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RESEARCH REPORTS
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Cost-effectiveness of One- and Two-step Incomplete and Complete Excavations

ABSTRACT

The treatment of deep caries lesions carries significant risks for the integrity of the pulp and often initiates a cascade of re-interventions. Incomplete caries removal may reduce these risks and avoid or delay re-treatment. The present study analyzed the cost-effectiveness of one- and two-step incomplete as well as complete excavations. We used Markov models to simulate treatment of a molar tooth with a deep caries lesion in a 15-year-old patient. Retention of the tooth and its vitality as effectiveness measures as well as accruing costs were analyzed over the patient's lifetime. The model adopted a public-private-payer perspective within German health care. Transition probabilities were calculated based on literature reviews. Monte-Carlo microsimulations were performed with 6-month cycles. One-step incomplete excavation resulted in lower long-term costs and in longer-retained teeth and their vitality (means: 53.5 and 41.0 yrs) compared with two-step incomplete (52.5 and 37.5 yrs) and complete excavations (49.5 and 31.0 yrs), and dominated the other strategies in 70% to 100% of simulations. Regardless of the assumed willingness-to-pay ceiling value, one-step incomplete excavation had the highest probability of being cost-effective. Despite limited evidence levels of input data, we expect one-step incomplete excavation to reduce costs while retaining deeply carious teeth and their vitality for longer.

KEY WORDS: dental caries, dental cavity preparation, health care economics, dental economics, Monte Carlo method, economic model.

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INTRODUCTION

Deep caries lesions usually require invasive treatment, including caries removal and restoration of the cavity. The removal of caries in proximity to the pulp is often associated with immediate or long-term complications, which initiate a cascade of re-treatment with progressive removal of dental hard tissue, eventually leading to loss of pulpal health or the tooth (Brantley *et al.*, 1995). Delaying this vicious cycle might allow both retention of teeth and their vitality for longer and reduction of the economic burden resulting from the treatment of deep lesions.

Complete removal of all carious dentin has been shown to have increased risks of pulpal exposure and post-operative pulpal symptoms in comparison with incomplete caries excavation (Ricketts *et al.*, 2013; Schwendicke *et al.*, 2013a). Such incomplete excavation can either be performed in 2 steps ("stepwise"), with incomplete removal of carious biomass in the first and complete excavation in the second step, or in 1 step ("partial excavation"), where carious dentin is sealed under the definitive restoration. Both techniques aim at avoiding pulpal complications but are not commonly used in general dental practice, partially since professional regulations do not support or incentivize such treatments (Oen *et al.*, 2007; Schwendicke *et al.*, 2013c).

Since one- and two-step incomplete removals instead of complete caries removal alter the probability and sequence of re-interventions, they are likely to influence health outcomes and costs. Changing the practice of treating deep caries lesions may therefore have considerable health and cost implications. Based on current evidence, the present study investigated long-term cost-effectiveness of incomplete and complete removal of deep caries.

MATERIALS & METHODS

Model

We used Markov simulation models to follow an initially vital, asymptomatic molar with a deep caries lesion treated with different caries removal strategies. We compared 3 interventions (one- and two-step incomplete as well as complete caries removal) in the context of German health care. For each excavation strategy, we constructed a model involving the sequence of events emanating from the initial therapy based on assumptions of clinical reality in Germany (TreeAge Pro 2013, TreeAge, Williamstown, MA, USA). For two-step excavation, we assumed that the second excavation stage and provision of the definitive restoration were performed 6 mos after the first step.

