Retaining or replacing molars with furcation involvement: a cost-effectiveness comparison of different strategies


Abstract
Aim: The comparative cost-effectiveness of retaining or replacing molars with furcation involvement (FI) remains unclear. We assessed the cost-effectiveness of retaining FI molars via periodontal treatments versus replacing them via implant-supported crowns (ISCs).
Methods: Using tooth-level Markov models, we followed a molar with FI degree I or II/III in a 50-year-old patient over his lifetime. Tooth-retaining periodontal treatments (scaling and root planing, flap debridement, root resection, guided-tissue regeneration, tunnelling) were compared with tooth replacement using ISCs. We analysed costs, time until first re-treatment and total time of tooth or implant retention. The model adopted a private payer perspective within German health care. Transition probabilities were calculated based on current evidence. Monte-Carlo microsimulations were performed, and robustness of the model and effects of heterogeneity assessed using sensitivity analyses.
Results: Despite requiring re-treatment later than other strategies, ISCs were the most costly therapy. Compared with most periodontal treatments, ISCs were retained for shorter time than natural teeth regardless of the degree of FI, the patients’ age or risk profile (smoker/non-smoker).
Conclusions: Based on available data and within its limitations, our study indicates that retaining FI molars via periodontal treatments might be more cost-effective than replacing them via ISCs. Changes in the underlying evidence or the setting might alter these results.

Conflict of interest and source of funding statement
The authors have no conflicts of interest. No external funding, apart from the support of the authors’ institution, was available for this study.

Retention of periodontally compromised posterior teeth has been found both beneficial for masticatory functionality and generally achievable, with only a very limited proportion of teeth getting lost during regular supportive treatment, often caused by other, non-periodontal reasons (Hatch et al. 2001, Loesche et al. 2002, Fardal et al. 2004, Chambrone & Chambrone 2006, Graetz et al. 2011, 2013). Moreover, retaining teeth via supportive periodontal treatment (SPT) was shown affordable in several settings, with both initial and long-term costs generally being lower for retained teeth than for their replacement (Pretzl et al. 2009, Fardal & Grytten 2013). Such replacement via implant-supported crowns (ISCs), however, is increasingly common, but generates high initial costs (Pretzl et al. 2009, Fardal & Grytten 2013, Lang-Hua et al. 2013), and might also be costly long term due to technical and biological complications (Jung et al. 2012).

Key words: dental; furcation; health economics; implant; modelling; periodontal

Accepted for publication 18 September 2014
For periodontally compromised molars with furcation involvement (FI), survival has been found inferior compared to single-rooted or non-FI teeth, with higher effort and more complex treatment being required to retain such teeth (Dannenwitz et al. 2006; Pretzl et al. 2009; Lee et al. 2012). In addition, it was speculated that long-term retention of such teeth might increase local bone loss, thereby compromising the eventual replacement of these teeth with implants (Friberg et al. 1991). Thus, for molars with FI, the cost-effectiveness of tooth retention versus tooth replacement might be different from that of non-FI teeth. Therefore, the aim of this study was to assess the cost-effectiveness of retaining or replacing molars with FI using periodontal treatments versus ISCs, respectively.

### Material and Methods

#### Treatment alternatives

We evaluated the cost-effectiveness of treatment alternatives for periodontally affected, vital molars with FI, comparing tooth-retaining strategies with tooth removal and replacement via ISC. Note that we did not compare different periodontal strategies with each other, as they are not totally interchangeable (see below). We did also not assess the cost-effectiveness of tooth replacement with fixed dental prostheses, that is dental bridges, as they were shown to be similarly expensive as ISCs (Bragger et al. 2005; Incici et al. 2009; Schueller et al. 2012), whilst requiring preparation of adjacent abutment teeth with the inherent risk of endodontic complications.

