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Ante's (1926) law revisited: a systematic review on survival rates and complications of fixed dental prostheses (FDPs) on severely reduced periodontal tissue support

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Abstract

Background: In subjects suffering from generalized severe periodontitis, only a few teeth may be treated and used as abutments for fixed dental prostheses (FDPs).

Objective: To systematically review the impact of severely reduced, but healthy periodontal tissue support on the survival rate and complications of FDPs after a mean follow-up time of at least 5 years.

Search strategy: Publications considered for inclusion were searched in MEDLINE (PubMed) and relevant journals were hand searched. The search was performed in duplicate and was limited to human studies published in the dental literature from 1966 up to and including September 2006. Only publications in English, in peer-reviewed journals, were considered. Abstracts were excluded.

Selection criteria: Prospective and retrospective cohort studies were included. The primary outcome measure included survival rates of FDPs and abutment teeth, whereas biological and technical complications of FDPs and abutment teeth represented secondary outcome measures.

Data analysis: Summary estimates of survival rates and of biological and technical complications were calculated after 5 and 10 years.

Results: The search provided 860 titles of which six publications were included. A total of 579 FDPs were incorporated and followed up to 25 years. Meta-analysis yielded an estimated FDP survival rate of 96.4% [95% confidence interval (95% CI): 94.6–97.6%] after five and of 92.9% (95% CI: 89.5–95.3%) after 10 years, respectively. After 10 years, the estimated rate of abutment teeth without endodontic complications amounted to 93% (95% CI: 62.6–98.9%). The 10-year estimated rate of caries-free abutment teeth was 98.1% (95% CI: 88.2–99.7%). FDPs without loss of retention were estimated to occur in 95.4% (95% CI: 92.6–97.2%) of cases after 10 years.

Conclusions: These results showed that (i) masticatory function could be established and maintained in subjects receiving FDPs on abutment teeth with severely reduced but healthy periodontal tissue support and (ii) FDPs survival rates compared favourably with those of FDPs incorporated in subjects without severely periodontally compromised dentitions.

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In advanced stages of generalized periodontitis, much of the supporting tissues has been lost. Around some teeth, tissue destruction has progressed so far that they have either exfoliated spontaneously or have been extracted because of excessive mobility. In such cases, a comprehensive treatment plan encompassing non-surgical and surgical periodontal therapy, as well as prosthetic rehabilitation, is needed in order

to restore health, function and aesthetics (Nyman & Lindhe 1976a, 1976b, 1977). However, opinions on how much occlusal load a reduced but healthy periodontium can withstand, and what type of prosthetic reconstruction should be incorporated, have been influenced for decades by a series of paradigms based predominantly on biomechanical concepts and generally not substantiated. The concern about occlusal overload and presumptive consequences of trauma from occlusion have led to the meticulous replacement of missing teeth and the incorporation of a large number of abutment teeth into fixed dental prostheses (FDPs). Moreover, increased tooth mobility *per se* was considered to be a pathological sign jeopardizing the longevity of a tooth. These thoughts coalesced into a paradigm that was adopted as a therapeutic concept for fixed reconstructions for more than 50 years (Ante 1926). Ante's law postulated that 'the total periodontal membrane area of the abutment teeth must equal or exceed that of the teeth to be replaced'. Later statements claimed that 'the length of the periodontal membrane attachment of an abutment tooth should be at least one half or two thirds of that of its normal root attachment' (Tylman & Tylman 1960; Reynolds 1968; Tylman & Malone 1978). As a logical consequence, a number of teeth with substantially reduced periodontal tissue support could no longer be used as abutment teeth for FDPs, and hence were extracted and replaced. In this context, it is important to realize that tooth mobility *per se* does not represent a pathological condition. Rather, it represents a physiological tissue adaptation to altered function (Svanberg & Lindhe 1974; Lindhe & Ericsson 1976; Ericsson & Lindhe 1977, 1984). Teeth display a physiologic mobility as they are not ankylosed in the alveolar bone, but suspended in it by means of the periodontal ligament. Tooth mobility is clinically assessed as the amplitude of the crown displacement and results from the application of a standardized force (Mühlemann 1954; Persson & Svensson 1980). The magnitude of this amplitude has been used to distinguish between 'physiological' and 'pathological' tooth mobility. The height of the supporting periodontal tissues and the ligament's width determine the mobility of healthy teeth. Even after the achievement of periodontal health by means of successful therapy and optimal self-performed plaque control, persisting increased tooth mobility has erroneously been regarded as 'pathologic'. However, if the width of the periodontal ligament remains unchanged, it should be realized that the amplitude of root mobility within the alveolus corresponds to that of a tooth with normal height of periodontal support. Hence, increased mobility of a tooth, with healthy but reduced periodontal support and without widened periodontal ligament, should be considered as 'physiologic' tooth mobility (Nyman & Lang 1994; Nyman & Lindhe 1976a, 1976b). Furthermore, results from studies incorporating force transducers into prosthetic reconstructions have demonstrated that cross-arch FDPs on abutment teeth with reduced, but favourably distributed periodontal support (i) can withstand occlusal forces of normal magnitude and (ii) do not negatively influence closing and chewing patterns (Lundgren & Laurell 1984, 1986; Laurell & Lundgren 1985a, 1985b).