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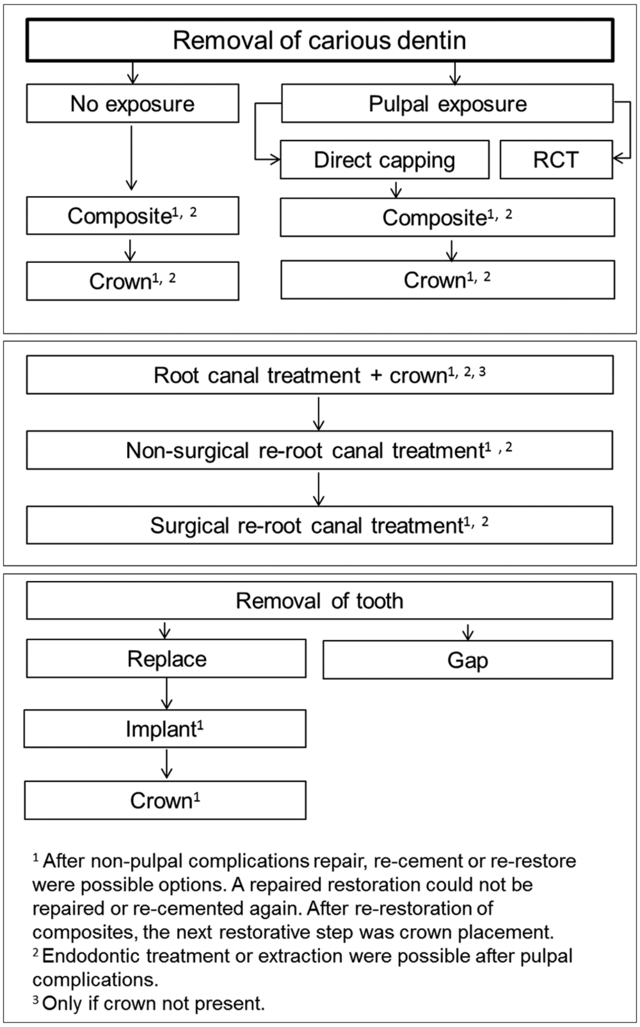

Figure 1. State transition diagram of the underlying model. Within each cycle, teeth either remained within their respective state or were translated to the next health state based on transition probabilities. Translation was performed by traversing treatment states, with associated costs. RCT = Root canal treatment.

Complications and subsequent treatments were chosen according to current evidence and in consultation with an expert consensus panel (FS, HML, SP, CD). Simulation was performed in discrete 6-month cycles. Teeth either remained in their respective state or were translated to the next health state, based on transition probabilities. Translation was performed by traversing treatment states, accruing costs (Fig. 1). We modeled only complications related to the treatment of deep caries. Model validation was performed internally (by sensitivity analyses) and externally (peer review by an experienced health economist [MS]).

Estimation of Parameters

To calculate transition probabilities during or after initial caries removal, we first performed a systematic review of the literature, using the methodology of a previously published study (Schwendicke *et al.*, 2013a). Details of inclusion criteria, search strategy, and evidence grading can be found in the Appendix (Appendix Tables 1-6). Since follow-up was usually not more than 2 yrs, and there is currently no indication that long-term risks differ for incompletely and completely excavated teeth, we inferred that risk of failure was independent of the choice of initial excavation method after 2 yrs. Since this assumption lacks sufficient evidence, doubts remain regarding the long-term non-pulpal risks of one-step incomplete excavation. Thus, we explored the effects of increasing these risks on cost-effectiveness (see below).

Risk of failure in subsequent health states was assumed to be independent of the excavation method. To estimate these probabilities, we performed a non-systematic literature search. Based on identified studies, weighted annual failure rates (AFR) and 95% confidence intervals (95% CI) were calculated. AFRs and 95% CIs were estimated depending on the time spent in each state, with 3 time plateaus being modeled (0-2, 2-5, > 5 yrs after the last treatment). Allocation probabilities were based on reviewed studies and final consensus of the abovementioned panel.

The model adopted a mixed public-private-payer perspective characteristic of German health care. Calculation was based on Fee Catalogues for the statutory public insurance, which covers 88% of all Germans. For treatments which are not fully reimbursed, calculation was based on the private dental catalogue (GKV-Spitzenverband, 2013; KZBV, 2013). Factoring of chargeable item points is common to determine costs of private treatment in Germany. The standard multiplication factor (×2.3) was used. Items were restricted in number and character to reflect cost limitations and awareness. Total costs *per* course of treatment were calculated after quantification of itemized costs. Costs were calculated in Euros and future costs discounted at 3% *per annum* (IQWiG, 2009). No such discounting was performed for future effectiveness, since it remains unclear whether and how to discount years of tooth retention.