Categories of tooth-retaining strategies were derived from the literature (Huynh-Ba et al. 2009), with separate analyses for teeth with FI degree I and degrees II or III (Hamp et al. 1975). For the former, periodontal treatment options comprised conservative, non-surgical furcation therapy involving scaling and root planing (SRP), and scaling and root planing with surgical access (flap debridement, FD). For teeth with FI II or III, root resection (RR, i.e. hemisection, trisection or amputation), guided-tissue regeneration (GTR), including insertion of bone substitute material and placement of a resorbable membrane, and – for mandibular molars only – tunnelling (TU) were evaluated. Tooth-retaining strategies were then compared with the removal and replacement of teeth with ISCs. Teeth with FI II and III were combined, as there was insufficient data to separately analyse these degrees of FI. Note that we also did not model treatment of different furcations within one tooth due to paucity of data. Similarly, treatment of molars with FI II/III via SRP or FD was not modelled.

#### Setting and model

Analyses were performed in the context of German health care, with the simulation of a 50-year-old male patient with an average remaining life expectancy of 29.7 years (Statistisches Bundesamt 2013). We assumed that the tooth would have been previously restored with an extensive but sufficient composite restoration, as can be expected in patients of this age (Micheulis & Schiffner 2006). We controlled for the effects of this assumption using sensitivity analysis (see below).

A tooth-level decision model was constructed using a modified Markov design and a private payer perspective comparing each tooth-retaining strategy with ISCs (TreeAge Pro 2013; TreeAge Software, Williamstown, MA, USA). The model consisted of the initial and follow-up health states (Fig. 1), simulating the natural history of a periodontally affected tooth or an ISC. The likelihood of teeth translating from one to the other health state was based on transition probabilities, with each transition generating certain costs according to what kind of treatment was performed. Simulation was performed in discrete 6-monthly cycles, with the sequence of events constructed according to current evidence and in consensus of experienced clinicians (FS, CG, CD). Model validation was performed internally (by varying distributions and key parameters to check their impact) and externally (by comparing modelled outcomes with those from population-based studies, and additional reviewing by an experienced health economist [MS]). The model was based on the following assumptions (Kocher et al. 2000, Graetz et al. 2011):

- All initial therapies comprised full case assessment including oral hygiene assessment, advice and motivation, radiographs, scale and polish, re-evaluation and active periodontal treatment as outlined above including anaesthesia, possible endodontic, surgical or prosthetic procedures and short-term post-operative care.
- Supportive periodontal or implant treatment (SPT/SIT) involved biannual re-evaluation (Pretzl et al. 2009), scale and polish, subgingival re-treatment and antiseptic irrigation, as well as radiographic reassessment every 2 years. For teeth but not implants, fluoridation of root surfaces was assumed to be additionally performed (Dannenwitz et al. 2006). We controlled for effects of different intervals of SPT/SIT or the assumption of fluoridation being provided (see below).
- We discriminated fatal complications, that is those leading to loss of the tooth or the implant (e.g. periodontal complications or untreatable root caries, or untreatable peri-implantitis or implant fracture, respectively) from non-fatal complications, for example treatable caries at restoration margins, treatment-responsive peri-implantitis, or loss of crowns or abutments. Mending of complications was assumed to generate costs, and involved repair or renewal of restorations, re-cementation or re-fixing of crowns or abutments and peri-implant treatment following CIST (Cumulative Interceptive Supportive Therapy) guidelines (Mombell & Lang 1998). Allocation of non-fatally failed teeth to follow-up treatments was estimated from the literature and based on an existing study (Schwendicke et al. 2013).
- Lost teeth or implants were assumed to be replaced using implants. As this approach (especially if re-treating a failed implant) is not always feasible, and patients might be willing to accept a shortened dental arch (Wollart et al. 2014), we additionally evaluated the cost-effectiveness of different treatments if no replacement was performed after failure of tooth or implant.
- Patients’ risks of periodontal or implant failures were assumed to
Molars with FI I or III  

- SRP  
- FD  
- Periodontal/Endodontic/Restorative complications  
- RCT

Molars with FI II or III  

- ISC  
- RR  
- GTR  
- TU  
- Technical/Biological complications  
- Recement/crown  
- RCT  
- Refill/repair/crown

