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REVIEW

Endodontics or implants? A review of decisive criteria and guidelines for single tooth restorations and full arch reconstructions

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Abstract

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This review describes practical criteria and a systematic process to aid the treatment planning decision of whether to preserve teeth by root canal treatment (RCT) or extract and provide an implant. Recommendations presented are based on best available evidence from the literature and the expert views of specialists in endodontics and restorative dentistry, including dental implantology. A MEDLINE search was conducted using the terms 'root canal therapy', 'dental implants', 'decision making', 'treatment planning', 'outcome' and 'human', and supplemented by hand-searching. When evaluating the outcome of root canal treatment, an observation period of 4–5 years is required for complete healing of periapical lesions. Dental implants, however, present a *de novo* situation and a functional period of at least 5 years is often required before peri-implant diseases are established and detected. Good long-term success rates and greater flexibility in clinical management indicate that RCT or retreatment should be performed first in most instances unless the tooth is judged to be unrestorable. When deciding if a compromised tooth of questionable prognosis should be maintained or replaced by an implant, both local, site-specific and more general patient-related factors should be considered. Following systematic evaluation and consideration of the best treatment option in a particular case, a treatment recommendation may then be given in favour or against tooth retention. Whilst single risks are possibly accepted for single tooth restorations, teeth with questionable prognosis and multiple pre-treatment requirements are better not included as abutments in fixed dental prostheses to reduce the risk to survival of the entire restoration.

Keywords: decision making, dental implants, endodontics, long-term results, review, tooth prognosis.

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Introduction

Clinicians frequently face the dilemma of whether to endodontically treat and retain a questionable tooth or to extract and potentially replace it with a dental implant. Dentists appear to make the decision for extracting a tooth on the basis of multiple risk factors including endodontic and periodontal criteria, remaining tooth structure, restorability with core build-ups and post and core, extent of previous restorations as well as the perceived strategic value of a tooth within the dentition. Whilst single identifiable risks may be easy to manage clinically, the presence of multiple risks appears to jeopardize the survival of a compromised tooth (Pothukuchi 2006, Wolcott & Meyers 2006). Evidence-based data from the literature should be the

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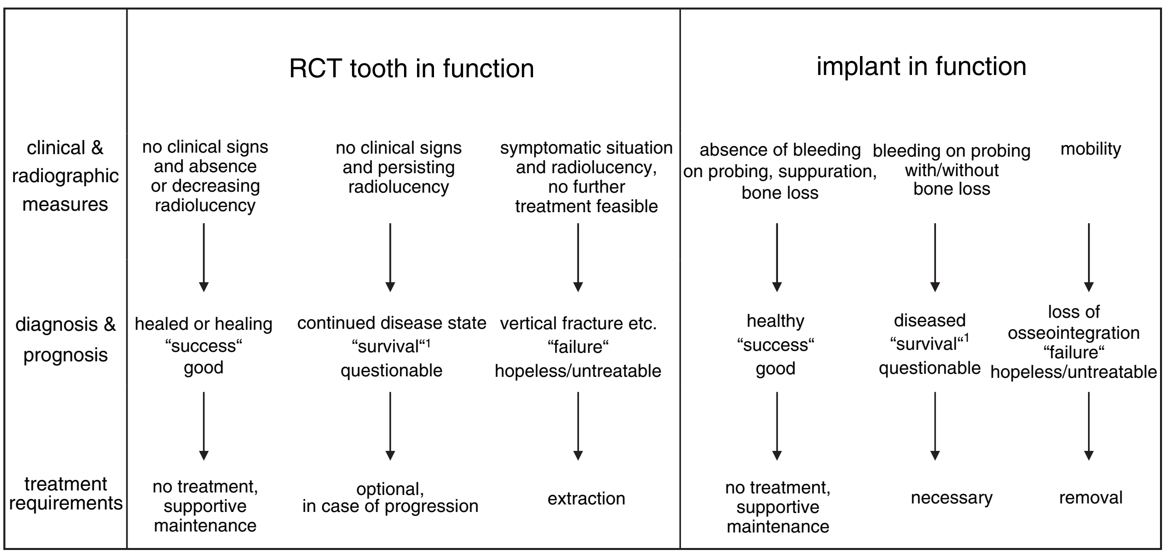
foundation for the individual risk assessment and determination of the long-term prognosis of the respective tooth requiring root canal treatment (RCT) or extraction and replacement with an implant. The literature, however, contains inconsistencies in terms of the definitions of success and survival of endodontically treated teeth and implants (Iqbal & Kim 2007). Equally, the reported success rates do not necessarily equate to the probability of a favoured outcome (prognosis) when applied to a particular case or clinical scenario (John *et al.* 2007). In a systematic review, Iqbal & Kim (2007) observed that much more stringent outcome criteria were normally applied to the assessment of 'successful' RCT, including the absence of a periapical radiolucency. On the other hand, the use of less stringent criteria in implant studies (generally simple survival) may translate inherently to higher success rates. This is even more obvious when early implant losses that occur during the initial healing period are not accounted for. According to a recent review, the survival of sound and even compromised and treated teeth surpassed that of oral implants, provided that implant loss before loading was added to that during function over 10 years (Holm-Pedersen *et al.* 2007). Further misunderstanding is provoked because, in some studies, survival or retention rates include both successful teeth/implants and those classified as surviving (instead of reporting successful, surviving and failed teeth/implants separately, Fig. 1). In implant studies, the reader must also be aware of the differences in outcome data either based on implant level or on the restoration level, which involves both implants and superstructures (Pjetursson *et al.* 2004a).

In response to the differences in success criteria for RCT and implants, Iqbal & Kim (2007) restricted their outcome measure to 'survival', which was defined as the clinically observed presence of the root canal treated tooth or implant in the mouth. The authors included 13 studies involving RCT and 55 with implants in their meta-analysis, with only one study (Doyle *et al.* 2006), involving a comparison of both. With proportion estimates for survival of 94% for RCT and 96% for implant-supported single crowns (ISC) at 5 years, and 97% (RCT) and 94% (ISC) at 6 years and overlapping confidence intervals at any time-point, the review did not reveal any differences between the two treatment modalities. Comparing initial nonsurgical RCT and single tooth implants (STI) in a retrospective cross-sectional analysis, similar failure rates (6%) were reported for both treatments, but significantly more implants required some type of post-treatment intervention and were classified as 'surviving' instead of 'successful' (Doyle *et al.* 2006). Hence, clinical complications were observed in 18% of the restored implant cases and 4% amongst the RCT teeth. In RCT teeth, these complications were mainly related to endodontic retreatment, or persistent apical periodontitis (AP) as assessed from radiographs, whilst in implants, several



[1] In some studies survival data are presented as sum of surviving and successful RCT teeth/ implants

Figure 1 Success criteria for root canal treated (RCT) teeth and implants.

technical problems occurred or surgical interventions were required to treat peri-implantitis (Doyle *et al.* 2006).

