Meta-analysis of Failure and Survival Rate of Implant-supported Single Crowns, Fixed Partial Denture, and Implant Tooth-supported Prostheses

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Abstract:
Background: Dental implants have become the most viable option for rehabilitation. Although, many studies report the success of these reconstructions using implants, a cumulative data about the various studies and the failure rate still remain unaddressed. Therefore, the purpose of this systematic review was to analyze these data and to derive the cumulative survival rate of different implant-supported prostheses.

Materials and Methods: Manual searches followed by a MEDLINE search were conducted to select prospective and retrospective cohort studies on single crowns (SCs), fixed partial denture (FPD), and tooth implant connected prostheses with a mean follow-up time of minimum of 5 years. Random-effects Poisson’s regression models have been used to obtain summary estimates for implant failure and survival rates.

Results: Data were extracted from the final selected 63 studies. In a meta-analysis of these studies, the survival rate of SCs supported by implants (95% CI) was 96.363%, for FPDs was 94.525% and implant tooth-supported prostheses was 91.27% after 5 years of function. The cumulative failure rate per 100 FPD years of the SCs, FPDs, and implant tooth-supported prostheses were 0.684, 0.881, and 1.514, respectively.

Conclusion: The study concludes high survival rates for implant-supported SCs followed by implant-supported FPDs can be expected over an observation period of 5 years. However, tooth implant-supported prostheses can be provided if there are certain limitations prohibiting the completely implant-supported prostheses.

Key Words: Case-control, cohort, failure, implants, survival

Introduction
The use of dental implants in the rehabilitation of partially edentulous patients has become a well-established and accepted contemporary clinical method with predictable long-term success.¹ The majority of studies examining implant success have emphasized the integrity of implant-bone support and the quality of osseointegration typically evaluated using parameters such as implant mobility, inflammation, infection around the implant site, and peri-implant bone loss. Predictable results are believed to depend on good initial implant stability, controlled loading conditions, and an osseo-conductive implant surface.² As implant therapy evolves and becomes the standard of care, and the population seeks out alternatives to traditional fixed partial dentures (FPDs), success will be dependent on more than simply osseointegration.

Restorative therapy using dental implants is considered a safe and predictable treatment procedure in edentulous and partially dentate patients. These therapies range from cantilevers, resin-bonded bridges, FPDs to implant-supported SCs, and bridges.²⁶ Changes in the restorative treatment patterns and the introduction of new and improved restorative materials and techniques have greatly influenced the longevity and esthetic outcomes.⁶ The focus of implant research is shifting from descriptions of clinical success to the identification of factors associated with failure.⁷

To date, most studies evaluating risk factors for failure are flawed in terms of their statistical analysis. Many researchers assessed survival in a binary manner (yes or no) (Jemt et al., 1996; Lazzara et al., 1996; Rosenquist and Grenthe, 1996; Cooper et al., 1999; Chaffee et al., 2002) or applied statistical methods assuming that the implant observations were independent of each other (Wheeler, 1996; Buser et al., 1997; Brocard et al., 2000; Testori et al., 2001). Prospective and longitudinal studies related to partial edentulous indicate cumulative survival rates ranging from 89% to 95% and cumulative survival rates ranging from 93.6% to 96.7%, 3–7 years after loading.³ In addition, for a meaningful interpretation of the survival rate, a minimum of 5-year follow-up would be required.⁹

Recent systematic reviews have evaluated the survival of tooth- and implant-supported reconstructions of different...
designs and described the incidence of biological and technical complications after a 5-year period.\textsuperscript{9,11} The survival of FPD with two different designs ranged from 92.5% for cantilever FPDs to 93.8% for conventional FPDs in this study.\textsuperscript{6,9}

However, data toward the failures occurring in various implant-supported fixed prosthesis like single crowns (SCs), bridges, as well as implant and tooth connected prostheses still have not been evaluated.

Although, many studies report the success of these reconstructions using implants, a cumulative data about the various studies and the failure rate still remain unaddressed. Therefore, the purpose of this systematic review was to analyze these data and to derive the cumulative survival rate of different implant-supported prosthesis.

Materials and Methods

Search strategy and study selection

A MEDLINE search from 1986 up to and including 2015 was conducted for publications in Journals using the following search terms and limited to human trials: “implants” and “survival,” “implants” and “survival rate,” “implants” and “survival analysis,” “implants” and “cohort studies,” “implants” and “case-control studies,” “implants” and “controlled clinical trials,” “implants” and “randomized-controlled clinical trials,” “implants” and “complications,” “implants” and “clinical,” “implants” and “longitudinal,” “implants” and “prospective” and “implants” and “retrospective.” Additional search strategies included the terms “single tooth,” “failure,” “peri-implantitis,” “fracture,” “complication,” “technical complication,” “biological complication,” “screw loosening” and “maintenance.”