Replace with ISC  

Replace with ISC  

Replace with ISC

Fig. 1. State transition diagram. Molars with FI I and II/III were analysed separately, with different treatments being compared. All periodontal treatments (SRP scaling and root planing, FD flap debridement, RCT root resection, GTR guided-tissue regeneration, TU tunnelling) were compared with implant-supported crowns (ISCs). For teeth, periodontal, endodontic and restorative complications were modelled, with fatal (leading to tooth loss) and non-fatal (mendable) complications being simulated separately. For implants, we modelled technical loss (loss of crowns, abutment fracture, implant fracture) and biological complications (peri-implantitis), again with separate simulation of fatal and non-fatal failures. If complications were mendable, teeth and implants were allocated to follow-up treatments, which generated costs. Lost teeth or implants were assumed to be replaced using ISCs. Note that within the base case analysis, all failed teeth or implants were assumed to be (re-)replaced. To explore effects of this assumption, sensitivity analyses were performed. Repair was assumed to be performed only once. Similarly, if re-filled teeth failed, placement of a crown was modelled. In contrast, re-cementation was assumed to be repeatable. As (re-)implantation might not always be possible, we additionally analysed the cost-effectiveness of strategies if lost teeth and implants were assumed to not be replaced. Abbreviation: RCT Root canal treatment. CIST Cumulative Interceptive Supportive Therapy.

differ. To account for such heterogeneity, we performed subgroup analysis for different ages or smoker status (see below).

Transition probabilities and hazards

Transition probabilities were derived from existing systematic reviews. For failure of periodontally treated FI molars, studies included in the review by Huynh-Ba et al. (Huynh-Ba et al. 2009) were screened, and those allowing separate data analyses for different degrees of FI were meta-analysed further, with sample-size-weighted means and 5–95% percentiles of yearly probabilities being calculated (Table S1). To re-calculate yearly probabilities into transition probabilities per simulated cycle ($p_{(c)}$), we used the formula (Miller & Homan 1994):

$$p_{(c)} = 1 - (1 - \bar{a} \times y)^{(1/(2y))}$$

with $\bar{a}$ being the mean annual probability for the follow-up period $y$ (in years) of the study. Per-cycle probabilities were then meta-analysed as described, and linear hazard functions were calculated (SPSS 22, IBM, Chicago, USA). We controlled for the effects of using linear versus non-linear functions in a sensitivity analysis.

Based on a recent meta-analysis (Jung et al. 2012), transition probabilities of ISCs were derived similarly, with annual failure probabilities of implant loss, crown loss and further technical complications being transformed as outlined above. For biological complications, we consulted another review (Mombelli et al. 2012), and derived the probability of developing treatment-responsive and non-responsive peri-implantitis from those studies using CIST (Mombelli & Lang 1998) case definition (Table S2). Eventually, the probability of peri-implantitis and implant loss were adjusted to explore the effects of treating different risk groups of patients (Table S3).

Probabilities of non-periodontal complications were adopted from an existing cost-effectiveness analysis (Schwendicke et al. 2013). More advanced efforts of retaining the tooth, for example using secondary endodontic treatment, were not simulated. Assuming that fatal failures were included in the calculated probabilities for tooth or implant loss, estimates of mendable failures were adjusted accordingly. Non-linear transition probabilities were calculated as described (Table 1).

Costs

The model adopted a private payer perspective in German health care. Costs were derived from the private item fee catalogue (GOZ), which allows more detailed calculation than the public fee catalogue, BEMA (KZBV 2013) and has been used for similar calculations (Pretzl et al. 2009). For GOZ, factoring of chargeable item-points is common to determine prices, allowing to individualize the fee according to the required time and effort for each treatment. The present analysis used the standard multiplication factor ($\times 2.3$). Average national multiplication factors (Niehaus et al. 2011) were used within a sensitivity analysis. Items were restricted in number and character to reflect cost limitations, and items covering the treatment of more than one tooth were re-calculated into costs per tooth. Costs were calculated in Euro, and future costs discounted at 3% per annum (IQWIG 2009). No such discounting was performed for future effectiveness within the base case analysis, whereas we performed effectiveness discounting with 3% per annum in a sensitivity analysis.