Cost-effectiveness Analyses (CEAs)

Two CEAs were performed: In the first CEA, the retention time of a tooth, regardless of its vitality, was used as the effectiveness parameter. In the second CEA, the time a tooth remained vital was evaluated. Treatment of exactly one molar in a 15-year-old male patient with a remaining life expectancy of 63.5 yrs was simulated (Statistisches Bundesamt, 2013). To re-calculate evidence-based mean annual failure rates into 6 monthly transition probabilities, we used the following formula:

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

p = transition probability *per* cycle,

$\bar{a}$ = mean annual failure rate for the respective time plateau, and

y = time plateau in yrs (*e.g.*, 2 for 0-2 yrs).

We performed Monte-Carlo microsimulations and introduced joint parameter uncertainty by randomly sampling time-dependent transition probabilities of follow-up treatments from a uniform distribution of parameters between 95% CI (Briggs *et al.*,

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Table 1. Estimated Transition Probabilities

Risk of Failure after Different Excavation Strategies

Risk of	During or After	(Annual)[1] Failure Rates in % (95% CI) During/After: Two-step Incomplete Removal	One-step Incomplete Removal	Complete Removal	Transition to	Allocation Probability (%) for Each Scenario: Base-case Scenario	Less Invasive Scenario	More Invasive Scenario
Pulpal exposure[1]	1st step	0.8 (0.0/2.1)	1.4 (0.0/6.0)	32.4 (22.0/52.0)	Direct capping	95	100	50
	2nd step	10.4 (2.0/18.0)	-	-	Root canal treatment	5	0	50
Pulpal complication	0-2 yrs	6.2 (0.0/10.0)	1.0 (0.0/1.5)	9.1 (0.0/14.0)	Root canal treatment	95	100	80
	2-5 yrs		1.3 (0.4/2.0)[2]		Extraction	5	0	20
	> 5 yrs		1.2 (0.8/1.6)[2]					
Non-pulpal complication	0-2 yrs	3.1 (0.0/14.0)[3]	0.6 (0.0/1.1)	3.1 (1.0/14.0)	Re-restore composite[4]	60	50	0
	2-5 years		4.6 (2.5/8.4) [2,3]		Re-restore crown	20	10	95
	> 5 yrs		3.4 (2.0/5.7) [2,3]		Repair[5]	15	35	0
					Extraction	5	5	5

Risk of Failure after Different Follow-up Treatments

Transition Probability after	Annual Failure Rates in % (95% CI) Depending on Time after Last Treatment: 0-2 yrs	2-5 yrs	>5 yrs	Transition to	Allocation Probability (%) for Each Scenario: Base-case	Less Invasive	More Invasive
Direct capping and	18.7 (10.0/26.0)	9.7 (4.0/15.8)	4.7 (1.5/7.9)	Root canal treatment	95	100	80
				Extraction	5	0	20
composite restoration or	5.3 (0.6/13.0)	4.6 (2.5/8.4)	3.4 (2.0/5.7)	Re-restore composite[4]	60	50	0
				Repair[5]	15	35	0
				Restore with crown	20	10	95
				Extraction	5	5	5
crown placement	1.5 (0.5/2.5)	1.3 (0.4/2.0)	1.2 (0.8/1.7)	Re-cementation[5]	15	40	15
				Repair[5]	10	20	0
				Re-restore crown	50	30	40
				Extraction	25	10	45
Crown placement on vital tooth without previous exposure	3.0 (1.0/5.0)	2.5 (0.7/4.0)	2.4 (1.5/3.5)	Root canal treatment	40	40	20
				Re-cementation[5]	15	25	15
				Re-restore with post-crown	30	10	25
				Repair[5]	5	15	0
				Extract	10	10	40
Root canal treatment and	2.8 (1.0/7.5)	2.0 (0.6/5.0)	1.7 (0.5/3.5)	Non-surgical re-treatment	20	80	0
				Surgical re-treatment	30	10	50
				Extraction	50	10	50
crown placement[3]	1.5 (0.5/2.5)	1.3 (0.4/2.0)	1.2 (0.8/1.7)	Re-cementation[5]	15	40	15
				Repair[5]	10	20	0
				Re-restore with post-crown	50	30	40
				Extraction	25	10	45
Non-surgical re-rooting of canal and	5.8 (4.2/6.9)	2.5 (1.7/3.6)	2.3 (1.7/3.2)	Surgical re-treatment	25	50	0
				Extraction	75	50	100
crown placement[6]	1.5 (0.5/2.5)	1.3 (0.4/2.0)	1.2 (0.8/1.7)	Re-cementation[5]	15	40	15
				Repair[5]	10	20	0
				Re-restore with post-crown	50	30	40
				Extraction	25	10	45
Surgical re-root canal treatment and	10.5	5.6	6.0	Extraction	100	100	100
crown placement[6]	1.5 (0.5/2.5)	1.3 (0.4/2.0)	1.2 (0.8/1.7)	Re-cementation[5]	15	40	15
				Repair[5]	10	20	0
				Re-restore with post-crown	50	30	40
				Extraction	25	10	45