Full-text articles were analyzed, and the related articles were also searched from the bibliography. Furthermore, following journals from 1986 to 2015: Australian Dental Journal, British Journal of Oral and Maxillofacial Surgery, Clinical Implant Dentistry and Related Research, Clinical Oral Implants Research, European Journal of Oral Sciences, International Dental Journal, International Journal of Oral and Maxillofacial Implants, International Journal of Periodontics and Restorative Dentistry, International Journal of Prosthodontics, Journal of Prosthetic Dentistry, Journal of Oral and Maxillofacial Implants, Journal de Parodontologie, Journal of Clinical Periodontology, Journal of Dental Research, Journal of Oral Implantology, Journal of Oral Rehabilitation, Journal of Periodontology, Quintessence International, Swedish Dental Journal, Schweizerische Monatsschrift Zahnmedizin.

Inclusion criteria

This systematic review was based on prospective or retrospective cohort studies. The inclusion criteria for study selection were:

- The studies had a minimum of 5-year follow-up
- The patients included had been examined clinically and/or radiographically at the follow-up visit
- Publications that reported findings for both implant-supported FPDs and implant and tooth-supported FPDs were also included.

Selection of studies

The articles obtained were first scrutinized by two reviewers, and any disagreement was resolved by discussion. Data were extracted individually by the reviewers. Any discrepancy in the records by the two reviewers was resolved by discussion and re-evaluation.

Excluded studies

The main reasons for exclusion were:

- Mean observation period of less than 5 years
- No mention of type of reconstructions or totally/partially edentulous patients
- Surveys, case reports and reviews.

Data extraction

Of the 63 studies included, information on the survival and failure rate of the reconstructions was retrieved.

From the included studies, the number of failures for all of the three types of reconstructions was obtained and the total exposure time was calculated.

Statistical analysis

Failure rates were calculated by dividing the number of failures in the numerator by the total exposure time obtained in the denominator, which was calculated by taking the sum of:

(1) Exposure time of implants that survived the total follow-up time
(2) Exposure time up to the failure of implants lost during the observation time
(3) Exposure time up to the end of follow-up time for implants that did not complete the observation period due to any reason.

The total number of failures was considered to be Poisson distributed and Poisson’s regression with a logarithmic link function was used (Kirkwood and Sterne, 2003a). Standard errors were calculated to obtain 95% confidence intervals (CIs) of the summary estimates of the failure rates.

To assess heterogeneity of the study-specific event rates, Cochran’s Q and I\(^2\) statistics was done and also the P-value was calculated. If the P<0.05, indicating heterogeneity, random-effects Poisson’s regression was used to obtain a summary estimate of the failure rates. Survival proportions were calculated by the relationship between failure rate and survival function.
All analysis were done using MedCalc Statistical Software version 15.4.

**Result**

**Study characteristics**

Nearly 63 studies included in this systematic review ranged from 1988 up to 2015. The articles on implant-supported SCs had 2004 as a median year of publication (Table 1).

The majority of studies on implant-supported reconstructions (58 out of 73) were prospective in nature. The highest proportion of studies was found for the implant-supported SCs (Table 2).

**Survival**

Survival was defined as the prostheses remaining *in situ* over the observation period.

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**Table 1: Review of the studies included in the meta-analysis.**

| Type of reconstruction | Year of publication | No. of publication | Study design | No. | Median | Follow-up time | Median |
|------------------------|---------------------|--------------------|--------------|-----|--------|----------------|--------|
| SCs                    | 1996-2014           | 33                 | Prospective  | 28  | 5      | 5-10           | 5      |
| FPDs                   | 1994-2015           | 26                 | Prospective  | 21  | 5      | 5-15           | 5      |
| Implant tooth          | 1988-2007           | 14                 | Prospective  | 09  | 5      | 5-10           | 6.75   |