As the majority of German patients are enrollees of the statutory public, not the private insurance (GKV-Spitzenverband 2013), we performed an additional sensitivity analysis to assess the cost-effectiveness in publicly insured patients. Note that for these patients, not all items are covered by the public insurance, resulting in mixed public–private treatment courses (Schwendicke et al. 2013). In addition, the average out-of-pocket expenses of publicly insured patients were calculated. Details regarding costs can be found in the appendix (Table S4).
Table 1. Annual failure rates (AFR) of different treatments. If available, AFR were estimated according to the time spent in the health state, with different time plateaus being modelled (<2, 2–5, >5 years). Mean and 5–95% percentiles were used to construct triangular distributions for random sampling (Briggs et al. 2002). Failure occurred, teeth translated to follow-up health states according to allocation probabilities (right columns). We distinguished fatal (i.e. leading to tooth or implant loss) from non-fatal failures.

<table>
<thead>
<tr>
<th>Failure</th>
<th>Health state</th>
<th>Mean (5–95% percentiles) annual failure rate* (%)</th>
<th>Reference</th>
<th>Allocation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fatal failure</td>
<td>SRP</td>
<td>0.2 (0.0–0.4)</td>
<td>Table S1</td>
<td>Removal†</td>
</tr>
<tr>
<td></td>
<td>FD</td>
<td>0.7 (0.4–2.9)</td>
<td>Table S1</td>
<td>Removal†</td>
</tr>
<tr>
<td></td>
<td>RR</td>
<td>0.9 (0.0–1.1)</td>
<td>Table S1</td>
<td>Removal†</td>
</tr>
<tr>
<td></td>
<td>TU</td>
<td>1.2 (0.0–1.9)</td>
<td>Table S1</td>
<td>Removal†</td>
</tr>
<tr>
<td></td>
<td>GTR</td>
<td>0.3 (0.0–1.1)</td>
<td>Table S1</td>
<td>Removal†</td>
</tr>
<tr>
<td></td>
<td>ISC</td>
<td>0.6 (0.4–0.8)</td>
<td>Table S1</td>
<td>Removal†</td>
</tr>
<tr>
<td></td>
<td></td>
<td>0.6 (0.4–0.8)</td>
<td>Jung et al. (2012)</td>
<td>Removal†</td>
</tr>
<tr>
<td>Non-fatal failures</td>
<td>Composite</td>
<td>5.3 (0.6–13.0)</td>
<td>Schwendicke et al. (2013)</td>
<td>Repair‡</td>
</tr>
<tr>
<td></td>
<td>Crown on vital tooth</td>
<td>3.0 (1.0–5.0)</td>
<td>Schwendicke et al. (2013)</td>
<td>Crown</td>
</tr>
<tr>
<td></td>
<td>Crown on non-vital tooth</td>
<td>1.5 (0.5–2.5)</td>
<td>Schwendicke et al. (2013)</td>
<td>RCT</td>
</tr>
<tr>
<td>Implant</td>
<td>ISC</td>
<td>1.9 (1.2–3.1)</td>
<td>Table S2§</td>
<td>Repair‡</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1.8 (1.0–3.2)</td>
<td>Jung et al. (2012)§</td>
<td>Re-cement</td>
</tr>
<tr>
<td></td>
<td></td>
<td>0.8 (0.5–1.6)</td>
<td>Jung et al. (2012)§</td>
<td>Re-restore</td>
</tr>
<tr>
<td></td>
<td></td>
<td>0.7 (0.5–1.1)</td>
<td>Jung et al. (2012)§</td>
<td>RCT</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Renew crown</td>
</tr>
</tbody>
</table>

SRP, scaling and root planing; FD, flap debridement; RR, root resection; TU, tunnelling; GTR, guided-tissue regeneration; ISC, implant-supported crown; RCT, root canal treatment.

*To estimate hazard functions; AFR were recalculated into hazards per-cycle; meta-analysed; and eventually linearly regressed.
†Lost teeth or implants were assumed to be replaced using implants. As this approach (especially if re-treating a failed implant) is not always feasible, we additionally evaluated lifetime costs if no replacement was performed after failure of tooth or implant.
‡In case restorations were repaired, we modelled only one repair, that is in case of second failure, renewal or further restoration was performed.
§Transition probabilities of implants and implant-supported crowns were extracted from Jung et al., with annual rates of implant loss, crown loss and further, technical complications being extracted. For biological complications, we consulted another review (Mombelli et al. 2012), and extracted probabilities of developing peri-implantitis (Table S2). As we assumed that those cases of peri-implantitis leading to crown loss and further, technical complications being extracted. For biological complications, we consulted another review (Mombelli et al. 2012), and extracted probabilities of developing peri-implantitis (Table S2). As we assumed that those cases of peri-implantitis leading to implant loss were included in the review by Jung et al., we adjusted the probability of mendable peri-implantitis accordingly.