(continued)

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Table 1. (continued)

Transition Probability after	Annual Failure Rates in % (95% CI) Depending on Time after Last Treatment			Transition to	Allocation Probability (%) for Each Scenario		
	0-2 yrs	2-5 yrs	>5 yrs		Base-case	Less Invasive	More Invasive
Post-crown and	1.6 (0.0/3.2)	2.5 (2.0/3.0)	1.6 (1.5/1.7)	Re-cementation[5]	15	50	15
				Re-restore	40	35	20
				Extraction	45	15	65
(re-) root canal treatment	See above			See above			
Implant and crown	1.3 (1.3/1.3)	0.9 (0.6/1.1)	0.8 (0.5/1.1)	Re-cementation/Re-fixing	60	70	40
				Re-restore crown	20	10	40
				Renew implant + crown	20	20	20

Failures occurring directly after excavation or after follow-up treatments are shown in the upper and lower parts of the Table, respectively. Risk of pulpal exposure and weighted annual failure rates are given. 95% Confidence Intervals (in parentheses) were used within scenario sensitivity analyses or to allow for random sampling. Annual failure rates were varied depending on the time spent in the respective health state.

[1]For pulpal exposure, risk was not calculated annually, but was event-based.

[2]After 2 post-excavation yrs, failure rates were assumed to be independent of the initial caries removal strategy and based on estimations for composite restorations after conventional excavation. The resulting uncertainty was analyzed (Appendix Table 9).

[3]Since data for non-pulpal failure of two-step incomplete excavations were sparse, we conservatively assumed that there was no difference between two-step incomplete and complete removal regarding non-pulpal failure.

[4]Composites could be re-restored only once; otherwise, crowning would be performed.

[5]Re-repair or re-cementation of previously repaired restorations was not assumed to be an option. If repair or re-cementation was not possible, allocation probability of extraction increased accordingly.

[6]Since approximately 50% of failures of vital crowns were assumed to be of pulpal origin, we adjusted failure rates for non-vital teeth accordingly.

2002). Mean point estimates for costs were used to rank strategies, and incremental cost-effectiveness ratios (ICER = $\Delta c/\Delta e$) were calculated (Drummond *et al.*, 2005). Additionally, we plotted the probability of being cost-effective against different willingness-to-pay ceiling values, *e.g.*, the additional costs a decision-maker is willing to sacrifice for an additionally gained unit of effectiveness (Briggs *et al.*, 2002).

We analyzed the effects of variability of failure rates for different excavation methods using best- and worst-case scenario analyses. Furthermore, effects of possibly increased long-term non-pulpal risk of one-step incomplete excavation were analyzed. Effects of uncertainty of allocation were explored for 2 scenarios (a less and a more invasive approach to dental treatment). Univariate sensitivity analyses investigated further effects of uncertainty, heterogeneity, and distribution of input variables.

RESULTS

Our estimation of transition probabilities after incomplete excavation was based on 9 studies (Appendix Tables 3, 4, Appendix Fig. 1), which had moderate to high risk of bias, resulting in very low to moderate evidence levels (Appendix Tables 4, 5). Performed meta-analyses and estimates of cost *per* course of treatment are shown in Table 1 and Appendix Tables 6 to 8, respectively.