SCs: Single crowns, FPDs: Fixed partial dentures

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**Table 2: Failure and survival rate of implant supported SCs.**

| Study            | Year | Total FPDs | Mean follow-up | Number of failures | Total exposure time | Estimated failure rate (per 100 years) | Estimated survival rate |
|------------------|------|------------|----------------|--------------------|---------------------|----------------------------------------|------------------------|
| Boicelli         | 2014 | 54         | 5              | 1                  | Na                  | 0.37                                   | 98.15                  |
| Zembic           | 2012 | 28         | 3              | 5                  | Na                  | 2.14                                   | 89.29                  |
| Felice           | 2014 | 116        | 5              | 17                 | 572                 | 2.97                                   | 85.59                  |
| Visser           | 2009 | 92         | 5              | 1                  | 458                 | 0.22                                   | 98.91                  |
| Calandriello     | 2011 | 40         | 5              | 1                  | 199.2               | 0.50                                   | 97.50                  |
| Romeo            | 2014 | 12         | 5              | 0                  | 60                  | 0                                      | 100                    |
| Wagenberg        | 2006 | 401        | 5.9            | 18                 | 2266                | 0.79                                   | 95.51                  |
| Bernstein        | 2005 | 39         | 5              | 0                  | 190                 | 0                                      | 100                    |
| Elkhoury         | 2005 | 39         | 5              | 0                  | 195                 | 0                                      | 100                    |
| De Boever        | 2005 | 10         | 5              | 1                  | 50                  | 2.00                                   | 90                     |
| Wennstrom        | 2005 | 45         | 5              | 1                  | 208                 | 0.48                                   | 97.78                  |
| Levin            | 2005 | 30         | 5.1            | 2                  | 153                 | 1.31                                   | 93.33                  |
| Taylor           | 2004 | 39         | 5              | 1                  | 190                 | 0.53                                   | 97.44                  |
| Bernard          | 2004 | 32         | 5              | 0                  | 158                 | 0                                      | 100                    |
| Romeo            | 2004 | 123        | 5.8            | 7                  | 711                 | 0.99                                   | 94.31                  |
| Bianchi          | 2004 | 116        | 5.2            | 0                  | 594                 | 0                                      | 100                    |
| Godfredsen       | 2004 | 20         | 5              | 0                  | 100                 | 0                                      | 100                    |
| Anderson         | 2002 | 8          | 5              | 0                  | 40                  | 0                                      | 100                    |
| Haas             | 2002 | 76         | 5.5            | 5                  | 407                 | 1.23                                   | 93.42                  |
| Gibbard          | 2002 | 49         | 5.9            | 1                  | 287                 | 0.35                                   | 97.96                  |
| Mericse Stern    | 2001 | 26         | 6.5            | 2                  | 169                 | 1.18                                   | 92.31                  |
| Palmer           | 2000 | 15         | 5              | 0                  | 70                  | 0                                      | 100                    |
| Vigolo           | 2000 | 52         | 5              | 3                  | 245                 | 1.22                                   | 94.23                  |
| Thilander        | 1999 | 15         | 8              | 0                  | 120                 | 0                                      | 100                    |
| Poluzzi          | 1999 | 30         | 5.3            | 1                  | 158                 | 0.63                                   | 96.67                  |
| Andersson        | 1998 | 38         | 5              | 0                  | 182                 | 0                                      | 100                    |
| Andersson        | 1998 | 65         | 5              | 1                  | 305                 | 0.33                                   | 98.46                  |
| Scheller         | 1998 | 99         | 5              | 3                  | 411                 | 0.73                                   | 96.97                  |
| Henry            | 1996 | 107        | 5              | 3                  | 477                 | 0.63                                   | 97.20                  |
| Buser            | 1996 | 5          | 5              | 0                  | 25                  | 0                                      | 100                    |
| Jent             | 2005 | 10         | 5              | 0                  | 48                  | 0                                      | 100                    |
| Boever           | 2005 | 42         | 10             | 0                  | 420                 | 0                                      | 100                    |
| Braeger          | 2005 | 69         | 10             | 5                  | 672                 | 0.74                                   | 92.75                  |

Total: Fixed effects = 10550; Random effects = 10550

Cohran’s Q (df) = 13.52-62.26; df = 5; p = 0.0054; 95% CI for I² = 13.52-62.26; df = 5; I² = 32; 95% CI for I² = 57.38

CI: Confidence interval
Implant-supported SC
Of 1833 SCs, 72 were lost, and the study specific survival varied between 89.29% and 100%. In meta-analysis, the annual failure rate was estimated at 0.684 (0.472-0.936) per 100 FPD years (Graph 1) translating into the survival of implant-supported FPDs of 96.363 (Table 3 and Graph 2).

Implant-supported FPDs
About 26 studies provided data on the survival of solely implant-supported FPDs (Table 1). In meta-analysis, the annual failure rate was estimated at 0.881 (0.480-1.402) per 100 FPD years (Graph 3) translating into the survival of implant-supported FPDs of 94.525 (Table 3 and Graph 4).