Cost-effectiveness analyses

We assessed cost-effectiveness as lifetime treatment costs (in Euro) per retention time of the tooth or implant (in years). In addition, we calculated the time until the first retreatment for each therapy, the cost-effectiveness using discounting outcomes and the total and out-of-pocket costs for publically insured patients. All analyses were performed separately for molars with FI I, lower molars with F II/III and upper molars with FI II/III.

To calculate cost-effectiveness, we performed Monte-Carlo microsimulations, and introduced parameter uncertainty by randomly sampling transition probabilities from triangular or uniform distributions between 5 and 95% percentiles or ranges (Briggs et al. 2002). We performed several univariate sensitivity analyses: First, we assessed how the assumption that long-term tooth retention increases local bone loss and thereby increases the costs for an eventual implantation affects our estimates, with costs for a ridge augmentation (GOZ 9100, 348.19 Euro) being added. Second, we checked for effects of varying patients’ age and risk profile (smoker versus non-smoker). Third, we controlled how linearity or non-linearity of hazard functions affect our results. Further sensitivity analyses explored effects of teeth having received a crown before, SPT not generating costs for fluoridation, discounting effectiveness, patients being enrollees of the public insurance, or using average national instead of standard fee multiplication factors.

The net benefit of each treatment was calculated using the formula (Stinnett & Mullaly 1998):

\[ \text{NB} = \lambda \times \Delta c - \Delta e, \]

with \( \lambda \) denoting the ceiling threshold value of willingness-to-pay, that is the maximum costs a decision-maker is willing to pay to gain one additional unit of effectiveness, that is a year of tooth or implant retention. If \( \lambda > \Delta c / \Delta e \), an alternative is considered more cost effective than the comparator despite possibly being more costly (Briggs et al. 2002). Using this approach, cost-effectiveness acceptability curves were generated, plotting the probability that the treatment is cost effective over a range of values placed on a unit gain in outcome (i.e. a range of thresholds).
Results

For molars with FI I, SRP was found both less costly and more effective than ISC. Compared with FD, ISC was non-dominated (Fig. 2a), being always more costly but also more effective in 86% of simulations. The resulting ceiling threshold was 847.24 Euro, that is decision-makers willing to invest this sum for one additional year of retaining the tooth or implant would find ISCs the more cost-effective option (Fig. 2b). Regardless of the dental arch, treating molars with FI II/III via tooth-retaining options was found more effective and less costly than tooth removal and replacement via ISCs (Fig. 2c,d), despite ISCs requiring re-treatment significantly later than most tooth-retaining options. Discounting outcomes with 3% per year did not significantly alter this cost-effectiveness ranking (Table 2). The domination of ISCs by most tooth-retaining options was reflected by cost-effectiveness acceptability curves (Fig. S1).

We controlled for the effects of different intervals of SPT on lifetime costs, and did not find significant changes in the cost-effectiveness ranking except for RR being dominated by ISCs if recall intervals were decreased to <3 months (Fig. S2). Assuming that the long-term retention of compromised molars would lead to increased local bone loss, which – in case of their eventual replacement – might require additional surgical efforts, the average lifetime cost of periodontal treatments increased (max. +38.00 Euro after discounting), but never reached those of ISCs. Eventually, we compared the cost-effectiveness of different strategies in case teeth had been restored with crowns before APT. In such case, costs for all tooth-retaining strategies except RR increased moderately (max +3%), which did not change the cost-effectiveness ranking. For RR, costs were significantly decreased (−28%). The effectiveness of strategies was not significantly affected (<±0.5%).

