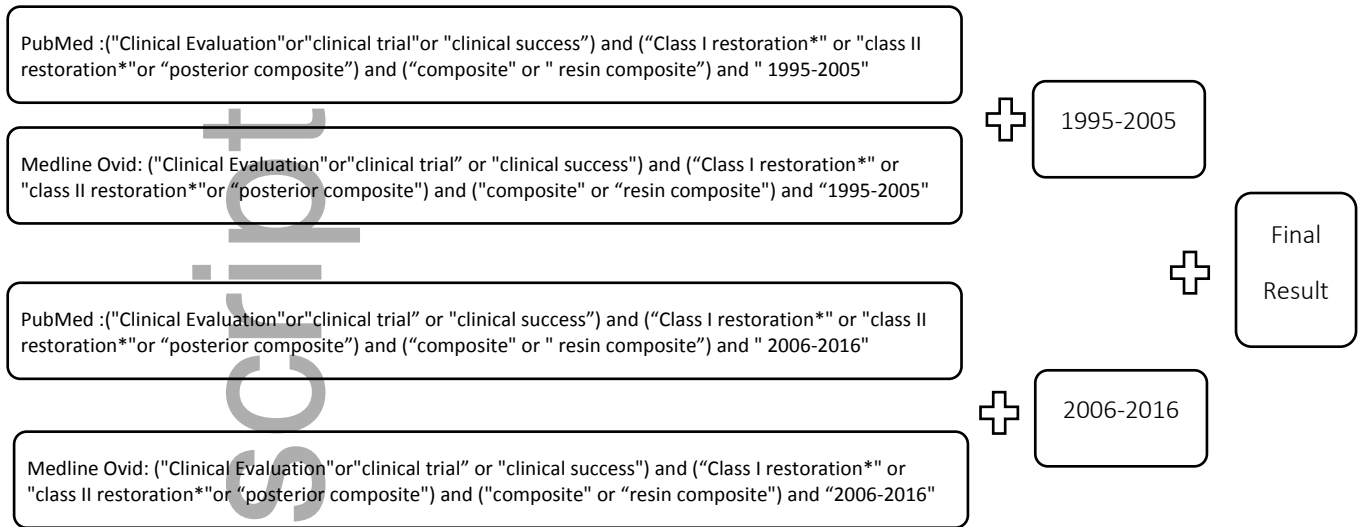


Figure 1

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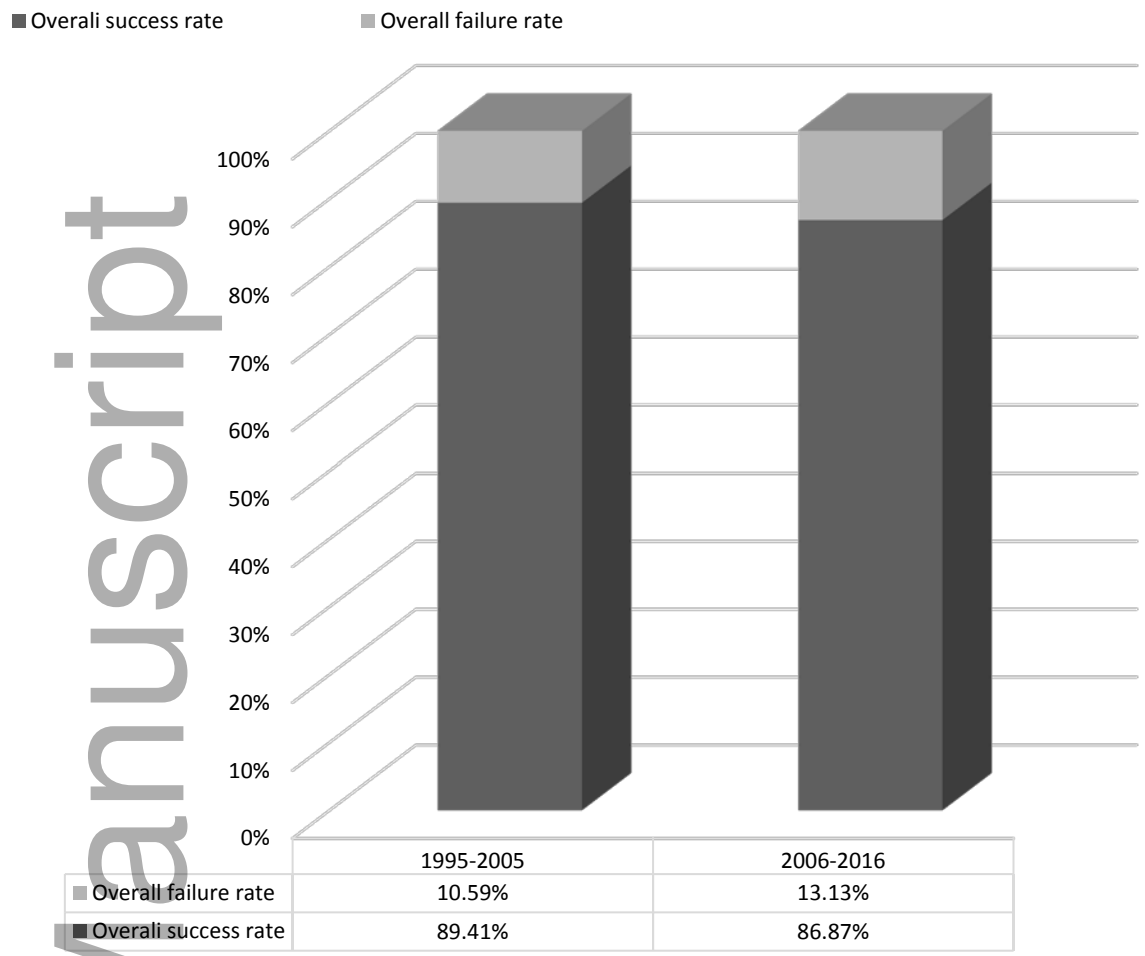