Combined tooth-implant-supported FPDs
Fourteen studies provided results on the survival of combined tooth-implant-supported FPDs (Table 4). In this meta-analysis, the annual failure rate (Graph 5) was estimated at 1.514 (0.79-2.45) per 100 FPD years, translating into the survival of tooth-implant-supported FPDs (Graph 6) of 91.27 (85.93-95.433).

Comparison of survival rates
After the total follow-up, the annual failure rates of different types of reconstructions ranged from 0 to 8.3, and the estimated survival rate ranged from 61.017% to 100%.
### Table 3: Failure and survival rate of implant-supported FPD.

| Study    | Year | Total FPDs | Mean follow-up | Number of failures | Total exposure time | Estimated failure rate (per 100 years) | Estimated survival rate |
|----------|------|------------|----------------|--------------------|---------------------|----------------------------------------|------------------------|
| Dedigi   | 2005 | 9          | 7              | 1                  | 63                  | 1.59                                   | 88.889                 |
| Becker   | 2004 | 51         | 5.1            | 0                  | 260                 | 0                                      | 100                    |
| Wennstrom| 2004 | 56         | 5              | 3                  | 280                 | 1.07                                   | 94.643                 |
| Preiskel  | 2004 | 78         | 6.6            | 2                  | 514                 | 0.39                                   | 97.436                 |
| Andersson| 2003 | 36         | 5              | 1                  | 180                 | 0.56                                   | 97.222                 |
| Jent     | 2002 | 63         | 5              | 3                  | 315                 | 0.95                                   | 95.238                 |
| Naert    | 2002 | 409        | 5.5            | 15                 | 2249                | 0.67                                   | 96.333                 |
| Gottfredsen | 2001 | 52        | 5              | 2                  | 260                 | 0.77                                   | 96.154                 |
| Bragger  | 2001 | 40         | 5              | 1                  | 200                 | 0.50                                   | 97.5                   |
| Mengel  | 2001 | 7          | 5              | 0                  | 35                  | 0                                      | 100                    |
| Behneke  | 2000 | 68         | 5.4            | 1                  | 367                 | 0.27                                   | 98.529                 |
| Hosny    | 2000 | 18         | 6.5            | 0                  | 117                 | 0                                      | 100                    |
| Otrop    | 1999 | 68         | 5              | 3                  | 340                 | 0.88                                   | 95.588                 |
| Wennerberg | 1999 | 133       | 5              | 2                  | 665                 | 0.30                                   | 98.496                 |
| Wyatt    | 1998 | 97         | 5.4            | 16                 | 523                 | 3.06                                   | 83.505                 |
| Olsson   | 1995 | 23         | 5              | 4                  | 115                 | 3.48                                   | 82.609                 |
| Leikhom  | 1994 | 197        | 5              | 13                 | 985                 | 1.32                                   | 93.401                 |
| Cecchinato | 2008 | 115       | 5              | 3                  | 575                 | 0.52                                   | 97.391                 |
| Larson   | 2010 | 25         | 5              | 0                  | 125                 | 0                                      | 100                    |
| Galluchi | 2009 | 45         | 5              | 2                  | 225                 | 0.89                                   | 95.556                 |
| Blanes   | 2007 | 192        | 6              | 0                  | 1152                | 0                                      | 100                    |
| Derks    | 2015 | 118        | 9              | 46                 | 1062                | 4.33                                   | 61.017                 |
| Bragger  | 2005 | 33         | 10             | 2                  | 330                 | 0.61                                   | 93.939                 |
| Leikhom  | 1999 | 163        | 10             | 21                 | 1630                | 1.29                                   | 87.317                 |
| Gunne    | 1999 | 23         | 10             | 4                  | 230                 | 1.74                                   | 82.609                 |
| Nielsen  | 2011 | 221        | 15             | 0                  | 3315                | 0                                      | 100                    |