Further sensitivity analyses did not find cost-effectiveness rankings to be greatly variable: Changing patients’ risk profile (Table S5) or age (Table S6) as well as using non-linear instead of linear hazard functions, that is simulating reduced early and increased late hazards, had only limited effects on the calculated cost-effectiveness (Table S7). Similarly, long-term costs were nearly unaffected when assuming that lost teeth or implants were not to be replaced (Fig. S3), or root surfaces would not be fluoridated regularly. Cost-effectiveness rankings were confirmed for publically insured patients or using national average multiplication factors (Table S8). For publically insured patients, ISC generated the highest out-of-pocket expenses (Fig. S4).

Discussion

The cost-effectiveness of retaining molars with FI via periodontal treatments versus their replacement with ISCs has not been extensively evaluated. Considering the high prevalence of periodontitis and the limited resources for its treatment (Marcenes et al. 2013), cost-effectiveness is relevant, and costs might further be important as they influence patients’ utilization of dental services (Zhong 2010). We found retaining teeth less costly than removing and replacing them. The latter was found significantly more costly initially, and whilst ISCs required re-treatments later than natural teeth, these re-treatments, for example for peri-implantitis, were also relatively costly.
Given the character of our study and the underlying evidence, our results should be interpreted with caution: First, it should not be attempted to compare different periodontal treatments with each other, as their indications differ, thereby limiting the options of performing comparative trials and explaining the paucity of comparative data for FI molars (Flemmig & Beikler 2009). Second, the database for our study comprises many studies performed in university settings in highly selected populations. Given the retrospective character of these studies, they are prone to selection, performance and reporting bias. However, including such studies might increase general uncertainty rather than introduce systematic bias (Deeks et al. 2003). This uncertainty was reflected by our model, which was additionally conservative using uniform or triangular distributions of variables for random sampling, thus increasing uncertainty even further. Third, our analysis did not allow separate treatment of different furcations within the same tooth. Given the costs difference between most tooth-retaining options and ISCs, it is unlikely that such separate analyses would significantly alter or even reverse our cost-effectiveness rankings. Similarly, varying clinical conditions was not found to change our ranking, whilst new data – for example regarding the combined effects of smoking and compliance of patients on survival of teeth (or implants) might affect our results (Salvi et al. 2014).

It should be noted that within this study, cost-effectiveness was assessed as costs per retention year of tooth or implant. Whilst such survival data is frequently used when comparing teeth with implants, one has to be aware that retaining periodontally affected teeth and retaining implants might not be identical. Moreover, retention does not necessarily mean similar functional rehabilitation or quality of oral life. We nevertheless chose this approach, as there is insufficient data regarding the effects of retaining or replacing molars on subjective, patient-reported outcomes, and it can be questioned if retaining a molar has any relevant universal effect on patients’ quality of life (Wolfart et al. 2017). Thus, despite being desirable, a cost-utility analysis was not possible (Flemmig & Beikler 2009), whereas the comparative analysis of implant and tooth retention was both feasible and relevant.

Table 2. Cost-effectiveness of different tooth-retaining strategies (SRP scaling and root planing, FD flap debridement, RR root resection, GTR guided-tissue regeneration, TU tunnelling) for molars with furcation involvement (FI) compared with implant-supported crowns (ISCs). We separately analysed molars with FI I and FI II/III. Mean (standard deviation) costs and effectiveness were calculated. We analysed lifetime costs as well as the time a tooth/implant was retained. In addition, we assessed the discounted effectiveness (retention years after discounting with 3% per year) and the time until first re-treatment. The scenario simulated a patient aged 50 years, a replacement rate of 100% of lost teeth or implants, and 3% cost discounting (IQWIG 2009). ISC was always more costly than tooth-retaining strategies, being dominated by all strategies except FD when using undiscounted effectiveness.