Hence, the aim of the present systematic review was to assess survival rates and incidences of biological and technical complications of FDPs on abutment teeth with severely reduced, but healthy periodontal tissue support over a mean follow-up time of at least 5 years.

Material and methods

Search strategy

A search in the MEDLINE (PubMed) database, from 1966 up to and including September 2006, was made. Only publications in English appearing in peer-reviewed journals were considered. Abstracts were excluded. The search strategy included the key words: *fixed prosthodontics, fixed partial denture(s), fixed reconstruction(s), oral rehabilitation, bridge(s), partial edentulism, periodontitis* and *periodontal disease(s)*.

A complementary manual search from 1986 up to September 2006 was carried out in the following journals: *Acta Odontologica Scandinavica, Journal of Oral Rehabilitation, Journal of Prosthetic Dentistry, International Journal of Prosthodontics, International Journal of Periodontics and Restorative Dentistry, Swedish Dental Journal, Journal of Clinical Periodontology, Journal of Dental Research and Journal of Periodontology*.

In addition, the reference lists of articles selected for inclusion in this review were screened.

Selection criteria

Prospective and retrospective cohort studies with a mean follow-up time of at least 5 years were included (Fig. 1).

Inclusion criteria

- Mean follow-up time $\geq$ 5 years,
- Severely reduced periodontal tissue support of abutment teeth based on clinical and/or radiographic data,
- FDPs on abutment teeth not meeting Ante's law,
- FDPs supported by at least four abutment teeth/dental arch (i.e., publications with cross-arch FDPs supported by only two abutment teeth were excluded),
- FDPs with end abutment teeth, unilateral and bilateral cantilever segments,
- Clinical examination at the follow-up visits (i.e., publications based on patient's records, questionnaires or interviews were excluded),
- Detailed information on the periodontal conditions of the abutment teeth and the characteristics of the FDPs.

Validity assessment

Two reviewers (M. L. and G. E. S.) independently screened titles and abstracts of the search results for possible inclusion. The discrepancies were resolved by discussion. Publications of potential interest were searched for in order to evaluate the full text. Both reviewers screened the included publications independently against the inclusion criteria. Again, any disagreement was resolved by discussion between the two reviewers.

Data extraction

The primary outcome variable addressed the survival rate of the abutment tooth and/or its FDP. Survival was defined as presence of the FDP *in situ* in its original extension at follow-up examination.

The secondary outcome variable addressed the presence or absence of biological and/or technical complications. Success was defined as presence of the FDP *in situ* without any biological and/or technical

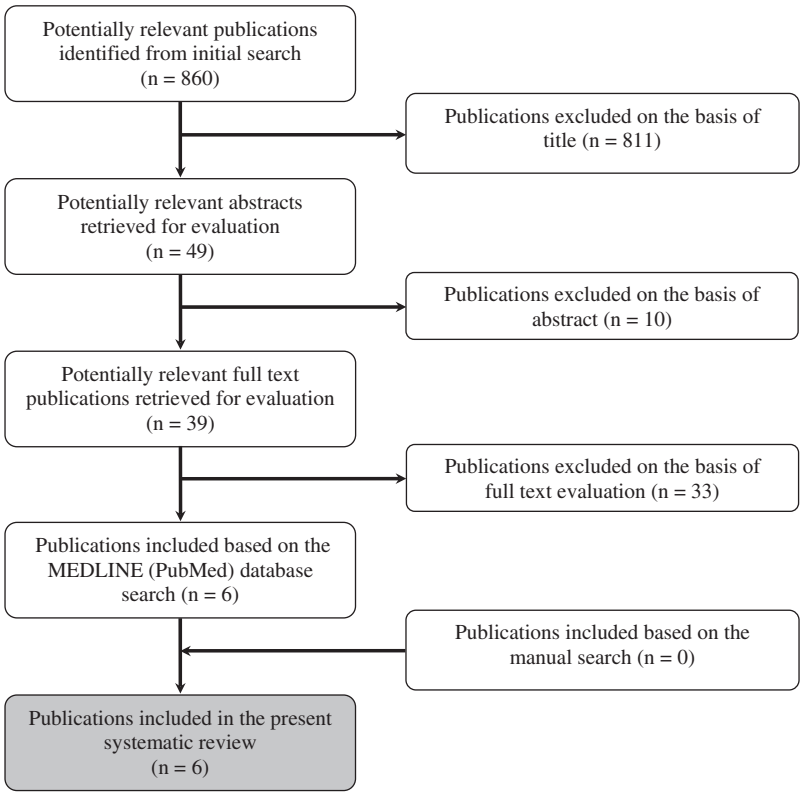

Fig. 1. Selection process of the included publications.

complications during the entire follow-up period.