In numerous publications discussion occurred on whether tooth preservation by nonsurgical and surgical endodontic means, or extraction and replacement with an implant is more valuable in the long-term, i.e., whether 'the implant is better than a tooth' or 'the implant is a more reliable abutment' (Lewis 1996, Bader 2002, Cohn 2005, Felton 2005, Ruskin *et al.* 2005, Trope 2005, Dawson & Cardaci 2006, Spangberg 2006, Thomas & Beagle 2006, Torabinejad & Goodacre 2006, White *et al.* 2006, Mordohai *et al.* 2007, Iqbal & Kim 2008, Kao 2008). These publications focus mainly on single anterior or posterior teeth with compromised prognosis and their possible replacement by an implant. In most clinical situations, however, the conditions of the adjacent teeth and the entire dentition must be considered when deciding upon adequate treatment.

Due to the similar outcomes of implant treatment and RCT, the decision to treat a tooth endodontically or replace it with an implant, must be based on factors other than anticipated treatment outcome alone. It was the aim of this review to describe the decisive criteria and a systematic procedure for deciding upon endodontic treatment or the implant alternative, based on best evidence from the literature. Regarding those treatment considerations which lack distinct evidence-based guidelines, a consensus was accomplished amongst the authors specialized in endodontics and restorative dentistry, including dental implantology.

Search strategy and inclusion of publications in the review

A MEDLINE search (PubMed) up to July 2008 (database 1966–2008 July, week 4) was conducted using different keyword combinations including the terms 'root canal therapy', 'dental implants', 'decision making', 'treatment planning', 'outcome' and 'human' (Table 1). In addition, bibliographies of all relevant papers and previous review articles were hand-searched. Any relevant work published in the English language and presenting pertinent information related to single-tooth and full arch reconstructions was considered for inclusion in the review. Titles were excluded, if no abstract was available, single case reports or conference reports were presented, or the topic was not related to the subject of the current review.

Table 1 Search strategy and two-step selection procedure

Keyword combination in Medline	**Number of retrieved articles**
Root canal therapy AND dental implants AND human	153
Decision making AND root canal therapy AND outcome	20 (plus 13 already listed)
Decision making AND dental implants AND outcome	22 (plus 13 already listed)
Treatment planning AND dental implants AND root canal therapy	10 (plus 17 already listed)
Total	205
Manual search	30
1st step: screening of 235 titles and abstracts, reasons for elimination:	Number of eliminated articles
Non-english publication	13
No abstract available	17
Single case report or conference report	6
Not related to the current subject	97
2nd step full text analysis of 102 articles (72 from PubMed, 30 from hand-searching), reasons for elimination:	Number of eliminated articles
Not related to the current subject	51
Identical issue discussed by the same author in another journal (more pertinent publication was selected)	2
Included articles (49):	
From PubMed	34
From manual search	15

The combinations of search terms resulted in a list of 205 publications from PubMed, and an additional 30 papers were retrieved by hand-searching. In the first step, titles and abstracts were screened. In the second step, full text analysis was performed from 102 possibly relevant publications, out of which 49 were included (Table 1). Publications from the same author discussing identical issues were identified and the more relevant publication was selected for this review.

Longevity of root canal treated teeth and implants

When comparing outcome data for root canal treated teeth and dental implants, clinicians must be aware that several differences exist, associated with the origin of the tooth and the implant, the definition and interpretation of success and survival, the study design and samples, operators conducting the treatment, and changes in treatment modalities overtime (Fig. 1). Several preoperative, intraoperative and postoperative

Table 2 Factors influencing endodontic and implant treatment outcome

	Initial RCT	Endodontic retreatment	Apical surgery	Implant treatment
Preoperative	+ Vital pulp tissue – Periapical lesion	+ Root canal filling >2 mm short of the apex + No periapical lesion – Large periapical lesion – Altered root-canal morphology or perforation – Adequate existing root canal filling	+ Orthograde retreatment feasible + Significant overfill or root canal filling >2 mm short of the apex – Lesion ≥5 mm – Persisting lesion despite satisfactory root canal filling – Combined endo-perio lesion – Previous surgical treatment	– Insufficient bone volume – Specific anatomic findings – History of periodontitis – Previous implant failure – Insufficient oral hygiene and smoking (see also Table 3)
Intraoperative	+ Root canal filling with no voids extending to 2 mm within apex (radiographically) + Sufficient coronal restoration – Missed canals and inadequate cleaning – Errors such as ledging, instrument fracture, root perforations – Inadequate obturation – Root canal filling >2 mm short of the apex or overfill	+ Addressing previous technical shortcomings + Adequate root canal filling feasible	+ Root-end filling – Poor accessibility	+/– Type of implant and surface +/– Type of bone – Fenestration, bone defects – Specific anatomic findings – Bone augmentation – Immediate implant placement
Postoperative	– Restoration failure (coronal leakage)	– Restoration failure (coronal leakage, no cuspal coverage)	+/– No obvious influence by antibiotics	– Wound healing problems – Iatrogenic factors (e.g., excess cement) – Insufficient oral hygiene and smoking – Peri-implantitis

+ positively influencing factors; – negatively influencing factors.

factors influence the prognosis of root canal treatment, and have also been identified for the implant treatment outcome (Table 2).

Success and survival of RCT teeth

A tooth considered for primary RCT or endodontic retreatment may has been in function for many years or even decades. Reasons for treatment may include irreversible pulpitis due to microbial infection originating from a carious lesion, trauma or periodontal involvement, or AP in teeth with nonvital pulp. The starting point for any longevity assessment is thus a disease state, involving the pulp tissues and/or the periapical bone and the primary goal is the eradication of infection. Although clinical symptoms regularly diminish within several hours or days of initiating root canal treatment, complete healing of the periapical bony lesion may require several months or even years (Friedman 2002). The absence of clinical symptoms and a radiograph with an intact periodontal ligament space in the apical region are indications of healing, whilst the persistence of AP is a sign of a continued disease state. If the radiolucency decreases overtime (within 4–5 years), the pathosis is also considered to be 'healing'. This healing pattern, particularly in teeth with AP at the time of initial treatment, indicates that success rates of RCT (in terms of periapical health) start at 0% and increase overtime. Fristad *et al.* (2004) found a 95.5% radiographic success rate with retreated teeth recalled 20–27 years postoperatively, whilst the same sample had a 85.7% success 10 years previously. The teeth deemed to be failures radiographically at 10–17 years were still functioning after another 10 years and healing was observed after the extended observation time. This study not only shows the potential for late healing, but also the inadequacy of a 'radiographic only' assessment (Fristad *et al.* 2004, Wolcott & Meyers 2006). Applying only clinical measures (no signs and symptoms), however, led to an overestimation of favourable outcomes, whilst the radiographic measure (with/without periapical radiolucency) was found to be a better predictor for the outcome of RCT (Farzaneh *et al.* 2004b). The use of cone beam computed tomography with three-dimensional images, has the potential to add further information about the periapical status of endodontically treated teeth (Walter *et al.* 2009). The awareness that pulpal and periradicular disease may be managed, but not always entirely eliminated led to an important change in evaluating outcomes (Fig. 1). Hence, RCT outcome is better evaluated in terms of 'healed or healing/success', 'diseased/survival' and 'failure' rather than just 'success' and 'failure' (Friedman 2002, Farzaneh *et al.* 2004b).