<table>
<thead>
<tr>
<th>FI</th>
<th>Treatment</th>
<th>Total costs (Euro)</th>
<th>Retention time of tooth/implant (years)</th>
<th>Discounted retention time of tooth/implant (years)</th>
<th>Time until 1st re-treatment (years)</th>
</tr>
</thead>
<tbody>
<tr>
<td>FI</td>
<td>SRP</td>
<td>814.02 (21.29)</td>
<td>29.5 (0.5)</td>
<td>15.0 (0.5)</td>
<td>15.0 (0.5)</td>
</tr>
<tr>
<td></td>
<td>FD</td>
<td>943.74 (35.34)</td>
<td>24.5 (1.0)</td>
<td>12.5 (0.5)</td>
<td>13.5 (1.0)</td>
</tr>
<tr>
<td></td>
<td>ISC</td>
<td>2229.33 (31.59)</td>
<td>26.0 (1.0)</td>
<td>13.5 (0.5)</td>
<td>15.5 (1.0)</td>
</tr>
<tr>
<td>FII/III</td>
<td>RR</td>
<td>1647.12 (23.15)</td>
<td>26.5 (1.0)</td>
<td>13.5 (0.5)</td>
<td>19.5 (1.0)</td>
</tr>
<tr>
<td></td>
<td>GTR</td>
<td>1164.36 (27.45)</td>
<td>28.0 (1.0)</td>
<td>14.0 (0.5)</td>
<td>14.5 (1.0)</td>
</tr>
<tr>
<td></td>
<td>TU</td>
<td>942.01 (31.15)</td>
<td>26.0 (1.0)</td>
<td>13.5 (0.5)</td>
<td>13.5 (1.0)</td>
</tr>
<tr>
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</tr>
</tbody>
</table>

Cost-effectiveness of treating FI molars

Given the character of our study and the underlying evidence, our results should be interpreted with caution: First, it should not be attempted to compare different periodontal treatments with each other, as their indications differ, thereby limiting the options of performing comparative trials and explaining the paucity of comparative data for FI molars (Flemmig & Beikler 2009). Second, the database for our study comprises many studies performed in university settings in highly selected populations. Given the retrospective character of these studies, they are prone to selection, performance and reporting bias. However, including such studies might increase general uncertainty rather than introduce systematic bias (Deeks et al. 2003). This uncertainty was reflected by our model, which was additionally conservative using uniform or triangular distributions of variables for random sampling, thus increasing uncertainty even further. Third, our analysis did not allow separate treatment of different furcations within the same tooth. Given the costs difference between most tooth-retaining options and ISCs, it is unlikely that such separate analyses would significantly alter or even reverse our cost-effectiveness rankings. Similarly, varying clinical conditions was not found to change our ranking, whilst new data – for example regarding the combined effects of smoking and compliance of patients on survival of teeth (or implants) might affect our results (Salvi et al. 2014).

It should be noted that within this study, cost-effectiveness was assessed as costs per retention year of tooth or implant. Whilst such survival data is frequently used when comparing teeth with implants, one has to be aware that retaining periodontally affected teeth and retaining implants might not be identical. Moreover, retention does not necessarily mean similar functional rehabilitation or quality of oral life. We nevertheless chose this approach, as there is insufficient data regarding the effects of retaining or replacing molars on subjective, patient-reported outcomes, and it can be questioned if retaining a molar has any relevant universal effect on patients’ quality of life (Wolfart et al. 2017). Thus, despite being desirable, a cost-utility analysis was not possible (Flemmig & Beikler 2009), whereas the comparative analysis of implant and tooth retention was both feasible and relevant.

Calculated cost estimates apply to German health care only. However, the used item-based calculation reflects the efforts required per treatments, with our cost estimates concurring with those obtained in different settings (Flemmig & Beikler 2009, Pretzl et al. 2009, Fardal & Grytten 2013). Cost estimates calculated based on different assumptions of German health care (privately or publically insured, standard or average national multiplication factor) were similar as well. However, it was not possible to quantify opportunity costs, for example those occurring by patients not being able to work or having to travel to the dentist, whilst these have been shown to affect cost-effectiveness comparisons as well (Bragger et al. 2005). Introducing them to our model would require patient-related data, which was not available.