Cost-effectiveness was analyzed based on 100 simulations, each with 100 random samples. One-step incomplete excavation retained teeth and their vitality longer (means: 53.5 and 41.0 yrs) and at lower costs (265 €) than two-step incomplete (52.5 and 37.5 yrs, 360 €/+36%) and complete excavations (49.5 and 31.0 yrs, 398 €/+50%) and dominated the other strategies in 70% to 100% of simulations. One-step caries removal had the highest probability of being cost-effective regardless of the chosen ceiling value in both analyses (Fig. 2, Appendix Fig. 2, Table 2).

One-step caries removal was the most cost-effective strategy in scenario and univariate sensitivity analyses (Table 2, Appendix Table 9, Appendix Figs. 3, 4). In the best-case scenario, one-step excavation was more than twice as cost-effective as complete excavation (Table 2). Within the worst-case scenario, two-step-incomplete excavation was found slightly less cost-effective than complete excavation (Table 2, Appendix Fig. 3). The assumption of increased long-term risk of non-pulpal complications for one-step incomplete excavation (9.2% annually after 2-5 yrs and 6.8% annually after >5 yrs) had only limited effects on cost-effectiveness of one-step incomplete excavation (mean retention time of tooth and vitality, 52.5 and 40.0 yrs, respectively, at mean costs of 294 €).

DISCUSSION

Dentinal caries lesions and deep restorations still have a high prevalence, even in industrialized countries, with a considerably skewed epidemiological distribution (Ridell *et al.*, 2008; Schiffner *et al.*, 2009). Changing the initial treatment of such lesions may reduce costs and improve oral health, with patients with high treatment needs being likely to benefit the most. Based on the best available evidence, the present study found one-step incomplete excavation to be the most cost-effective strategy compared with two-step incomplete excavation and complete caries removal, retaining teeth and their vitality longer at lower costs. Our analysis was based on several assumptions.

Cost-estimation adopted a payer perspective and neglected costs for transport or loss of working time. This seemed justifiable, since the time spent for dental treatment is generally relatively short, resulting in low or no frictional costs. The German

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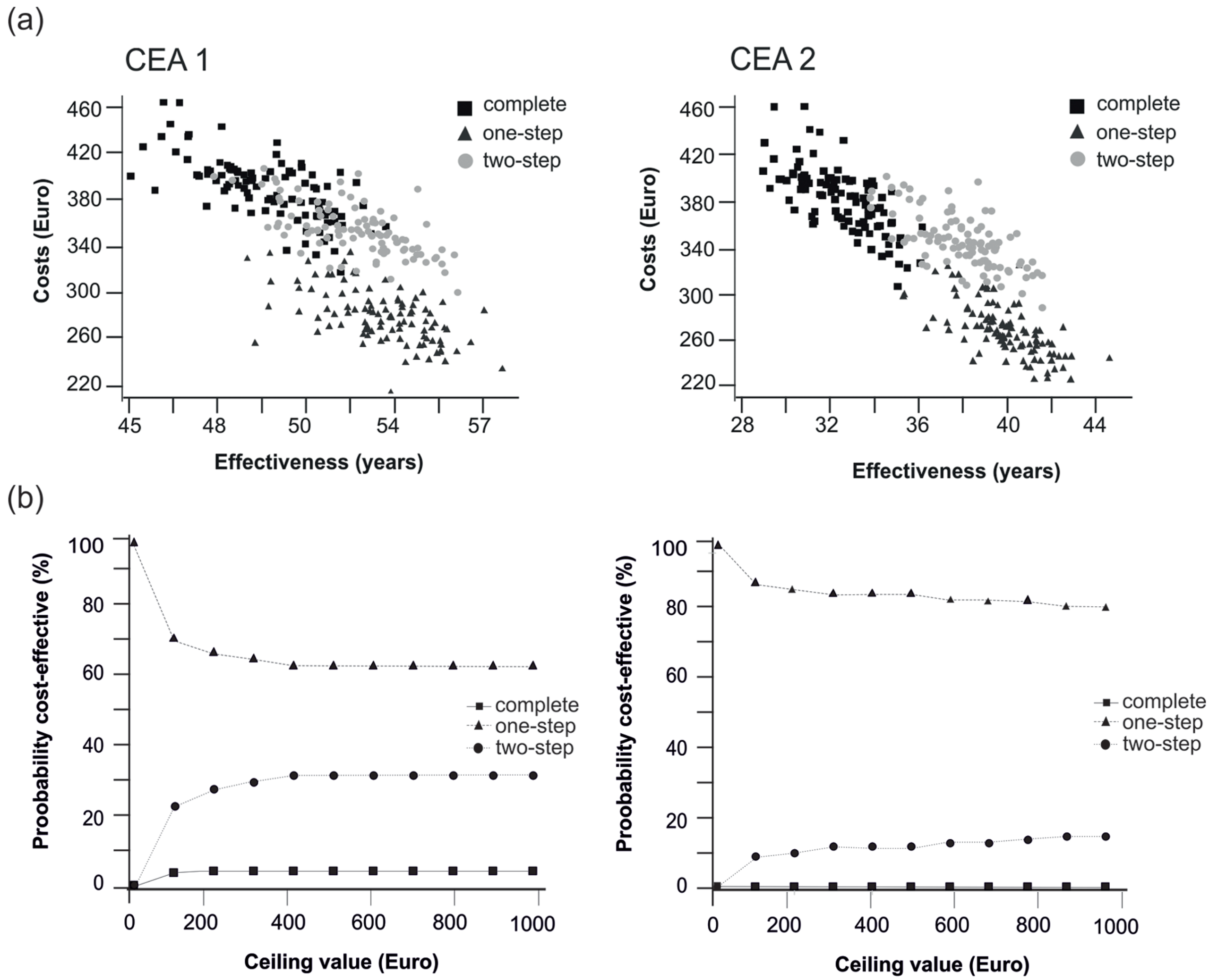