Biological complications included:

- change in pocket probing depth (PPD),
- change in clinical attachment level (CAL),
- change in Plaque Index (PlI) score,
- change in Gingival Index (GI) score,
- change in bleeding on probing (BOP) score,
- change in radiographic alveolar bone height,
- change in FDP mobility,
- change in pulpal conditions,
- incidence of caries,
- change in periodontal ligament area (PLA) (% or mm^2).

Technical complications included:

- loss of retention,
- fracture of abutment tooth,
- fracture of metal framework.

Statistical analysis

The statistical methods applied for the present systematic review have been reported previously (Kirkwood & Sterne 2003a, 2003b; Lang et al. 2004).

Briefly, failure and complication rates were calculated by dividing the number of events (i.e., failures or complications) in the numerator by the total exposure time (i.e., FDPs time and/or abutment teeth time) in the denominator. The numerator could usually be extracted directly from the publication. However, the total exposure time of the FDPs or the abutment teeth needed to be calculated. The total exposure time represented the sum of (i) exposure time of FDPs/abutment teeth that could be followed for the entire observation period, (ii) exposure time up to a failure of the FDPs/abutment teeth that were lost due to failure during the observation period, and (iii) exposure time up to the dropout of the subjects who did not complete the observation period.

Results

The initial electronic search yielded 860 titles. Independent initial screening of the titles and abstracts resulted in further consideration of 49 publications. Based upon abstract screening, 39 full-text articles were obtained. From these articles, six publications were selected.

Characteristics of the publications

Based on the initial screening process of 860 titles, publications were excluded for the following reasons: mean follow-up time <5 years, cross-sectional design, review article, removable dental prostheses (RDPs), implant-supported reconstructions, tooth-implant supported reconstructions, reconstructions on single-unit crowns, focus on biomechanical and functional aspects, focus on furcation therapy and case reports.

After completion of the initial screening process, abstracts were obtained from the remaining 49 publications for further evaluation. Based on abstract's screening, 10 additional publications were excluded for the following reasons:

- *Mean follow-up time <5 years:* Felton et al. (1991), Freilich et al. (1991).
- *Less than four abutment teeth/dental arch:* Öwall et al. (1991), Carlson et al. (1993), Carlson & Yontchev (1996).
- *Lack of clinical examination:* Randow et al. (1986).
- *Review:* Yeo & Cheok (2006).
- *Case report:* Marchini et al. (2001), McClain (2004), Wagenberg (2005).

The full text articles of the remaining 39 publications were obtained for further evaluation. Thirty-three additional publications were excluded for the following reasons:

- *Lack of informations on periodontal conditions of abutment teeth:* Ericsson & Marken (1968), Roberts (1970), Lundgren et al. (1975), Karlsson (1986, 1989), Budtz-Jörgensen & Isidor (1990), Hochman et al. (1992), Palmqvist & Swartz (1993), Karlsson et al. (1995), Decock et al. (1996), Swartz et al. (1996), Fayyad & al-Rafee (1997), Näpänkangas et al. (1997), Walton (2003), Nevalainen et al. (2004), De Backer et al. (2006), Petersson et al. (2006)
- *Abutment teeth without severe loss of periodontal tissue support:* Tamarin (1967), Silness (1974), Silness & Gustavsen (1985), Gustavsen & Silness (1986), Reichen-Graden & Lang (1989), Isidor & Budtz-Jörgensen (1990), Valderhaug et al. (1993), Sundh & Ödman (1997), Hämmerle et al. (2000), Moser et al. (2002)

- *Lack of clinical examination:* Leempoel et al. (1995)
- *Case report:* Nyman & Lindhe (1976a, 1976b, 1977), Lee et al. (2000)
- *Review:* Marken et al. (1974a, 1974b)

Therefore, from the electronic search of the MEDLINE (PubMed) database, six publications were selected. The manual search and screening of the reference lists of included publications did not yield further publications. Thus, a total of six publications were included in the present systematic review.

General outcomes

Details of the included six publications are summarized in Table 1.

