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Root Canal Treatment versus Vital Pulp Therapy after Carious Exposure: A Cost-effectiveness Analysis in the United States Healthcare System.

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ABSTRACT

Introduction: This cost-effectiveness analysis compared root canal therapy (RCT), direct pulp cap (DPC), partial pulpotomy (PP) and full pulpotomy (FP) in the U.S. healthcare system. **Methods**: A decision tree was constructed for a simulated adult patient with a permanent, mature, cariously exposed, asymptomatic tooth. Transition probabilities were obtained from previously published literature. National average costs for each treatment were obtained from published dental fees survey. A Monte Carlo simulation served for analysis of the CEA. **Results**: Monte Carlo simulation found cost-effectiveness ratio of 7.19, 29.53, 37.02 and 41.32 for FP, DPC, RCT and PP respectively. **Conclusions**: Our study found FP to be significantly more cost-effective than NSRCT, DPC and FP. More research is needed in assessing and defining parameters for future CEAs in endodontics and dentistry in general.

INTRODUCTION

Pulpal exposure is a common occurrence when removing large caries lesions. In these cases, tooth preservation strategies include vital pulp therapy or root canal therapy.

When successful, vital pulp therapy (VPT) for the exposed pulp, which includes direct pulp capping (DPC), partial pulpotomy (PP), and full pulpotomy (FP), preserves tooth vitality. Risks associated with unsuccessful vital pulp therapy include painful pulpitis, pulpal necrosis, or apical periodontitis. In such cases, root canal therapy remains a treatment option. Historically, VPT procedures have been reserved for the young, immature pulp (1); however, with the advent of newer materials and protocols, recent research has demonstrated their effectiveness in mature pulps (2-11).

In the United States, root canal therapy (RCT), which has consistently been associated with excellent success rates in the dental literature, has been the recommended treatment for carious pulp exposures (12). Despite its good outcomes, RCT involves the removal of varying amounts of tooth dentin, and the risks of such treatment are vertical root fractures (VRFs) and persistent endodontic disease. Unless the entire fractured root segment can be surgically-resected without significantly compromising the tooth, extraction is usually indicated in cased with VRF. Persistent endodontic disease is often a result of intracanal infection, and non-surgical retreatment in such cases can be a treatment option. For cases in which iatrogenic mishaps such as canal transportations, retained separated instruments, or significant ledging prevent adequate cleaning and shaping of the apical canal, endodontic microsurgery might be the only predictable, remaining option aimed at tooth retention.

Cost-effectiveness analyses (CEA) estimates costs and benefits associated with various interventions or procedures and makes comparisons among alternatives from an economics point of view. Such studies are generally conducted using available data from

previous articles or reports, and simulated using computer software. A variety of results could unfold from this type of study. The cost of one treatment could be less than the other, but the benefits might not outweigh the lower cost. Such results are important in the decision of treatments for clinicians, patients, and entities in the allocation of time and resources.

The dental literature has seen an increase in the number of high quality cost-effectiveness publications, especially in the last 10 years (18). In the field of endodontics, however, fewer studies have been developed comparing RCT with other treatment modalities (19, 20). With many considerations and biases factoring into our decision-making, it is important to develop objective methods like CEA to inform our treatment recommendations. The purpose of this study was to compare the cost-effectiveness of RCT, DPC, PP and FP in the U.S. healthcare system.

METHODS

A decision analysis model was built using TreeAge Pro Healthcare software (TreeAge Software, Williamston, MA). The model followed a mandibular molar tooth after carious exposure throughout different treatment paths. For the purpose of our research, we followed the treatment of a tooth in a 27-year old patient as research showed that this was the average age for our patient population (21). Our patient's life expectancy was set at 78.6 years old which corresponds to the national average (22).

The Model

A decision tree model was built to simulate our scenario (Figure 1). After carious exposure, the tooth will be faced with 4 treatment options: RCT, DPC, PP or FP. Transition probabilities were based on the review of the literature and determined the probability of transition to a subsequent state. Certain parameters were calculated for the completion of the model. At each decision-tree node, event rates/probabilities were calculated from previously published peer-reviewed literature, while costs were extracted from previously published survey data.