According to a recent meta-analysis, the pooled outcome of primary RCT was 75% when strict success criteria (absence of periapical radiolucency) were applied, and reached 85% based on loose criteria (reduction in size of radiolucency) (Ng *et al.* 2007). Preoperative absence of a periapical radiolucency, root filling with no voids, root filling extending to 2 mm within the radiographic apex and satisfactory coronal restoration were found to improve the outcome of primary RCT significantly (Table 2) (Ng *et al.* 2007, 2008b). In teeth without a periapical radiolucency, initial RCT secured a success rate of 96% after 8–10 years, whilst healing was reduced to 86% in cases with pulp necrosis and periapical radiolucency (Sjögren *et al.* 1990). Highest success rates exceeding 90% (with periapical health as outcome measure) have been achieved following RCT in teeth with vital pulps (Friedman 2002, Hørsted-Bindslev & Løvschall 2002, Gesi & Bergenholtz 2003).

Reasons for persistent or emerging disease associated with root filled teeth are either endodontic in nature, or, more frequently, related to nonendodontic factors:

(1) Endodontic causes include residual intracanal infection in nonaccessible regions of the canal system or periapical infections due to persisting microbiota, vertical root fractures, presence of true cysts, or foreign body reactions, e.g., to overfilled root canals (Sjögren *et al.* 1990, Kojima *et al.* 2004, Stoll *et al.* 2005).

(2) Nonendodontic reasons for RCT failure are related to pre-existing factors such as severe periodontal disease, or to post-endodontic factors such as recurrent caries, improper reconstructions with coronal leakage and subsequent reinfection or fracture (Ray & Trope 1995, Aquilino & Caplan 2002, Iqbal *et al.* 2003). RCT teeth not restored with crowns were extracted at a rate 6.0 times greater than teeth crowned after root filling (Aquilino & Caplan 2002).

In a study evaluating the reasons for failure of RCT teeth, prosthetic reasons (crown fracture, root fracture at the level of a post, traumatic fracture) dominated and explained almost 60% of the failures; 32% failed due to periodontal reasons, whilst pure endodontic failures (vertical root fracture, instrumentation failure, root resorption) were rare and accounted for less than 10% (Vire 1991). Whilst prosthetic and periodontal failures occurred following 5–5.5 years on average, endodontic failures were recognized within a 2-year period after RCT had been completed (Vire 1991). Similarly, Chen *et al.* (2008) reported from an epidemiologic study that extensively decayed or unrestorable teeth were the main reason for tooth extractions (40%). Other causes were tooth fracture (28%), and periodontal disease (23%), whilst endodontic reasons were rare at 9% (Chen *et al.* 2008).

Clinical studies investigating the long-term survival of fixed dental prostheses (FDP) showed that as soon as 1 or more RCT abutments were involved, the survival rate of all restoration at 20 years was reduced to 57% compared with 69% when the FDP comprised abutments with healthy pulps only (De Backer *et al.* 2006, 2008). According to a multivariate analysis of abutment failures (365 teeth with vital pulps, 122 root filled teeth), additional influencing factors other than RCT were distal terminal position in the FDP, and advanced marginal bone loss as initially assessed from radiographs. Several variables were stronger multivariately than bivariately and this indicated that a combination of risk factors is the most detrimental for the longevity of the restorations (Palmqvist & Söderfeldt 1994).

In epidemiological studies investigating the retention of RCT teeth based on data from insurance companies, so called 'untoward events' yielding further insurance claims such as extraction, retreatment, or apical surgery were evaluated (Lazarski *et al.* 2001, Salehrabi & Rotstein 2004, Chen *et al.* 2008). Eight years after initial nonsurgical root canal treatment, 96% of all teeth (almost 1.5 million) were retained without any untoward event; 0.4% required nonsurgical retreatment, in 0.6% apical surgery was performed, and 2.9% were extracted. Extractions occurred mainly within 3 years from completion of the RCT, and affected primarily those teeth without full coronal coverage (Salehrabi & Rotstein 2004). Chen *et al.* (2007, 2008) also reported a high 5-year tooth retention rate of 93% following nonsurgical RCT in more than 1.5 million teeth. In all, almost 10% were affected by untoward events (6.9% of the teeth were extracted, 2.3% required nonsurgical retreatment, and in 0.5% apical surgery was performed) (Chen *et al.* 2007, 2008).

Success and survival of dental implants

A functioning dental implant represents a *de novo* situation, in which neither caries nor endodontic problems exist. In contrast to root canal treatment, implants are placed into relatively healthy surroundings. Complications and failures, however, occur either prior to implant osseointegration (early implant loss) or after initially successful osseointegration (late implant loss) and disease manifestation may necessitate several years or even decades of function (Quirynen *et al.* 2007). Osseointegration is considered to be a phenomenon of direct apposition of bone substance on the implant surface followed by structural adaptation in response to mechanical load (Schenk & Buser 1998). Whilst initial implant fixation following placement is simply derived from mechanical stabilization, osseointegration with an intimate contact between living bone and the titanium surface requires several weeks (Berglundh *et al.* 2003, Abrahamsson *et al.* 2004). Early implant failures occur mainly during the first weeks or months after implant placement and are frequently related to surgical trauma, complicated wound healing, insufficient primary stability and/or initial overload (Listgarten 1997, Esposito *et al.* 1998). Late implant losses are caused by microbial infection, overload or toxic reactions from implant surface contamination (e.g., acid remnants). Whilst overload leads to a sudden loss of osseointegration with implant mobility, microbial infection initiates peri-implant mucositis that corresponds to gingivitis and may progress into peri-implantitis that corresponds to periodontitis. According to the consensus report from the 1st European Workshop on Periodontology (EWOP, Albrektsson & Isidor 1994), peri-implant mucositis was defined as a reversible inflammatory reaction in the soft tissues surrounding an implant, and peri-implantitis was described as inflammatory reactions associated with loss of supporting bone around an implant in function. Hence, peri-implantitis is clinically diagnosed by bleeding on probing (and/or suppuration) in combination with radiographic bone loss (Heitz-Mayfield 2008). During the first year following implant placement, bone remodelling may cause bone resorption in the marginal area (average 1.3–1.5 mm around implants placed at the bone level). Any further bone loss, particularly reaching ≥2.5 mm, is considered as disease manifestation (Berglundh *et al.* 2002), and affects at least 28% of subjects (Zitzmann & Berglundh 2008a, Zitzmann *et al.* 2008b). Despite disease progression, the implant remains nonmobile until the apical portion of implant osseointegration is affected (Listgarten 1997). In the implant literature, the majority of studies report implant survival rates defined as simple retention (Berglundh *et al.* 2002, Zitzmann & Berglundh 2008a, Zitzmann *et al.* 2008b). If success criteria are applied, the absence of clinical symptoms, no signs of inflammation and a limited marginal bone loss (e.g., not exceeding 0.2 mm after the first year in function) (Smith & Zarb 1989) are frequently mentioned. In several studies, however, disease symptoms are not consistently investigated, i.e., probing is not applied, and bone level assessments are made from panoramic radiographs with limited accuracy (Zitzmann & Berglundh 2008a, Zitzmann *et al.* 2008b).