The first publication included in the present systematic review (Nyman et al. 1975) reported on 20 partially edentulous subjects treated for severe periodontal disease and rehabilitated with FDPs. The results showed that permanent stability of the reconstructions was obtained and maintained over a follow-up period of 2–6 years, even in conjunction with marked hypermobility of individual abutment teeth. The stability of the bridgework was achieved by proper treatment of the dis-

Table 1. **Details of the included publications**

Publication	Nyman et al.	Nyman & Lindhe	Nyman & Ericsson	Bergenholtz & Nyman
Date of publication	1975	1979	1982	1984
Type of study	Retrospective	Retrospective	Retrospective	Retrospective
Sampling method	Referred patients	Referred patients	Referred patients	Referred patients
Number of selected subjects	20	251	NA	52
Mean age at baseline (years)	48.9	NA	NA	47.1
Age range at baseline (years)	27–69	23–72	NA	21–68
Number of dropouts (subjects)	NA	NA	NA	NA
Systemic conditions	NA	NA	NA	NA
Smoking status	NA	NA	NA	NA
Periodontal diagnosis	Generalized severe periodontitis	Generalized severe periodontitis	Generalized severe periodontitis	Generalized severe periodontitis
Operator	University specialist clinic	University staff members and graduate students	University staff members and graduate students	University specialist clinic
Treatment	Periodontal therapy and fixed prosthetic rehabilitation	Periodontal therapy and fixed prosthetic rehabilitation	Periodontal therapy and fixed prosthetic rehabilitation	Periodontal therapy and fixed prosthetic rehabilitation
Total number of FDPs	26	332	60	82
Frequency of maintenance care	3–6 months	3–6 months	3–6 months	3–6 months
Mean follow-up time (years)	NA	6.2	NA	8.7
Follow-up range (years)	2–6	5–8	8–11	4–13
Outcome variables	Mean bone score Mobility of bridge (0, 1, 2)	Changes in: PPD, CAL, PlI, GI and alveolar bone height, loss of retention, fracture of metal framework, fracture of abutment teeth	Periodontal ligament areas of abutment and replaced teeth	Biological and technical complications of abutment and non-abutment teeth

Publication	Laurell et al.	Yi et al.
Date of publication	1991	1995
Type of study	Retrospective	Retrospective
Sampling method	Referred patients	Referred patients
Number of selected subjects	34	50
Mean age at baseline (years)	NA	NA
Age range at baseline (years)	NA	NA
Number of dropouts (subjects)	1	16
Systemic conditions	NA	NA
Smoking status	NA	NA
Periodontal diagnosis	Generalized severe periodontitis	Generalized severe periodontitis
Operator	University staff members and graduate students	University staff members and graduate students
Treatment	Periodontal therapy and fixed prosthetic rehabilitation	Periodontal therapy and fixed prosthetic rehabilitation
Total number of FDPs	36	43
Frequency of maintenance care	'Regular maintenance care'	$\geq 1 \times$ /year
Mean follow-up time (years)	8.4	15
Follow-up range (years)	5–12	10–25
Outcome variables	Survival rate Biological and technical complications	Changes in: BoP, PCR, PPD, bridge mobility, BS, PDL-T, PDL/DU, PSI

PPD, pocket probing depth; CAL, clinical attachment level; BoP, bleeding on probing; PlI, plaque index; GI, gingival index; PSI, periodontal support index; PDL-T, total periodontal ligament area; PDL/DU, dental unit periodontal ligament area; BS, bone support; PCR, plaque control record; FDP, fixed dental prosthesis; NA, not available.

eased periodontal tissues and by establishing a stable occlusion. When FDP mobility was anticipated due to excursive movements of the mandible, balancing contacts were established for the prevention of migration, tilting and increasing mobility. No statistically significant changes ($P>0.05$) in mean alveolar bone height and FDP mobility were observed in nine out of 20 subjects completing the 5-year follow-up examination. Furthermore, distal cantilever units incorporated in FDPs were used successfully to achieve and maintain the stability of the reconstructions.

A subsequent publication from the same group (Nyman & Lindhe 1979) presented the outcomes after treatment of 299 subjects diagnosed with generalized severe periodontitis (i.e., at least 50% loss of periodontal tissue support). In 48 subjects, a well-functioning dentition could be established with periodontal therapy alone, whereas in 251 subjects prosthetic rehabilitation was necessary subsequent to periodontal treatment. A total of 332 FDPs was incorporated in 251 subjects. Out of these 251 subjects, every fifth (i.e., a total of 50 subjects) was selected to form a group where 74 FDPs were incorporated and monitored longitudinally. According to their design, the 74 FDPs were divided into 21 cross-arch FDPs with end abutments, 39 cross-arch FDPs with unilateral or bilateral distal cantilever units and 14 FDPs of unilateral extension. These 50 subjects were followed up over a mean period of 6.2 years (range: 5–8 years). Overall, following comprehensive treatment, periodontal health could be maintained in these subjects enrolled in a supportive care program. Extensive reduction of periodontal tissue support around abutment teeth and differences in prosthetic design (i.e., with/without cantilever units) did not have a detrimental impact on periodontal status during the follow-up period.