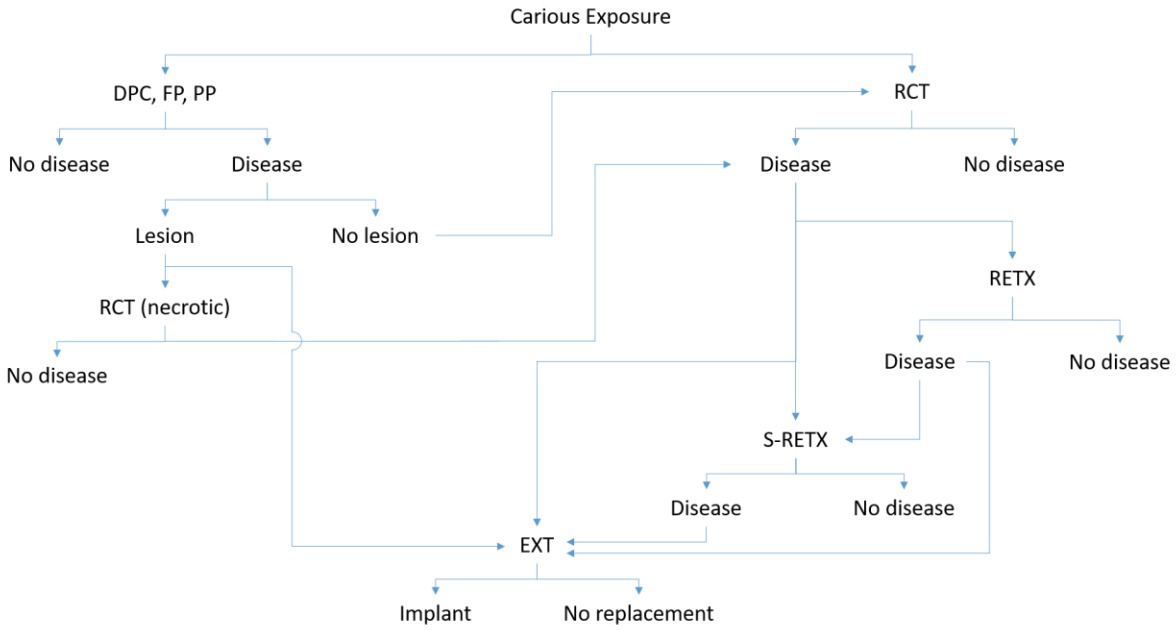

Figure 1. Decision tree diagram.

Probability Estimates

To provide data for the model, a systematic review of the literature was conducted to obtain success rates and follow-up times for the treatments of interest: RCT, DPC, PP and FP. Two electronic databases, PubMed and GreyLit, were screened using filters and Boolean search terms (Supplemental Figures 1 and 2). Supplemental Tables 1 and 2 show included and excluded articles and reasons for exclusion. Success rates up to 48 months of follow-up time were averaged to obtain a single numerical value that represented the transition probability from one node of the model to the other.

For non-surgical retreatment, surgical retreatment (SurRETX), and implants, previous systematic reviews or meta-analyses that reported outcome as success/survival rate and follow-up times for our population of interest were used (23, 24).

Cost Estimates

This simulation was built for the U.S. healthcare system. The cost for each treatment was obtained from the reported national average (25). General Practitioner numbers were used in our study with the assumption that most VPT procedures would be conducted by general practitioners (Table 1). Core build-up was added to costs for RCT and RETX. A two-surface resin-based composite (posterior) was added to the cost of treatment for each VPT. Crown and abutment costs were added to implants, with the abutment cost representing an average of prefabricated and custom abutments.

TABLE 1. Costs of treatment

Treatment	Cost ($)
Root Canal Therapy – GP – molar	1,092.43
Direct pulp cap	83.50
Partial pulpotomy	248.94
Full Pulpotomy	193.61
Retreatment – E – molar	1502.42
Core build-up – GP	279.72
Surgical retreatment – E – molar, two roots	1662.66
Extraction	187.36
Implant	2,023.55
Crown and abutment	2,240.46
Resin-based composite - two surfaces, posterior	241.59

Costs for each treatment used in the model. Core build-up cost was used as an added cost for RCT and RETX procedures. Resin-based composite cost was used as an added cost for all VPT procedures (DPC, FP and PP). Abutment cost was used as an added cost to implants, and was averaged from prefabricated (717.32) and custom (865.31) abutments.