Implant success can be further compromised by several biological and technical complications, which occur in association with dental implants and implant restorations. Whilst biological complications comprise any type of peri-implant diseases, a large variety of technical complications exist related to mechanical damage of the implant, implant components and/or the superstructure (e.g., implant fracture, abutment or occlusal screw loosening or fracture, fracture of veneering or framework, loss of retention in cemented restorations). According to a review analyzing long-term results of fixed implant restorations, 39% of all patients were affected by complications or failures during a 5-year observation period (Pjetursson *et al.* 2004a). The 10-year survival rates reached 93% (implant-FDP) and 94% (single tooth implants, STI) on an implant level, whilst survival of the implant restorations varied between 87% (implant-FDP) and 90% for the ISC (Pjetursson *et al.* 2004a). It should be noted that implant reconstructions exposed to biological or technical complications were at greater risk of recurrent problems or failures (Brägger *et al.* 2005). Similarly, patients who had experienced an implant failure, had a 30% increased risk of further failures (Weyant & Burt 1993).

Risk factors for developing peri-implant diseases are patient-related (e.g., susceptibility to periodontitis, diabetes), environmental (e.g., cigarette smoking, alcohol consumption), technological (e.g., exposed rough implant surface), or local. These local factors comprise poor personal plaque control, or iatrogenic factors such as insufficient access for oral hygiene due to implant position and/or restoration contour, or excess cement (Table 2). Limited evidence is available for an association between peri-implant disease and rough implant surfaces or genetic traits (Quirynen *et al.* 2007, Heitz-Mayfield 2008). Late implant failures due to occlusal overload occur when the load bearing threshold set by the biological phenomenon of osseointegration has been exceeded. Very little is known about this individual threshold and possible influencing factors such as bone quality, implant surface modifications and the type and direction of forces. Whilst clenching exerts mainly vertical forces, bruxism creates excessive lateral forces, which are suggested to be less well tolerated (Meffert 1997).

History and recent changes in endodontic and implant therapies

For both RCT and dental implants, efficacy i.e., the successful maintenance under optimal conditions has been proven mainly in controlled longitudinal studies in university settings. Both treatment options have also been evaluated for effectiveness, i.e., the effect has been verified under ordinary conditions as shown in retrospective studies and community-based trials. RCT has always been a part of general dental practice and specialist recognition was granted in some parts of the world in the 1960s or later. However, in the 1970s and 1980s, dental implants, were mainly placed at a specialist level, whilst today it is a common treatment modality amongst general dentists. Although some evidence suggests that general practitioners achieve implant survival rates similar to those of specialists (Andersson *et al.* 1998), it is assumed that results differ particularly for demanding procedures requiring additional bone augmentation and aesthetic management in the anterior region.

In the literature, data about implant survival and success are still dominated by studies from university clinics and/or specialists documenting its efficacy, whilst several studies investigating RCT include work from undergraduates and general practice (Lazarski *et al.* 2001, Salehrabi & Rotstein 2004, Iqbal & Kim 2007, 2008). Hence, comparing data from RCT teeth and implant studies in meta-analyses mixes efficacy and effectivenss.

Root canal treatment changes

During the last decade, RCT has benefited from improvements in techniques and equipment such as nickel–titanium rotary instruments, electronic apex locators and microscopic magnification for nonsurgical and surgical therapies (Manning 2000, John *et al.* 2007). Improvements in long-term success of surgical or nonsurgical RCT applying new technical developments have, however, not yet been proven on the basis of outcome of treatment provided by general dental practitioners (effectiveness) (Ng *et al.* 2007).

Changes in implant therapy

When implant treatment was introduced in the 1970s, several restrictions were defined in order to minimize the risk of implant failure or complications. Hence, implant therapy was not recommended in patients with xerostomia, osteoporosis, aggressive forms of periodontitis and heavy smokers (Brånemark 1985). Today, it is evident that the peri-implant tissues are not affected by hyposalivation and/or the symptoms of xerostomia. Further, a reduced bone mineral density in osteoporotic patients entails a reduced bone-to-implant contact, but does not appear to inhibit osseointegration (Table 3). Implant indications have been extended to patients with a history of periodontitis and also to smokers accepting an increased risk for complications and failures (See 'General endodontic and implant contraindications'). In an initial attempt at cautious restraint, any type of potential risk for implant failures was excluded, whilst current implant treatment modalities consciously include further risk factors such as immediate implant loading, even combined with immediate implant placement (Aparicio *et al.* 2003, Schropp & Isidor 2008).

General endodontic and implant contraindications

In patients with high caries activity, possibly related to dry mouth as a common side effect of several medications (e.g., antihypertensives, diuretics, antidepressants, atropine, anticonvulsants, spasmolysants and appetite suppressants) or associated with syndromes

Table 3 Contraindications and increased risk for implant failures

	Disease	Assessment
Medical contraindications	Acute infectious diseases	Absolute, but temporarily; wait for recovery
	Cancer chemotherapy	Absolute, but temporarily; reduced immune status
	Systemic bisphosphonate medication (≥2 year)	Risk of bisphosphonate-induced osteonecrosis (BON)
	Renal osteodystrophia	Increased risk for infection, reduced bone density
	Severe psychosis	Absolute; risk of regarding the implant as foreign body and requesting removal despite of successful osseointegration
	Depression	Relative
	Pregnancy	Absolute, but temporarily; to avoid additional stress and radiation exposure
	Unfinished cranial growth with incomplete tooth eruption	Relative, but temporarily; to avoid any harm to the growth plates, to avoid inadequate implant position in relation to the residual dentition; utilize hand-wrist radiograph to evaluate end of skeletal growth; single tooth implants in the anterior region not before 25th year of age
Intraoral contraindications	Pathologic findings at the oral soft- and/or hard tissues	Temporarily; increased risk for infection, wait until healing is completed
Increased risk for implant failure or complications	History of (aggressive) periodontitis	Relative, requires supportive periodontal care; increased risk to develop peri-implantitis
	Heavy smoking ≥10 pack-years (particularly in combination with HRT/oestrogen), alcohol and drug abuse	Relative or absolute, indicates cessation protocol; wound healing problems, locally reduced vascularization, impaired immunity, reduced bone turn over
	Insufficient oral hygiene	Absolute; wound healing problems, infection
	Uncontrolled parafunctions	Relative; increased risk for technical complications
	Post head and neck radiation therapy	Absolute, but temporarily; reduced bone remodelling, risk of osteoradionecrosis, implant placement 6–8 weeks before or ≥1 year after radiotherapy
	Osteoporosis	Relative; reduced bone-to-implant contact; consider calcium substitution, prolong healing period and avoid high torque levels for abutment screw fixation
	Uncontrolled diabetes	Relative, requires medical treatment; wound healing problems (impaired immunity, microvascular diseases)
	Status post chemotherapy, immuno-suppressants or steroid long-term medication, uncontrolled HIV infection	Absolute, but temporarily; wound healing problems, medical advice required (consider corticosteroid cover)

(e.g., Sjögren), less effort will be made to maintain a questionable tooth, and implant treatment may be favoured. Further, patients with diabetes seem to have a somewhat increased likelihood of endodontic complications (symptomatic periapical diseases and flare-ups) following nonsurgical RCT, particularly in cases with preoperative periradicular lesions (Fouad & Burleson 2003). Impaired integrity of the patient's nonspecific immune system was found to be a significant predictor for a negative outcome of initial nonsurgical RCT or retreatment, whilst other patient-related factors such as age and smoking had no impact on the healing rate (Marending *et al.* 2005). Other authors suggested a possible negative influence of smoking on the prognosis of RCT teeth, but this was mainly attributed to delayed bone healing, and to an increased prevalence of periodontal disease and root caries in smokers (Duncan & Pitt Ford 2006).