Out of the material of the previous publication (Nyman & Lindhe 1979), 60 FDPs were analysed with respect to the total PLA of the abutment teeth (Nyman & Ericsson 1982). The total area of the remaining periodontium around the abutment teeth was expressed as percentage of the PLA of the replaced teeth. In addition, a radiographic assessment of the interproximal alveolar bone height change of abutment teeth was performed. The results showed that only five out of the 60 FDPs (i.e., 8%) fulfilled the requirements for periodontal support outlined in Ante's law. Despite this fact, all the 60 FDPs functioned for 8–11 years without further attachment and alveolar bone loss around the abutment teeth.

Endodontic complications following periodontal and prosthetic treatment of 52 subjects with advanced periodontal disease were assessed retrospectively (Bergenholtz & Nyman 1984). In these subjects, 82 FDPs with/without distal cantilever segments were incorporated. Comparisons were made between 255 vital teeth used as abutments for FDPs and 417 vital non-abutment teeth. The mean observation period of the FDPs was 8.7 years (range: 4–13 years). Pulpal necrosis, including periapical lesions, developed with a statistically significantly higher frequency ($P<0.01$) in abutment teeth (e.g., 15%) compared with non-abutment teeth (e.g., 3%).

The long-term prognosis of 36 cross-arch FDPs, with unilateral or bilateral cantilever segments, was assessed in 34 subjects (Laurell et al. 1991). After completion of periodontal and prosthetic treatment, the subjects were enrolled in a regular supportive care program and followed up on average for 8.4 years (range: 5–12 years). The mean number of abutment teeth amounted to 4.6 (range: 2–7), whereas the corresponding mean number of pontics was 6.2 (range: 4–10). Thus, in each subject there were fewer abutment teeth than pontic units. During the follow-up period, one FDP was lost, yielding a survival rate of 97.2%. In 33 out of 36 FDPs, neither periodontal nor technical complications were recorded.

The periodontal conditions of abutment teeth supporting FDPs were reevaluated retrospectively after a mean follow-up time of 15 years (range: 10–25 years) in subjects with periodontally compromised dentitions (Yi et al. 1995). Out of 50 randomly selected patients, 34 subjects with 43 FDPs on 274 abutment teeth participated in a clinical and radiographic follow-up examination. Changes in the amount of periodontal tissue support were minimal. At the time of FDP incorporation, the remaining mean PLA amounted to 1167 mm^2, corresponding to 42.6% of the maximal PLA of the FDP. The PLA decreased on average by 96 mm^2 over the follow-up period, resulting in a mean annual reduction of 7 mm^2. The design of the incorporated FDPs (i.e., with end abutments or with unilateral or bilateral cantilever units) and the residual amount of supporting periodontal tissue at baseline did not significantly influence the longitudinal changes of periodontal conditions. At the end of the follow-up period, 70% of the FDPs were found to be unchanged. Except for cases in which fracture of the metal framework occurred (i.e., in 14% of FDPs), abutment tooth extractions due to root caries, endodontic complications and root fracture had been performed without altering the original extension of the FDP.

Survival rates of FDPs and abutment teeth

Tables 2 and 3 present the survival rates of FDPs and abutment teeth, respectively. Based on data from two publications (Laurell et al. 1991; Yi et al. 1995), an estimated FDP survival rate of 96.4% (95% CI: 94.6–97.6%) after 5 years and of 92.9% (95% CI: 89.5–95.3%) after 10 years was calculated. At the abutment tooth level, an estimated survival rate of 97.5% after 5 years and of 95% after 10 years was calculated based on data from one publication (Yi et al. 1995).

Biological complications of FDPs and abutment teeth

Summary estimates of biological complications after 5 and 10 years are presented in Table 4a–e. After 10 years, the estimated rate of FDPs without changes in mobility amounted to 93.8% (95% CI: 86.8–97.2%) (Table 4a). The 10-year estimated rate of abutment teeth, free of caries, was 98.1% (95% CI: 88.2–99.7%) (Table 4b). The estimated rate of abutment teeth, free of endodontic complications after 10 years, amounted to 93% (95% CI: 62.6–98.9%) (Table 4c). An estimated 10-year rate of 97.8%, of abutment teeth without changes in clinical attachment level (CAL) was calculated (Table 4d). After 10 years, 95.1% of abutment teeth did not present with changes in PLA (Table 4e).

Technical complications of FDPs and abutment teeth

Summary estimates of technical complications after 5 and 10 years are presented in Table 5a–c.