We separately assessed molars with different degrees of FI, but combined those with FI II and III, which is in accordance with reported differences in prognosis of FI molars (McGuire & Nunn 1996). For molars with FI I, SRP was found highly effective (10-year survival was 97%), concurring with previous studies (Svardstrom & Wennstrom 2000, Dannewitz et al. 2006), with SRPs consequently dominating ISCs. The high chance of retaining molars with FI I has been confirmed in a recent study as well, which did not find FI I to be a risk factor for tooth loss (Salvi et al. 2014). For FI I, FD was less effective than ISCs, which might reflect both its indication and its limited advantages compared with SRP (Heitz-Mayfield et al. 2002). For molars with FI II or III, different tooth-retaining strategies showed different cost-effectiveness, reflecting different indications. Especially for RR, there was uncertainty regarding its cost-effectiveness compared with ISCs. This might be due to its character as treatment of “last resort” (Lee et al. 2012), but also due to the efforts and costs associated with RR, requiring root canal treatment and crown placement (Carnevale et al. 1991, Huynh-Ba et al. 2009, Schwendicke et al. 2013). When considering that our results regarding RR (91% survival after 10 years) are optimistic compared to those from Hellden et al. (93% after 3.5 years), Blomlöf et al. (68% after 10 years)
or Little et al. (83% after 7 years), it remains unclear if retaining teeth via RR is truly cost effective (Heldon et al. 1989, Little et al. 1995, Blomlof et al. 1997).

As reported previously, ISCs are initially expensive ( Pretzl et al. 2009), and – despite requiring re-treatments less often – these re-treatments generate further and usually high costs (Fardal & Grytten 2013). This is especially true for peri-implantitis therapy, and given an incidence of approximately 10% after 5–10 years after implantation, peri-implantitis certainly affects the cost-effectiveness of ISCs (Jung et al. 2012, Mombel et al. 2012, Fardal & Grytten 2013). Whilst survival rates of implant have nevertheless been found to be similar or even higher than those for FI molars ( Faggazzotto 2001), the high costs associated with initial and follow-up treatments of ISCs compromise their cost-effectiveness, as demonstrated by our study. Only one comparison (FD versus ISC) found ISC more cost effective if decision-makers were willing to invest more than 847 Euro. Considering the lack of an accepted ceiling threshold to retain a posterior tooth or implant, interpretation of this value should be perform with caution, and it should best be used to demonstrate the effects of different cost sensitivities of payers. No such effects were found for other comparisons within the base case scenario.

Clinical decision-making will be guided not only by cost-effectiveness, but by setting and patients’ or providers’ priorities (predictability, access, treatment time per visit and number of visit, surgical or non-surgical approach, provision of technical equipment). In this sense, retention or replacement of teeth will not be the only viable treatment options for FI molars. Instead, their removal and non-replacement (shortened dental arch) might result in sufficient functionality and subjective oral health at limited costs as well ( Faggaggion et al. 2011, Wolfart et al. 2012, 2014).

Conclusions

Based on currently available evidence, most strategies of retaining molars with FI were more cost effective than tooth replacement via implant-supported crowns. Reported success or survival rates of treatments should be balanced against the costs emanating from initial and follow-up therapies, whereas further individual factors will eventually be integrated into clinical decision-making.

References


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Supporting Information

Additional Supporting Information may be found in the online version of this article:

**Table S1.** Studies used to estimate annual failure rates.

**Table S2.** Studies used to estimate the probability of developing treatment-responsive and non-responsive peri-implantitis.

**Table S3.** Adjustment of transition probabilities in different risk groups.

**Table S4.** Costs.

**Table S5.** Cost-effectiveness of different strategies to treat molars with furcation involvement (FI) for patients who currently smoke, with risk adjustment performed as described according to current evidence.

**Table S6.** Cost-effectiveness of different tooth-retaining strategies for molars with furcation involvement (FI) compared with implant-supported crowns (ISCs) in patients aged 65 years.

**Table S7.** Cost-effectiveness analysis assuming a non-linear hazard function.

**Table S8.** Costs of different tooth-retaining strategies for molars with furcation involvement (FI) compared with implant-supported crowns (ISCs).

**Figure S1.** With increasing willingness-to-pay ceiling threshold, the cost-effectiveness probability of ISCs increased.

**Figure S2.** Sensitivity analysis exploring the effects of varying recall interval within supportive periodontal or implant treatment (SPT/SIT).

**Figure S3.** Lifetime costs if lost teeth or implants are assumed to not be replaced after fatal failure.

**Figure S4.** Out-of-pocket expenses for different treatments for enrollees of the public insurance.

**Address:**

Falk Schwindicke
Department of Operative and Preventive Dentistry
Charité – Universitätsspital Berlin
Afinmannshausen Str. 4-6
14197 Berlin, Germany
E-mail: falk.schwindicke@charite.de