There are few absolute and permanent implant contraindications, but several temporary restrictions such as incomplete cranial growth (Table 3) (Zitzmann & Berglundh 2008a, Zitzmann *et al.* 2008b). In young adults requiring single tooth replacement in the maxillary anterior region, implant placement should be postponed until after the age of 25 due to the changes in anterior face height and posterior rotation of the mandible, particularly in women (Jemt *et al.* 2007). This continuous alveolar bone development entails a vertical infraposition of the implant with the mucosal margin too far apical and significant aesthetic implications may occur. Patients under intravenous bisphosphonate medication for more than 2 years and a history of complicated wound healing, e.g., following tooth extraction, are not a candidate for implant treatment due to the risk of bisphosphonate-induced osteonecrosis (BON) (Edwards *et al.* 2008). Considering early and late implant losses as well as biological and technical complications, several factors were identified to be associated with an increased risk for implant failure or complications (Table 3). According to a recent review, smoking is a significant risk factor for implant treatment and augmentation procedures accompanying implant therapies (Strietzel *et al.* 2007). In these situations with an enhanced risk for implant failure, preference to tooth preservation, and avoidance of extraction and of further implant surgery should be considered also in teeth with a questionable prognosis.

Further treatment modalities in case of primary endodontic failure

In cases of endodontic failure following primary RCT, nonsurgical retreatment is generally indicated provided that the root canals are accessible (Fig. 2). White *et al.* (2006) stated that endodontic surgery has been largely replaced by endodontic retreatment in specialist endodontic practice over the past decade. According to a recent systematic review, the pooled success rate for secondary RCT (judged by complete or incomplete healing) was 77% each (Ng *et al.* 2008a). Defining success as the absence of AP and any associated signs and symptoms, the 4- to 6-year overall success of orthograde retreatment was reported to be 81% (Farzaneh *et al.* 2004a). In cases with preoperative AP, the success rate of retreatment was lower (78%) than if such radiolucency was absent at the time of retreatment (97%, Table 2). These differences in outcome reflect the divergent indications either to improve a RCT in a tooth with no AP (e.g., before inclusion as abutment in an FDP), or to retreat a symptomatic tooth with AP (Bergenholtz *et al.* 1979, Farzaneh *et al.* 2004a). Further, the success of endodontic retreatment

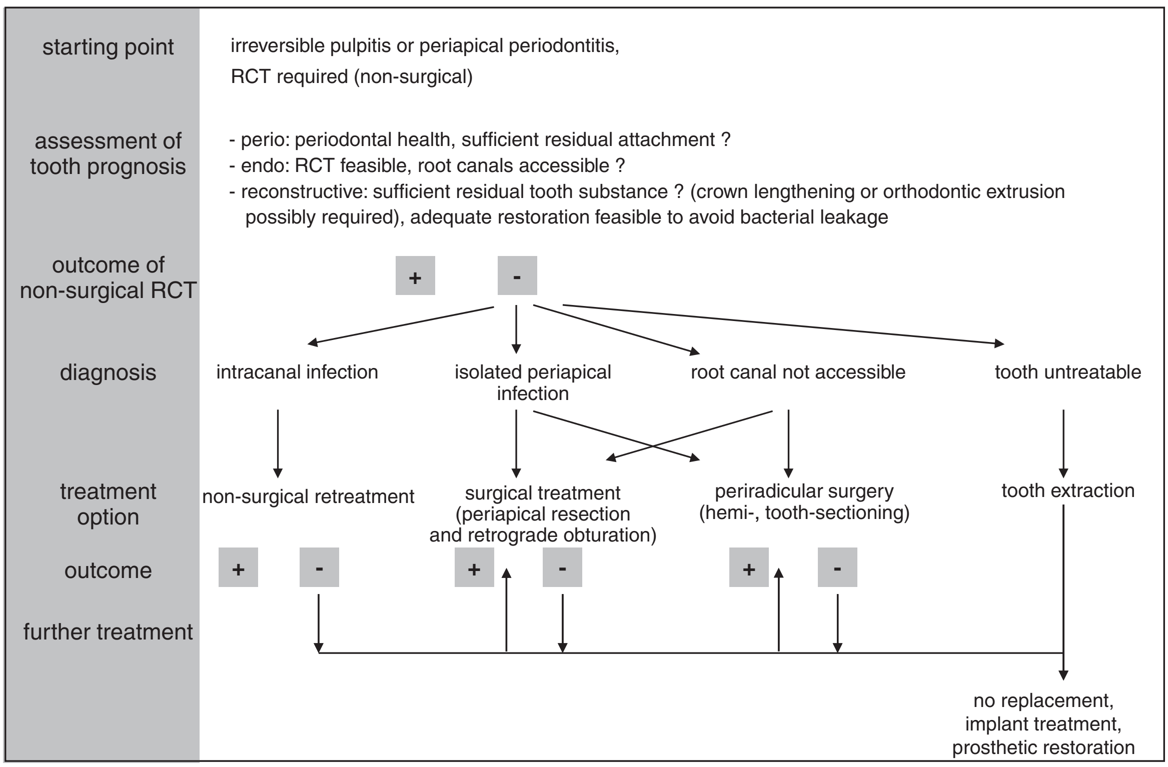


Figure 2 Treatment considerations for root canal treated (RCT) teeth.

depends on whether alterations in the natural course of the root canals were caused by previous root canal treatment (i.e., technical errors such as transportation, stripping or perforation, Table 2). Hence, teeth in which no significant anatomical changes were made by the previous RCT ('root-canal-morphology-respected') had 87% success, whilst only 47% of the teeth with damaged anatomy from previous treatment ('root-canal-morphology-altered') were successful after 2 years (Gorni & Gagliani 2004).