Figure 2. Cost-effectiveness of different excavation strategies for different effectiveness parameters (CEA 1, retention time of a tooth; CEA 2, retention time of pulpal vitality). **(a)** Costs and effectiveness for each simulation were plotted on the x- and y-axes, respectively. Vitality of the tooth was lost earlier than the tooth itself, reducing the effectiveness of all strategies and increasing the variability of effectiveness *per* simulation. Effectiveness advantages of one-step incomplete removal were more pronounced if retention of vitality was analyzed. Costs remained the same for both CEAs for each strategy, since the sequence of events and the resulting follow-up treatment did not differ between the 2 analyses. **(b)** Cost-effectiveness-acceptability curves for CEA1 and CEA2. For each strategy, the probability of being cost-effective is plotted against different willingness-to-pay ceiling values. A ceiling value reflects the maximum a decision-maker is willing to invest to achieve an additional unit of effectiveness (Briggs *et al.*, 2002). By increasing the ceiling value, effectiveness instead of cost differences between strategies become more important. If the ceiling value is higher than the incremental cost-effectiveness ratio, a strategy can become more cost-effective despite being more costly than its comparator. One-step incomplete excavation has the highest chance of being cost-effective compared with two-step incomplete and complete excavations, regardless of the chosen ceiling value. Raising the ceiling value from 0 to 400 € increases the probability of two-step excavation being cost-effective, with a more pronounced increase if retention time of a tooth regardless of its vitality is analyzed. The probability of complete excavation being cost-effective remains very low (0-5%), regardless of the chosen ceiling value.

fee-*per*-item system and item-factoring allowed for a detailed cost-calculation, reflecting a certain degree of cost-variability. However, cost-effectiveness is heavily influenced by the specifics of the health care: Despite low caries incidence and regular attendance of most patients (Schiffner *et al.*, 2009; Barmer-GEK, 2013), German dentistry is often focused on restoration longevity (Schwendicke *et al.*, 2013c), and certain treatments like surgical endodontics are more frequently performed than in other countries (Lumley *et al.*, 2008), possibly because they are relatively well-reimbursed (Barmer-GEK, 2013). Bridge replacements are common for the replacement of posterior teeth (Barmer-GEK, 2013), but considering the young age of the patient, we found an implant-retained crown the more sensible choice.