**Fixed effects**: 16112, 0.643 (0.525-0.778), 95.265

**Random effects**: 16112, 0.881 (0.480-1.402), 94.525

**Cohran's Q**: 213.5421

**df**: 25

**P**: <0.0001

**I²**: 0.8829

95% CI for I²: 84.08-91.39

*SCs: Single crowns, FPDs: Fixed partial dentures, CI: Confidence interval*

### Table 4: Failure and survival rate of implant- and tooth-supported prostheses.

| Study    | Year | Total FPDs | Mean follow-up | Number of failures | Total exposure time | Estimated failure rate (per 100 years) | Estimated survival rate |
|----------|------|------------|----------------|--------------------|---------------------|----------------------------------------|------------------------|
| Nickenig | 2006 | 84         | 5              | 2                  | 420                 | 0.48                                   | 97.62                  |
| Bragger  | 2001 | 18         | 5              | 1                  | 90                  | 1.11                                   | 94.44                  |
| Kindberg | 2001 | 41         | 5              | 3                  | 205                 | 1.46                                   | 92.68                  |
| Hosny    | 2000 | 18         | 6.5            | 0                  | 117                 | 0                                      | 100                    |
| Olsson   | 1995 | 23         | 5              | 2                  | 115                 | 1.74                                   | 91.30                  |
| Koth     | 1988 | 15         | 5              | 1                  | 75                  | 1.33                                   | 93.33                  |
| Romeo    | 2004 | 13         | 7              | 0                  | 91                  | 0                                      | 100                    |
| Blanes   | 2007 | 10         | 10             | 0                  | 100                 | 0                                      | 100                    |
| Bragger  | 2005 | 22         | 10             | 7                  | 220                 | 3.18                                   | 68.18                  |
| Gunne    | 1999 | 23         | 10             | 3                  | 230                 | 1.30                                   | 86.96                  |
| Stefanik | 1995 | 15         | 10             | 3                  | 150                 | 2                                      | 80                     |
| Jent     | 1989 | 12         | 5              | 1                  | 60                  | 8.33                                   | 91.67                  |

**Fixed effects**: 1873, 1.412 (0.93-2.05), 92.255 (88.67-94.99)

**Random effects**: 1873, 1.514 (0.79-2.45), 91.27 (85.93-95.433)

**Cohran’s Q**: 22.67

**df**: 11

**P**: 0.02

**I²**: 0.50

95% CI for I²: 6.21-74.89

*SCs: Single crowns, FPDs: Fixed partial dentures, CI: Confidence interval*
The relative failure rates of different types of prostheses, using implant-supported SCs as a reference, implant supported FPDs and the implant tooth connected prostheses showed more failure rates.

The highest survival was for implant-supported SCs 96.363% and implant-supported FPDs 94.525%. Lower survivals were reported for combined tooth-implant-supported FPDs 91.270% (Tables 2-4 and Graphs 1-6).

**Discussion**

A comparative analysis of three different designs of implant-supported prostheses including SCs, FPD and tooth-implant-supported prostheses was done. Prospective and retrospective cohort studies abiding by the inclusion criteria were included in this meta-analysis to summarize the data about survival and failure rates of implant-supported reconstructions after minimum 5 years. Although 5 years have been considered in this study, some researchers may contradict that this time period is too short to gather the necessary information. However, dental implants have been in use for the reconstruction since not many years. Therefore, the time period considered was minimum of 5 years.

After the investigated period, higher failure rates were seen for implant-supported FPDs (0.881 per 100 FPD years) and combined tooth-implant supported FPDs (1.514 per 100 FPD years). Combined tooth-implant supported FPDs had the highest annual failure rate (1.514). Statistically significant difference was observed in the failure rates. This result was contrary to the earlier studies reported by Pjeturson et al. The reason can be attributed to the better designs and treatment protocol being introduced over the recent years. The highest failure rates were seen with respect to combined tooth-implant-supported FPDs. This result had been reported earlier too in the literature.

This meta-analysis showing the failure and survival rates of implant-supported reconstructions of different types was based on the systematic reviews reported earlier. However, inclusion criteria were redefined, and the studies were selected till the most recent ones. Therefore, the newer concepts of fabricating the reconstructions have also been evaluated.

For instance, only studies with a clinical or radiological examination were included to avoid the potential subjective bias in failure description in studies based on patient questionnaire.

The limitations of this meta-analysis are that it was based on studies conducted in an institutional environment. Hence, the services provided in the private practice could not be evaluated. Furthermore, the data did not permit estimating annual failure rates separately for different time periods after insertion of the prostheses. Thus, it was not possible to assess if there was a substantial increase in the annual failure rate. Moreover, the prosthetic complications were not taken into consideration in this meta-analysis, therefore limiting our results to implant survival.

Moreover, the meta-analysis only included English-language publications. This could be problematic for two reasons: (a) Estimates is not complete if a significant number of studies published in other languages exist; (b) selection bias may occur if the results differ systematically from those of other languages.

**Research implications**

It was deduced from this meta-analysis that still more longitudinal studies are required with more years of observation.

**Clinical implications**

According to the results of the present meta-analysis, planning of prosthetic rehabilitations should preferentially include implant-supported SCs or solely implant-supported FPDs. Only for reasons of anatomical constraints, failure of implants or patient preferences, and as a second option should FPDs supported by a combination of implants and teeth be chosen.

**Conclusion**

Under the limitations of this meta-analysis, implant supported prostheses should be selected in the order of a single crown, followed by prostheses supported at the terminal ends by implants and lastly implant-tooth supported prostheses.

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