Surgical treatment is a valuable alternative if nonsurgical retreatment is not successful, not indicated (e.g., primary treatment was performed under best possible conditions), or not feasible (e.g., in teeth with adhesively cemented overextended zirconium or metal posts, teeth with alterations of the natural course of the root canal such as ledge formation from previous treatment, abutment teeth in existing FDP with radiographic root canal obturation; Fig. 2). Apical resection eliminates the periapical lesion (e.g., in lesions refractory to conventional treatment) or other irritants from the periapical tissues, allows healing and is best combined with a root-end filling (John *et al.* 2007). The large variety of healing rates (37–91%) reported in a review (Friedman 2005) may entail some restraint in considering resected teeth as abutments for an FDP (See 'Restorative aspects'). However, 80–94% of resected teeth remained in symptom-free function, even if they were not healed (Friedman 2005). Detailed analysis of the data revealed that the prognosis for apical resection is less favourable, when no nonsurgical retreatment was performed in advance and an infection possibly persisted in the root canal system. Additional factors for a reduced prognosis of periapical surgery are: poor accessibility in the molar region, persisting lesion despite apparently satisfactory filling, size of the lesion ≥5 mm, coronal leakage and surgical retreatment (Table 2) (Kvist & Reit 1999, Wang *et al.* 2004, Friedman 2005). Whilst first surgical interventions resulted in 74% success, surgical retreatment had an outcome of 62% (Kvist & Reit 1999, Wang *et al.* 2004, Friedman 2005). Repeated periapical surgery is only useful when primary surgery was performed under poor conditions such as inadequate equipment. Another factor for impaired prognosis of periapical surgery is periodontal involvement of the respective tooth: whilst isolated endodontic lesions revealed a 95% successful outcome following endondontic microsurgery, combined endodontic-periodontal lesions had a reduced healing rate of 77.5% (Kim *et al.* 2008).

According to the agreement of specialists, surgical intervention is probably not worth whilst in cases of limited prognosis of periapical surgery, e.g., when nonsurgical retreatment is not feasible due to inhibited access by an adhesively cemented zirconium or metal post reaching close to the apex. The buccal fenestration created to gain access to the periapical area may not heal with an intact bony plate resulting in a compromised site and precipitate the need for additional bone grafting if further implant treatment is planned (Greenstein *et al.* 2008). In molar teeth with sufficient root separation, periradicular surgery in terms of root amputation or root resection can be considered, particularly when a root canal is not accessible and there is concomitant periodontal involvement. Divergent failure rates have been documented for root-resected molars and vary between 7% and 38% after 10 years follow-up (Langer *et al.* 1981, Carnevale *et al.* 1998). Extraction of periodontally involved molars with advanced attachment loss, however, frequently entails complex bone augmentation procedures to prepare an adequate implant site.

Further treatment modalities in case of implant failure

Early implant failures and late losses due to overload are, in most instances, first recognized by implant mobility and there is no treatment available to save a mobile implant (Albrektsson & Isidor 1994). In sites affected by peri-implantitis, applied therapies aim in a resolution of the infection, but these measures are not predictably successful in achieving reosseointegration in the previously contaminated region (Claffey *et al.* 2008, Renvert *et al.* 2008). Depending on disease progression, implant loss occurs sooner or later and is frequently accompanied by substantial alveolar ridge defects (Lindhe & Meyle 2008). Further reimplantation may then entail additional bone augmentation in a staged approach.

It has been mentioned that particularly in younger patients, where a significantly long-term prognosis is required, a more aggressive approach in replacing questionable teeth with implants would be justified (Mordohai *et al.* 2005, 2007). The continuous alveolar bone growth, aesthetic concerns particularly in single tooth restorations, gingival recession over years, a possible susceptibility to periodontal and peri-implant diseases are important aspects that rather imply a more restrained approach, facilitating tooth maintenance for several years or even decades before tooth extraction may become inevitable.

These aspects related to the longevity of root canal treated teeth and implants, indicate that: (i) most endodontic failures are related to nonendodontic factors and RCT teeth survive better if properly restored (with single crowns being more favourable than FDPs), (ii) failures due to endodontic reasons can frequently be resolved by any type of retreatment, (iii) most implant failures are directly related to the implant itself and entail implant removal.

Restorative aspects

According to the view of the specialists, good long-term prognosis and greater flexibility in clinical management indicate that RCT and even retreatment should be performed first in most instances unless the tooth is judged to be untreatable when implants are considered (Fig. 2). As soon as other compromising factors or risks exist, such as insufficient coronal tooth structure and/or moderate to severe periodontal involvement, the time and cost efforts engaged with the RCT may be questionable. When deciding if an impaired tooth with a questionable prognosis is maintained or extracted and possibly replaced by an implant, several different aspects have to be taken into account. These aspects comprise site-specific factors, the entire oral situation and patient-related factors (Messer 1999).

Site-specific aspects

In order to evaluate the prognosis of a specific tooth, all required treatment measures should be listed initially and their degree of difficulty assessed. These treatment needs comprise not only nonsurgical and/or surgical endodontics, but post and core build-ups, periodontal treatment, restorations or crowning. Crown-lengthening or orthodontic extrusion are possibly needed in addition (Palmer & Howe 1999, Greenstein *et al.* 2007, Mordohai *et al.* 2007). Particularly in periodontics, an initial phase of pre-treatment followed by a re-evaluation is required to facilitate a complete estimation of the site-specific response and the patient's compliance. After successful periodontal treatment, however, teeth with reduced periodontal support are also capable of serving as foundations for single crowns or as abutments for FDPs (Nyman & Lindhe 1979). One of the most decisive site-specific factors is the remaining coronal tooth substance, which determines the dimension and extent of the coronal restoration. The easiest case is when tissue loss is minimal and the coronal restoration is a simple composite filling. It is much more complicated if a single crown is involved, possibly requiring crown-lengthening through surgery or orthodontic extrusion to facilitate sufficient cervical ferrule with the definitive crown engaging at least 1.5 mm tooth structure (Libman & Nicholls 1995, Tan *et al.* 2005, Türp *et al.* 2007). Surgical crown-lengthening for a tooth already compromised by a large post channel, and a poor crown to root ratio, does, however, place the respective tooth at high risk and extraction may be more appropriate (Bader 2002). Any additional pre-treatment requirement adds complexity, may present further complications and risks, increases treatment costs, and probably reduces the patient's willingness to accept RCT rather than implant placement (Torabinejad & Goodacre 2006).

If the degree of difficulty of the planned therapy is assessed, it seems that any type of endodontic or periodontal treatment is less time-consuming, less expensive, and easier to perform in anterior teeth than in multi-rooted premolars and molars, due to the simpler root morphology and root canal anatomy, and better accessibility and visibility particularly for periapical surgery (Fig. 3). After RCT in the anterior region, however, greyness of the clinical crown possibly impairs the aesthetic outcome and indicates bleaching and/or crown restorations. In implant treatment, the clinical crown can be designed so as to ideally mimic the symmetric situation on the contralateral site provided that the implant position is appropriate. The aesthetic outcome is, however, often compromised due to soft tissue recession from unpredictable healing following tooth extraction and implant surgery. Incisors have a marked undulation of the cemento-enamel-junction as well as of the gingival margin with long interproximal papillae, which are specific for anterior teeth and are bound to a sound periodontium. In the gingiva surrounding teeth, the collagen fibres are attached to the root cementum and are arranged in groups or bundles with distinct orientations such as dentogingival, dentoperiosteal, circular and transseptal fibres. Around implants, however, there is no periodontal ligament and the implant lacks a lining cementum with inserting collagen fibres (Berglundh *et al.* 1991). Particularly in patients with high aesthetic demands and a thin mucosal biotype, greater efforts should be made to save a questionable anterior tooth in order to ensure preservation of the soft tissue architecture (Kan *et al.* 2003, Greenstein *et al.* 2008). Posterior teeth with questionable prognosis, however, are