Effectiveness Estimates

Annual mortality rates (AMR) were calculated from the follow-up times reported from the studies selected. A yearly linear loss was assumed. Once AMR was obtained, the approximate tooth life years (ATLY) was calculated with the following equation:

$$ATLY = 1/AMR$$

Utility was obtained with the help of an expert panel. The panel consisted of two endodontic residents, two board-certified endodontists, one board-certified prosthodontist, and one board-certified periodontist. Based on previous publications, a questionnaire with standard gamble scenarios was provided to members of the panel to determine utilities (26). Answers were related to the preference of having a particular tooth state as opposed to an intact tooth (Supplemental Figure 3). Utilities (Table 2) were calculated as the average of the responses with the following equation:

$$Utility = \underline{(ER1) + (ER2) + (E1) + (E2) + (Per) + (Pro)}$$

$$6$$

(ER1: endodontic resident #1, ER2: endodontic resident #2, E1: board-certified endodontist #2, E2: board-certified endodontist #2, Per: board-certified periodontist, Pro: board-certified prosthodontist.)

TABLE 2. Utility Expert Panel Responses Table

Question	ER1	ER2	E1	E2	Per	Pro	Average
1	0.95	0.95	0.95	0.99	0.95	0.99	0.96
2	0.99	0.95	0.90	0.99	0.90	0.99	0.95
3	0.99	0.95	0.90	0.99	0.90	0.99	0.95
4	0.99	0.95	0.90	0.99	0.90	0.99	0.95
5	0.90	0.95	0.90	0.95	0.80	0.90	0.90
6	0.90	0.95	0.90	0.95	0.80	0.90	0.90
7	0.95	0.95	0.95	0.95	0.95	0.95	0.95
8	0.90	0.90	0.80	0.95	0.70	0.70	0.83
9	0.90	0.95	0.80	0.60	0.80	0.99	0.84
10	0	0	0	0	0	0	0

A total of ten scenarios were presented to the expert panel utilizing a scenario-based, standard gamble questionnaire. Percentage responses converted to decimal values and averaged for each scenario.

Quality Adjusted Tooth Years (QATY) was obtained by multiplying ATLY by Utility. This parameter was calculated for each branch of the tree and served as the final payoff of the accumulated treatments for the branch:

$$QATY = ATLY \times Utility$$

Cost-effectiveness Analyses

The costs and QATYs for each strategy were used to determine cost-effectiveness parameters and cost-effectiveness ratio. Cost for each branch represented the cumulative costs of all treatment in the branch, while the QATY calculation included cumulative ATLY and utility values. Cost-effectiveness ratio (C/E ratio) was calculated to represent the cost for each year of tooth life gained, and was calculated with the following:

$$C/E\ ratio = c/e$$

C/E ratio calculation where c = net cost and e = net effectiveness

We used rollback analysis to calculate these measures. Cost for each branch represented the cumulative costs of all treatment in the branch, while the QATY calculation included cumulative ATLY and utility values.

Cost-utility ratios (CUR) and net monetary benefits (NMB) and corresponding incremental cost-utility ratio (ICUR) and incremental net monetary benefits (INMB) were estimated. CUR estimates the cost per QATY generated and is calculated as Cost/QATY. The NMB is calculated as follows:

$$NMB = E \times WTP - C,$$

NMB calculation where E is the effectiveness, C is the cost, and WTP is the societal willingness-to-pay (WTP)

WTP is usually set at $50,000 (27). It combines cost, effectiveness, and societal WTP into a single measurement. The strategy with the lowest CUR and highest NMB is considered the most preferred strategy from an economic point of view.

Sensitivity Analyses

We followed Doubilet et al. and Jain et al. to conduct probabilistic sensitivity analysis (PSA) (28, 29). A mixed first-order and second-order Monte Carlo simulation was performed for 1,000 trials (random walks) with simultaneous sampling from estimated probability distributions of the model input parameters to obtain 1,000 sets of model input estimates. Each set represents the path of a hypothetical patient through the decision model. In each scenario, probabilities were sampled from the PERT distribution (30, 31), which is based on the β distribution and provides samples on a continuous curve in any bounded range. For the PERT distribution parameters we specified input parameter minimum, maximum, and likeliest values based on probability ranges reported in the literature. Costs and QALYs were sampled from normal distributions where mean estimates were derived from the literature (Supplemental Table 1) and the relative standard deviation was set at 10% (29).

Institutional Review Board approval was not required because this was a retrospective analysis of data obtained from the literature.

RESULTS

Table 3 summarizes the findings from the probabilistic, cost and effectiveness estimates.