Effectiveness was measured as the retention time of a tooth or its vitality. Measures like quality-adjusted life-years were not used, since they have only a limited association with the clinical condition and the individual oral health self-assessment, especially for a missing single posterior tooth (Oscarson *et al.*, 2007; Baba *et al.*, 2008; Ponsi *et al.*, 2011). In contrast, 'retaining teeth' was found to be a relevant parameter, determining if further treatment, with associated complications and costs, can be delayed or avoided (Lucarotti *et al.*, 2005a; Pjetursson *et al.*, 2007; Jung

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Table 2. Mean Costs (c) in Euros, Mean Effectiveness (e) in Retention Years (y), Mean Cost-effectiveness, Cost-effectiveness Ranking, and Incremental Cost-effectiveness Ratios (ICERs) of Different Caries Removal Strategies

Effectiveness Parameter	Scenario[1]	Strategy	c (€)	e (y)	CE (€/y)	Rank (d, u)	ICER[2] (Δ€/Δy)
CEA 1: Mean retention time of tooth	Base-case	One-step	265	53.5	5.0	1	
		Two-step	360	52.5	6.8	2 (d)	–95
		Complete	398	49.5	8.0	3 (d)	–33
	I Best-case	One-step	256	54.0	4.8	1	
		Two-step	323	53.0	6.0	2 (d)	–67
		Complete	476	47.5	10.0	3 (d)	–34
	II Worst-case	One-step	284	53.5	5.4	1	
		Two-step	370	52.5	7.0	3 (d)	–86
		Complete	348	51.5	6.8	2 (d)	–32
	III Less invasive	One-step	254	58.0	4.4	1	
		Two-step	348	57.0	6.2	2 (d)	–94
		Complete	387	51.5	7.6	3 (d)	–20
	IV More invasive	One-step	283	48.5	5.0	1	
		Two-step	413	48.0	8.6	2 (d)	–260
		Complete	470	45.5	10.4	3 (d)	–41
CEA 2: Mean retention time of vitality	Base-case	One-step	265	41.0	6.4	1	
		Two-step	360	37.5	9.6	2 (d)	–27
		Complete	398	31.5	12.6	3 (d)	–14
	I Best-case	One-step	256	44.0	5.8	1	
		Two-step	323	41.5	7.8	2 (d)	–27
		Complete	476	23.5	20.2	3 (d)	–13
	II Worst-case	One-step	283	39.5	7.2	1	
		Two-step	370	36.0	10.2	3 (d)	–25
		Complete	348	35.0	10.0	2 (d)	–14
	III Less invasive	One-step	254	41.0	6.2	1	
		Two-step	348	38.0	9.2	2 (d)	–31
		Complete	387	27.5	14.0	3 (d)	–10
	IV More invasive	One-step	283	40.5	5.8	1	
		Two-step	413	36.0	11.4	2 (d)	–29
		Complete	470	28.5	16.4	3 (d)	–10

Two CEAs were performed, each for a different effectiveness parameter (mean retention time of a tooth or its vitality). ICERs are calculated in comparison with the highest ranked strategy. Base-case and sensitivity scenario analyses were performed. Scenarios I and II explored the effects of maximal variation of transition probabilities during or after initial treatment of deep caries (see Table 1). Scenarios III and IV explored the effects of various allocation probabilities, simulating a less invasive or a more invasive treatment approach.

[1]For input data as shown, see Table 1.

[2]Calculated to highest ranked strategy. For our analysis, negative values indicate additional costs *per* effectiveness loss. Strategies were dominated (d) by the first-ranked strategy.

et al., 2008). In our simulation, 22%, 35%, and 42% of teeth were replaced after 63.5 yrs after one- and two-step incomplete and complete excavations, respectively, confirming the long-term consequences of the initially performed caries removal.

Besides leading to the longer retention of teeth, one-step excavation seemed most suitable to maintain pulpal vitality of deeply carious teeth. It seemed that, in particular, pulpal exposure has significant long-term influence on both effectiveness and costs, since follow-up treatments like direct capping or root-canal treatment either have relatively poor success rates (see Appendix Table 7) or are rather invasive and costly, thereby accelerating the "death spiral" of the tooth (Qvist, 2008). Thus, our study translates current evidence regarding pulpal exposure after one-step incomplete excavation, as outlined in the recent Cochrane review as well (Ricketts *et al.*, 2013), to long-term cost-effectiveness.