Figure 2

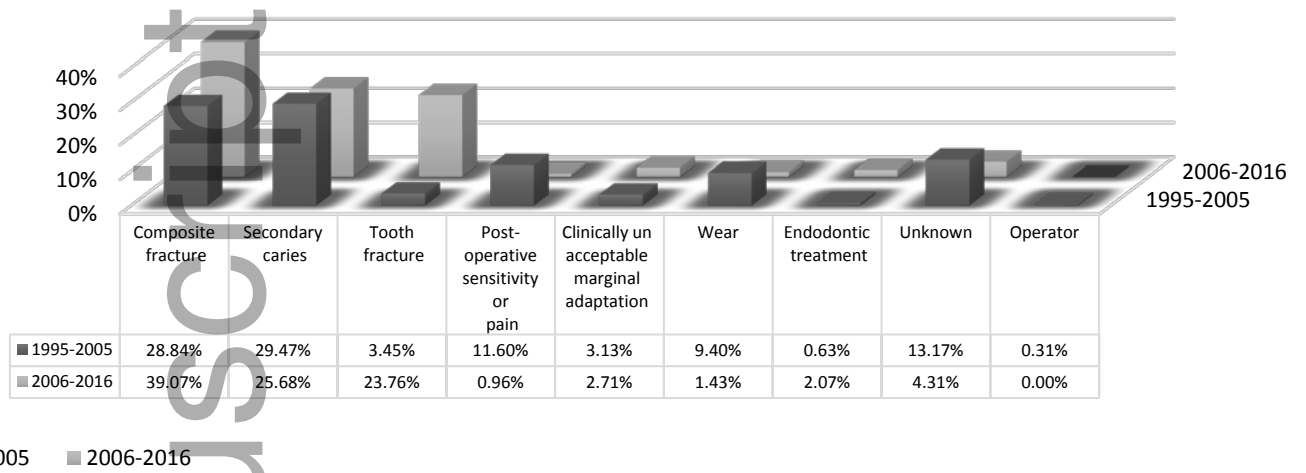


Figure 3

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Figure 4