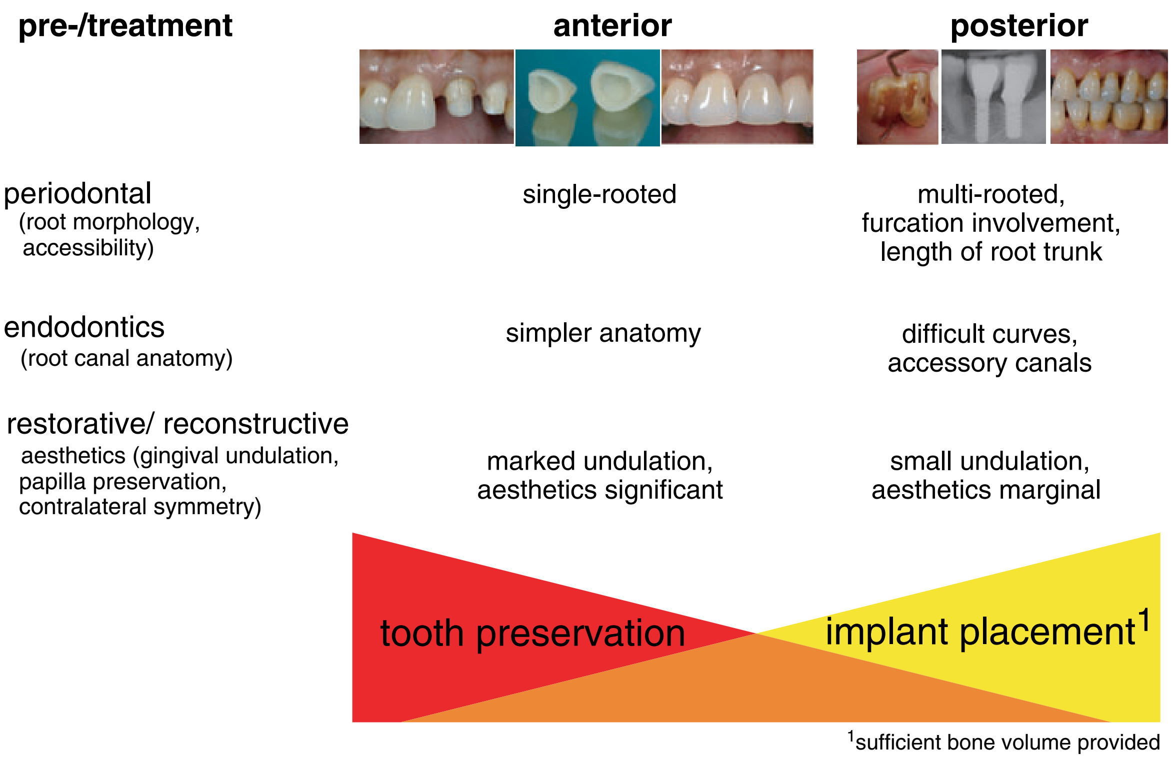


Figure 3 Local factors influencing the predictability of treatment outcomes.

replaced by an implant with less restraint, than in the aesthetic zone where concerns about the risks of gingival recession and a possible lack of interproximal mucosal tissues are of greater importance.

Oral situation

As soon as any restorative treatment requirements of an RCT tooth have been defined, the situation of the adjacent teeth and the entire remaining dentition is included in the treatment planning (Fig. 4) (Palmer & Howe 1999, Bader 2002). For a questionable tooth in an intact arch, which can be kept as a free-standing unit, a greater latitude for therapy can be implemented for retention, whilst a complex prosthetic plan possibly indicates extraction of a compromised abutment tooth. In accordance with the view of specialists, the following clinical scenarios are common in clinical practice and have to include assessments of potential risks and evaluation of the prognosis of the RCT tooth as well as of the entire restoration:

If maintenance or extraction of a questionable tooth is considered and the adjacent teeth obviously require full crown restorations, extraction and replacement by a conventional FDP may be favourable over tooth maintenance at high costs and increased risk for failure.

The same is true, if implant placement is needed in the adjacent tooth positions (i.e., anterior and posterior of the questionable tooth). Hence, a three-unit implant-FDP supported by two implants and tooth removal is a more reasonable treatment plan as compared to three single crowns with the questionable tooth maintained between the two implants (Fig. 4).

If the RCT tooth is planned to serve as an abutment and is located in a strategic position within a long-span tooth-supported FDP, its prognosis has to be good in order to ensure a noncompromised long-term success of the entire reconstruction (Davarpanah *et al.* 2000, Bader 2002). Having in mind that the potential risk for failure from endodontic, periodontal or prothodontic reasons after a 10-year observation period is 10% each, these multiple risk factors may theoretically accumulate and entail a reduced long-term success rate of 73% by multiplying 0.9^3.

On the other hand, with a questionable RCT abutment located in a strategic position of an existing and otherwise sufficient reconstruction, all efforts are made to save the tooth and the restoration.

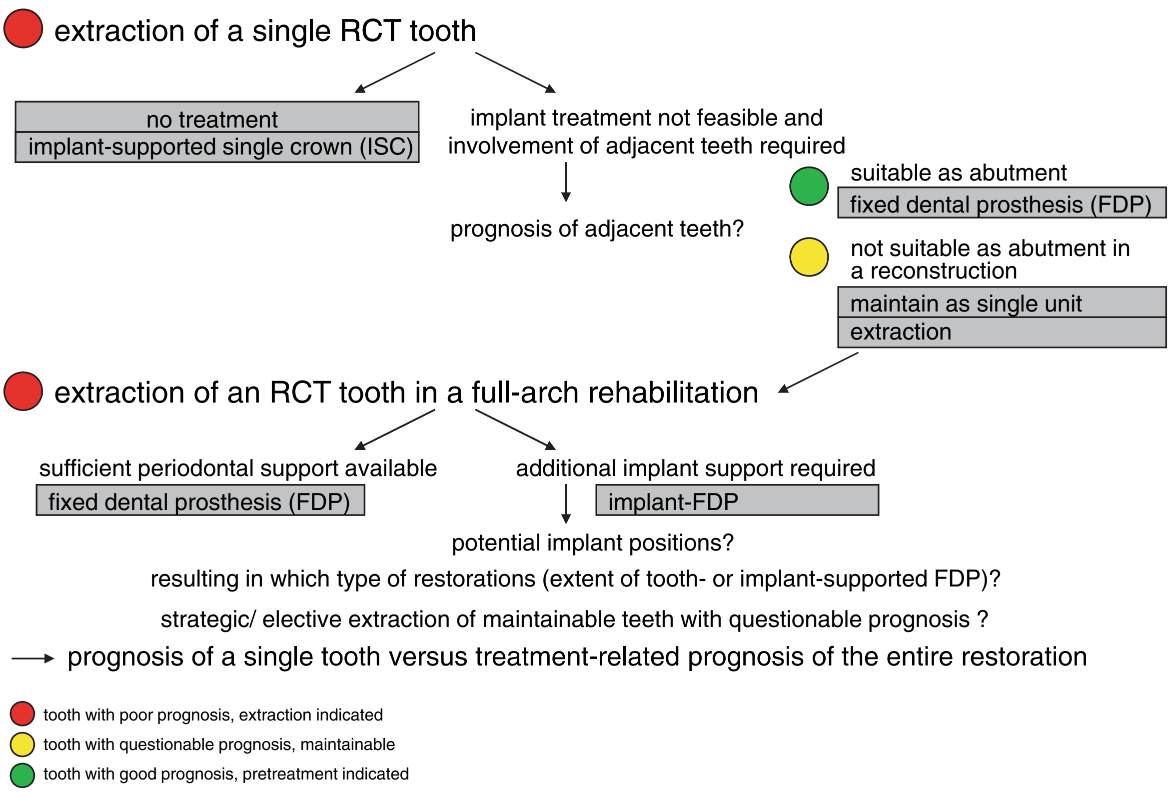


Figure 4 Reconstructive aspects in treatment planning.