FDPs without loss of retention were estimated to occur in 95.4% (95% CI:

Table 2. **Survival rates of FDPs**

	Nyman et al. (1975)	Nyman & Lindhe (1979)	Nyman & Ericsson (1982)	Bergenholtz & Nyman (1984)	Laurell et al. (1991)	Yi et al. (1995)
Total number of FDPs	26	332	60	82	36	43
Mean follow-up time (years)	NA	6.2	NA	8.7	8.4	15
Number of FDPs failures	NA	NA	NA	NA	1	6
Total FDPs exposure time	NA	2058	NA	713	300	645
Estimated 5-year FDP survival rate (%)	NA	NA	NA	NA	98.3	95.5
Estimated 10-year FDP survival rate (%)	NA	NA	NA	NA	96.7	91.1
Summary estimates						
5-year: 96.4% (95% CI: 94.6–97.6%)						
10-year: 92.9% (95% CI: 89.5–95.3%)						

FDP, fixed dental prosthesis; 95% CI, 95% confidence interval; NA, not available.

Table 3. **Survival rates of abutment teeth**

	Nyman et al. (1975)	Nyman & Lindhe (1979)	Nyman & Ericsson (1982)	Bergenholtz & Nyman (1984)	Laurell et al. (1991)	Yi et al. (1995)
Total number of abutment teeth	123	NA	NA	255	NA	274
Mean follow-up time (years)	NA	6.2	NA	8.7	8.4	15
Number of abutment tooth failures	NA	NA	NA	NA	NA	21
Total abutment tooth exposure time	NA	NA	NA	2219	300	4110
Estimated 5-year abutment tooth survival rate (%)	NA	NA	NA	NA	NA	97.5
Estimated 10-year abutment tooth survival rate (%)	NA	NA	NA	NA	NA	95

NA, not available.

92.6–97.2%) of cases after 10 years (Table 5a). An estimated 10-year rate of 96.3% (95% CI: 96–96.5%), of FDPs without abutment tooth fracture, was calculated (Table 5b). After 10 years, 95.8% (95% CI: 91.4–97.9%) of FDPs were estimated to be without fracture of the metal framework (Table 5c).

Discussion

The present systematic review assessed survival rates and incidences of biological and technical complications of FDPs on abutment teeth with severely reduced, but healthy periodontal tissue support. Despite advanced loss of periodontal tissue support and increased abutment tooth mobility, teeth could be used successfully as abutments for extensive FDPs with or without the incorporation of cantilever units.

The estimated 10-year survival rate of 92.9% of FDPs included in the present systematic review compared favourably with those of FDPs incorporated in subjects without severely periodontally compromised dentitions (Pjetursson et al. 2004; Tan et al. 2004). The latter publications reported an estimated 10-year survival rate of 89.1% for conventional (Tan et al. 2004) and of 81.8% for cantilever (Pjetursson et al. 2004) FDPs, respectively.

Although the purpose of this systematic review was not to include a detailed presentation of surgical and technical aspects necessary to achieve optimal long-term treatment outcomes in subjects in need of a fixed prosthetic rehabilitation, some aspects warrant further discussion.

In all of the publications included in this systematic review, periodontal and prosthetic treatment was provided in specialist clinics of Swedish universities. This may partly explain the favourable long-term outcomes of FDPs compared with those obtained by general practitioners. An overall failure rate of 26% over 14 years was reported for FDPs incorporated by general practitioners (Karlsson 1989). This failure rate increased from 12% for FDPs with end abutments to 36% for those with cantilever units (Karlsson 1989). On the other hand, in subjects treated in specialist clinics (Laurell et al. 1991; Yi et al. 1995), an estimated 10-year FDP survival rate of 92.9% was calculated. It has to be kept in mind, however, that generalization of these outcomes is limited, as all treatments were provided in two Swedish specialist centres (i.e., Gothenburg and Jönköping).

Treatment of advanced periodontal disease was carried out in phases including non-surgical and surgical therapy, followed by a careful evaluation of the periodontal tissues after healing (Lindhe & Nyman 1975). Such a comprehensive treatment was provided to highly motivated patients, willing and capable of maintaining a high standard of plaque control. In this respect, the detrimental effects of periodontal surgery, in subjects without renewed oral hygiene instruction and not enrolled in a maintenance care programme have been demonstrated (Nyman et al. 1977). Moreover, it has been well established that self-performed plaque control, combined with regular attendance of maintenance care following active periodontal treatment, represented an effective means of controlling gingivitis and periodontitis and limiting tooth mortality over a 30-year period (Axelsson et al. 2004).