Besides having a higher risk of pulpal exposure than one-step incomplete caries removal, two-step excavation leads to higher costs associated with the second treatment step. These costs decrease the cost-effectiveness of two-step excavation and could well be higher in other countries, since German health care reimburses only associated items like anesthesia, but not the re-restoration. If two-step excavation leads to both higher costs and lower effectiveness than one-step incomplete caries removal, the need to re-enter can be increasingly questioned. Based on studies reporting decreased fracture resistance of one-step incompletely excavated teeth *in vitro* (Hevinga *et al.*, 2010), it can be argued that two-step excavation may be a compromise between one-step incomplete and complete excavations. However, recent reviews did not find increased risks of non-pulpal failure for one-step compared with two-step incompletely excavated teeth (Schwendicke *et al.*, 2013b) or increased restor-

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ative failure after incomplete compared with complete excavations (Ricketts *et al.*, 2013). We simulated the possible increased long-term risk of non-pulpal failure after one-step incomplete excavation in a sensitivity analysis. Such increase did not have significant effects on cost-effectiveness or implied rankings. However, given the generally limited supporting long-term evidence, some of our conclusions may have to be revised, if future research findings prompt changes in the underlying assumptions.

Further factors might change our results. First, patient- and dentist-related factors influence the risk of failure (Burke *et al.*, 2005; Lucarotti *et al.*, 2005b). Such dentist-related effects were confirmed in our sensitivity analyses, with considerable influence of the treatment approach (less or more invasive) on the cost-effectiveness of all strategies. Patients usually show not independent, but rather, correlated risks of failure in different health states (*e.g.*, high-risk caries patients). Such correlation was not simulated, and sub-group analyses might be required to show which group of patients benefits the most from changes in the current practice of caries removal. Such analysis will most likely reflect the skewed distribution of deep lesions and could thus highlight the issue of social stratification. Second, we have not accounted for gender differences and future changes in life expectancy. Given the results of our sensitivity analyses, it is unlikely that such heterogeneity will alter our cost-effectiveness ranking. Third, we simulated the treatment of only permanent teeth. Since follow-up treatment of primary molars is less predictable in its sequence and considerably different from that for permanent teeth, we did not attempt CEA for primary teeth. We included data regarding risk of failure in primary teeth within our meta-analysis to increase the evidence supporting our study, since there are fewer studies analyzing partial excavation of permanent than primary teeth. This might introduce some bias into our results. However, a recent systematic review showed that incompletely excavated primary teeth have a higher risk of complications compared with permanent teeth (Schwendicke *et al.*, 2013b). Another review showed slightly increased risk of pulpal exposure in permanent teeth after two-step incomplete excavation, but reduced risks compared with primary teeth after one-step excavation (Ricketts *et al.*, 2013). Our own sensitivity analyses showed that basing our simulation solely on data from permanent teeth alters the estimates only slightly and leaves implied rankings unchanged. Analyzing cost-effectiveness in primary teeth, however, should be considered, and extended to compare null-step excavation (*i.e.*, caries sealing without any excavation) as well (Ricketts *et al.*, 2013).

The use of different restorative techniques in both dentitions (*e.g.*, use of amalgam or glass-ionomer cement restorations) may change our estimates. Different restorative choices may have an impact, since life cycles of restorations and re-interventions (repair or renew) differ. Effects on comparative cost-effectiveness rankings, however, are likely to be limited, if teeth are restored with similar materials regardless of the excavation method. Last, most studies included in the analysis were performed in university hospitals. In primary care, cost-effectiveness of incomplete excavations might be even higher, since complete excavation is usually performed under time constraints with rose-head burs (Schwendicke *et al.*, 2013c), and rubber-dam application is not common (Gilbert *et al.*, 2010). Conversely, practitioners who are not familiar with incomplete excavation may radiographically detect and re-treat residual lesions, which would decrease the cost-effectiveness of one-step incomplete excavation. Educating both dentists and patients regarding this treatment concept or radiopaque tagging of residual caries lesions may be strategies to overcome this problem.

In conclusion, we found one-step caries removal to be more cost-effective than both two-step incomplete and complete excavations of deep caries. This finding was robust within the limitations of a simulation model. Current levels of evidence limit the external validity of our results. Further research may allow for the transferring of scientific results regarding incomplete excavation into general practice.

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