In full arch reconstructions and few potential abutments maintained in a spread position, long-span tooth-supported FDPs, particularly those with high numbers of pontics and few abutments, can be avoided by adding implants supporting either single crowns or short-span implant-FDPs. After introducing implant-supported restorations as a treatment option in a specialist practice, the number of long-span FDP was reduced and the overall failure rate of tooth-supported FDPs decreased from 4% to 2% at 5–10 years observation (Walton 2009). Using less compromised teeth as abutments, not necessarily extracting and replacing them, but placing implants in addition, facilitates an improved outcome of tooth-supported FDP.

Replacing missing posterior teeth in free-end situations is a clear indication for implant placement in order to reduce the risk of FDP with distal cantilevers and to avoid combined tooth-implant-supported FDPs, as both treatment modalities are associated with an increased risk of failure (Lang *et al.* 2004, Pjetursson *et al.* 2004b).

Whilst a questionable tooth is probably planned for a single crown without restraints, particularly when the adjacent teeth are sound and implant placement would require additional bone and/or soft tissue augmentations, it may not be included as abutment in a long-span FDP. The situation of the remaining dentition and the full-mouth treatment planning decides, at least in part, whether or not to maintain a questionable tooth. Hence, a tooth with a relatively good prognosis, but requiring tremendous pre-treatment efforts may be intended for extraction, as treatment requirements in the adjacent tooth positions (either tooth- or implant-supported) overrule the decision made for the single tooth (Fig. 4).

Patient-related factors

The patient's expectations, medical contraindications (See 'General endodontic and implant contraindications' and Table 3) and his/her financial position are further aspects taken into account during treatment planning (Palmer & Howe 1999, Dawson & Cardaci 2006, Zitzmann & Berglundh 2008a, Zitzmann *et al.* 2008b). In general, RCT including a restoration with a single crown is less expensive, and entails fewer dental visits in a shorter time period than an ISC (Moiseiwitsch

& Caplan 2001). According to a cross-sectional study, even ISC performed as one- or two-stage procedure or as immediate placement had a longer time-to-function than RCT teeth (median 250 days for ISC vs. 67 days for RCT) (Doyle *et al.* 2006). Although recent protocols encourage immediate loading, most implant situations require several months for completion of treatment to ensure undisturbed osseointegration and maturation of the soft tissues. In addition to lower initial costs with RCT compared with ISC, a greater cost-benefit ratio is assumed, since RCT retains a natural tooth provided that no residual pathology of clinical significance persists, the tooth is in function and causes neither discomfort for the patient nor any aesthetic impairment (Torabinejad *et al.* 2007).

According to the agreement of specialists, all site-specific, oral and patient-related factors should be evaluated systematically, the strategic value of the tooth is determined and a risk analysis is performed before any definitive decision is taken. The existing evidence on the best treatment option in this particular case should be taken into account, and a treatment recommendation is then given in favour or against tooth maintenance. After case presentation and thorough objective information about the risk assessment, prognosis, possible complications and treatment alternatives, the final choice rests with the patient, who either accepts or refuses the treatment proposal. Patient attitudes, e.g., opposed to or approving of implants and/or bone augmentation procedures, seeking final solutions or not, may set a questionable tooth on a higher or lower strategic value. For instance, when molar extraction would result in sinus lifting procedures, which the patient wishes to avoid, the high strategic value justifies multiple extensive procedures for tooth retention. On the contrary, with multiple issues associated with endodontic therapy, minimal coronal tooth structure with decayed root dentine, and/or high caries index, which prohibits crown lengthening, replacement of the tooth with lower value may be prudent to avoid potential complications (Palmer & Howe 1999, Mordohai *et al.* 2005, 2007). Treatment alternatives should be estimated as true supplementing therapeutic options rather than as competing treatments, particularly when these are not part of the practitioners own repertoire. Especially for more demanding endodontic or implant therapies, referral to an experienced specialist (endodontist and implantologist), who has the clinical skills, the necessary equipment and resources is in the best interest of the patient and should be encouraged when appropriate (Messer 1999, Cohn 2005, Pothukuchi 2006, Wolcott & Meyers 2006). Patient's values and expectations may lead to a more value-based dentistry, where the patients' perceived benefit form the treatment outweighs the clinical decision-making procedure (Eckert 2005). It must be noted, however, that as soon as fixed or removable dental prostheses are part of the treatment requirements, the practitioner has the full responsibility for the reconstruction comprising also the laboratory work and he/she will possibly hesitate to include a questionable tooth in order to reduce the risk of the entire restoration due to economic considerations.

Conclusions

A simple comparison of long-term survival or success rates of root filled teeth and implants does not fulfil the demand for a comprehensive decision-making process, which includes multiple factors to evaluate, individual case evaluation and a thorough treatment planning. Several retrieved publications implied that the decision for extraction of a natural tooth depends less on the health of that individual tooth, but rather on the overall rehabilitation planned and that sacrificing a tooth can be preferable for a 'better, more predictable, more economic long-term rehabilitation on implants'. Applying this opinion without critical appraisal of site-specific and patient-related factors may fail to recognize risks for complications and failures possibly associated with implant treatment.

For single tooth restorations, an increased risk in restoring a tooth with a questionable prognosis is acceptable in a particular case. The respective tooth, however, should not be included as an abutment in a long-span FDP. Multiple risk factors may indicate tooth extraction and possible replacement by an implant, particularly in the posterior region and when aesthetics is not paramount. Although priority should be given to preservation of the natural dentition, implant placement enhances treatment planning options, thereby facilitating short-span reconstructions or single units with reduced risk of failure for the patient and the practitioner. Hence, using implants for replacement of single missing teeth may facilitate retention of a neighbouring compromised tooth, which otherwise would have been extracted.

In case of full-mouth rehabilitation, single tooth prognosis and the site-specific treatment recommendation is possibly overruled by the overall treatment planning and a therapy-related decision for a strategic extraction may be required to perform reasonable reconstructions with uncompromised long-term prognosis. Particularly in patients with a history of previous implant loss, and in young patients, in whom the final tooth position is not settled, and susceptibility to periodontal and/or peri-implant diseases are not yet predictable, the threshold for tooth extraction should be at its greatest. Irrespective of the type of the selected treatment option involving teeth and/or implants, ongoing maintenance is required to assure sufficient periodontal and peri-implant care, and to detect and treat any type of biological or technical complication at an early stage in order to reduce the risk of compromising the longevity of the reconstruction.

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