From a prosthetic point of view, particular attention was paid to keep the crown margins in a supragingival location, and the width of the interproximal areas was

Table 4. **Biological complications: (a) FDP mobility, (b) abutment teeth with caries, (c) abutment teeth with endodontic complications, (d) abutment teeth with change in clinical attachment level (CAL), (e) abutment teeth with change in periodontal ligament area (PLA)**

	Nyman et al. (1975)	Nyman & Lindhe (1979)	Nyman & Ericsson (1982)	Bergenholtz & Nyman (1984)	Laurell et al. (1991)	Yi et al. (1995)
(a)						
Number of FDPs	26	332	60	82	36	43
Mean follow-up time (years)	NA	6.2	NA	8.7	8.4	15
Total FDP exposure time	NA	2058	NA	713	300	645
Number of FDPs with mobility	0	NA	NA	NA	1	5
Estimated 5-year rate of absence of change in FDP mobility (%)	NA	NA	NA	NA	96.2	98.3
Estimated 10-year rate of absence of change in FDP mobility (%)	NA	NA	NA	NA	92.5	96.7
Summary estimates 5-year: 96.9% (95%CI: 93.2–98.6%) 10-year: 93.8% (95% CI: 86.8–97.2%)						
(b)						
Number of abutment teeth	123	NA	NA	255	NA	274
Mean follow-up time (years)	NA	6.2	NA	8.7	8.4	15
Total abutment tooth exposure time	NA	2058	NA	2219	NA	4110
Number of abutment teeth with caries	NA	NA	NA	10	NA	2
Estimated 5-year rate of caries-free abutment teeth (%)	NA	NA	NA	97.8	NA	99.8
Estimated 10-year rate of caries–free abutment teeth (%)	NA	NA	NA	95.6	NA	99.5
Summary estimates 5-year: 99.1% (95% CI: 93.1–99.9%) 10-year: 98.1% (95% CI: 88.2–99.7%)						
(c)						
Number of abutment teeth	123	NA	NA	255	NA	274
Mean follow-up time (years)	NA	6.2	NA	8.7	8.4	15
Total abutment tooth exposure time	NA	2058	NA	2219	NA	4110
Number of abutment teeth with endodontic complications	NA	NA	NA	38	NA	8
Estimated 5-year rate of absence of endodontic complications (%)	NA	NA	NA	91.8	NA	99
Estimated 10-year rate of absence of endodontic complications (%)	NA	NA	NA	84.3	NA	98.1
Summary estimates 5-year: 96.4% (95% CI: 79.1–99.4%) 10-year: 93% (95% CI: 62.6–98.9%)						
(d)						
Number of abutment teeth	123	NA	NA	255	NA	274
Mean follow-up time (years)	NA	6.2	NA	8.7	8.4	15
Total abutment tooth exposure time	NA	2058	NA	2219	NA	4110
Number of abutment teeth with CAL change	NA	NA	NA	5	NA	NA
Estimated 5-year rate of absence of CAL change (%)	NA	NA	NA	98.9	NA	NA
Estimated 10-year rate of absence of CAL change (%)	NA	NA	NA	97.8	NA	NA
(e)						
Number of abutment teeth	123	NA	NA	255	NA	274
Mean follow-up time (years)	NA	6.2	NA	8.7	8.4	15
Total abutment tooth exposure time	NA	2058	NA	2219	NA	4110
Number of abutment teeth with change in PLA	NA	NA	NA	NA	0	22
Estimated 5-year rate of absence of change in PLA (%)	NA	NA	NA	NA	NA	97.5
Estimated 10-year rate of absence of change in PLA (%)	NA	NA	NA	NA	NA	95.1

FDP, fixed dental prosthesis; 95% CI, 95% confidence interval; NA, not available.

contoured to allow optimal interdental cleansing. With respect to long-term maintenance of periodontal health, studies have shown that a supragingival location of the crown margin is more favourable compared with a subgingival location (Reichen-Graden & Lang 1989; Valderhaug et al. 1993).

The respect of fundamental principles regarding the design and construction of such extensive FDPs was of utmost importance for their long-term success. In all the

Table 5. **Technical complications: (a) FDPs with loss of retention, (b) FDPs with abutment tooth fracture, (c) FDPs with fracture of metal framework**

	Nyman et al. (1975)	Nyman & Lindhe (1979)	Nyman & Ericsson (1982)	Bergenholtz & Nyman (1984)	Laurell et al. (1991)	Yi et al. (1995)
(a)						
Number of FDPs	26	332	60	82	36	43
Mean follow-up time (years)	NA	6.2	NA	8.7	8.4	15
Total FDPs exposure time	NA	2058	NA	713	300	645
Number of FDPs with loss of retention	NA	11	NA	NA	0	NA
Estimated 5-year rate of absence of loss of retention (%)	NA	97.4	NA	NA	100	NA
Estimated 10-year rate of absence of loss of retention (%)	NA	94.8	NA	NA	100	NA
Summary estimates						
5-year: 97.8% (95% CI: 96.2–98.6%)						
10-year: 95.4% (95% CI: 92.6–97.2%)						
(b)						
Number of FDPs	26	332	60	82	36	43
Mean follow-up time (years)	NA	6.2.	NA	8.7	8.4	15
Total FDPs exposure time	NA	2058	NA	713	300	645
Number of FDPs with abutment tooth fracture	NA	8	NA	NA	1	NA
Estimated 5-year rate of absence of abutment tooth fracture (%)	NA	98.1	NA	NA	98.3	NA
Estimated 10-year rate of absence of abutment tooth fracture (%)	NA	96.2	NA	NA	96.7	NA
Summary estimates						
5-year: 98.1% (95% CI: 98–98.2%)						
10-year: 96.3% (96–96.5%)						
(c)						
Number of FDPs	26	332	60	82	36	43
Mean follow-up time (years)	NA	6.2	NA	8.7	8.4	15
Total FDPs exposure time	NA	2058	NA	713	300	645
Number of FDPs with fracture of metal framework	NA	7	NA	NA	0	6
Estimated 5-year rate of absence of metal framework fracture (%)	NA	98.3	NA	NA	100	95.5
Estimated 10-year rate of absence of metal framework fracture (%)	NA	96.7	NA	NA	100	91.1
Summary estimates						
5-year: 97.9% (95% CI: 95.6–99%)						
10-year: 95.8% (95% CI: 91.4–97.9%)						

FDP, fixed dental prosthesis; 95% CI, 95% confidence interval; NA, not available.

publications included, particular care was taken to select an adequate number and distribution of abutment teeth in relation to FDP extension. Whenever possible, end abutment teeth were incorporated. This implied that at least four abutments had to be available to support a cross-arch FDP, with two of the abutments being located in the premolar or molar area. Nevertheless, a mean of 63.6% of FDPs included in the present systematic review displayed unilateral or bilateral cantilever units. Publications with only two abutment teeth supporting cross-arch FDPs with extensive bilateral cantilever segments were, however, excluded on purpose, as such types of reconstructions may be considered of exceptional character in the prosthodontic literaure (Öwall et al. 1991; Carlson et al. 1993; Carlson & Yontchev 1996). Hemisections or root amputations of furcation-involved molars were included in the periodontal treatment phase in order to eliminate plaque-retentive areas and facilitate self-performed plaque control. A high survival rate (i.e., 93%) of root-resected, furcation-involved molars used as abutment teeth for single-unit crowns and FDPs has been reported after a follow-up period of 10 years (Carnevale et al. 1998).

In such periodontally compromised dentitions, long clinical crowns and large interocclusal spaces were available upon completion of wound healing after periodontal treatment. This facilitated ideal abutment preparation yielding optimal retention (i.e., long and parallel abutment surfaces) as well as proper dimensions of the metal framework and the veneering materials. The latter aspect was of particular importance, mesially and distally, to abutment crowns adjacent to cantilever units.

The maintenance of FDP stability over time was achieved by precluding undue strain concentrations in the supporting apparatus. In essence, progressive (i.e., increasing) mobility of the FDPs was successfully avoided through a rigid splint of the abutment teeth and a correct occlusal design including the incorporation of cantilever units. In these advanced reconstructive cases,

avoidance of increasing FDP and abutment mobility was achieved through careful control of occlusal force distribution and direction (Nyman et al. 1975; Nyman & Lindhe 1976b, 1977; Lundgren & Laurell 1994). In this context, it should be pointed out that abutment teeth with severely reduced, but healthy periodontal tissue support still possess periodontal mechanoreceptors in the apical third of the root contributing to tactile sensitivity (Jacobs & van Steenberghe 1994).

Endodontic complications developed more frequently in teeth used as abutments for FDPs compared with non-abutment teeth (e.g., 15% vs. 3%, $P<0.01$) (Bergenholtz & Nyman 1984). Considering the fact that abutment and non-abutment teeth displayed a comparable degree of periodontal tissue destruction and underwent similar periodontal treatment, the higher proportion of endodontic complications diagnosed in abutment teeth was strongly associated with trauma caused by crown preparation. Estimates of the proportions of crowned teeth with a vital pulp that remained free from signs and symptoms of pulpal deterioration were 98%, 92%, 87% and 83% after 5, 10, 20 and 25 years, respectively (Valderhaug et al. 1997).

In conclusion, within the limitations of this systematic review, (i) proper control of periodontal disease, (ii) strict adherence to a maintenance care programme and (iii) rigid splinting of mobile abutment teeth yielded an estimated 10-year survival rate of 92.9% of FDPs incorporated in subjects with treated generalized severe periodontitis, and hence substantially reduced periodontal tissue support.

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