TABLE 3. Summary of findings

Treatment	Net Probability	Probability range	Net Cost (year 2018)	AMR	ATLY	QATY	Sources
RCT	94.39	89.70 - 94.90	1,372.15	2.56	39.06	37.50	12, 13
RCTnec	88.83	89.70 - 94.90	1,372.15	12.07	8.29	7.88	13-16
RETX	80.00	69 - 88	1,782.14	10.00	10.00	9.00	22
SurRETX	92.00	76 - 100	1,662.66	4.00	25.00	20.75	22
DPC	88.50	73.80 - 100	325.09	7.00	14.29	13.58	2-7
PP	89.07	83 - 100	490.53	8.16	12.25	11.64	8, 9
FP	97.18	92.7 - 100	435.20	1.24	80.65	76.62	7, 10, 11
EXT	-	-	187.36	-	-	0.00	-
Implant	95.75	73.5 - 100	4,264.01	0.71	140.85	118.31	23

Net probability, probability range parameters and net cost were obtained from previously published data. AMR, ATLY and QATY were calculated. Net cost for RCT, RCTnec and RETX include cost of core build-up; DPC, PP and FP include cost of resin-based composite; implant include cost of crown and abutment. Root canal treatment – necrotic (RCTnec); extraction (EXT).

A rollback analysis algorithm was used to average cost and effectiveness of each node starting from the terminal ends of the decision tree and “folding back” to the initial nodes. Table 4 shows the result of the rollback analysis.

TABLE 4. Rollback analysis

Strategy	Cost	Incremental Cost*	Effectiveness	Incremental Effectiveness	Incremental C/E Ratio	NMB	C/E Ratio
FP	560.73	-	79.71	-	-	3,984,750	7.03
DPC	837.00	276.27	28.61	-51.09	-5.41	1,429,803	29.25
PP	1,006.67	445.94	24.42	-55.28	-8.07	1,220,180	41.22
RCT	1,621.87	1,061.14	43.87	-35.83	-29.61	2,192,082	36.97

* Incremental values are calculated in comparison to the most preferred strategy (FP).

Table 5 shows the result of the Monte Carlo simulation. Results show mean (± standard deviation) cost for RCT at 1657.27±151.43, for DPC at 867.92±235.08, for PP at 969.45±171.50, and for FP at 572.82±81.87; effectiveness for RCT at 44.77±3.86, for DPC at 29.39±7.02, for PP at 23.46±4.17 and for FP at 79.65±7.84; NMB for RCT at 2,236,601.21±193,185.94, for DPC at 1,468,532.85±350,886.11, for PP at 1,172,156.17±208,356.50 and FP at 3,981,797.55±391,972.72.

TABLE 5. Results from Monte Carlo simulation

Statistic	Cost (Root Canal)	Cost (Direct Pulp Cap)	Cost (Partial Pulpotomy)	Cost (Full Pulpotomy)	Effectiveness (Root Canal)	Effectiveness (Direct Pulp Cap)	Effectiveness (Partial Pulpotomy)	Effectiveness (Full Pulpotomy)	NMB (Root Canal)	NMB (Direct Pulp Cap)	NMB (Partial Pulpotomy)	NMB (Full Pulpotomy)
Mean	**1,657.27**	**867.92**	**969.45**	**572.82**	**44.77**	**29.39**	**23.46**	**79.65**	**2,236,601.21**	**1,468,532.85**	**1,172,156.17**	**3,981,797.55**
Std Deviation	**151.43**	**235.08**	**171.50**	**81.87**	**3.86**	**7.02**	**4.17**	**7.84**	**193,185.94**	**350,886.11**	**208,356.50**	**391,972.72**
Minimum	1,202.33	350.39	445.48	326.70	33.82	13.67	12.55	56.38	1,689,236.73	683,113.53	626,761.78	2,818,645.66
2.5%	1,364.15	471.70	659.06	418.61	37.31	17.11	15.55	64.27	1,863,903.07	855,024.63	776,781.28	3,212,975.56
10%	1,463.46	559.19	739.60	473.04	39.88	20.28	17.65	69.48	1,992,298.05	1,013,356.54	881,476.92	3,473,449.13
Median	1,650.91	855.69	971.88	569.69	44.53	29.09	23.64	79.57	2,224,828.22	1,453,659.14	1,180,982.87	3,978,109.16
90%	1,855.54	1,187.09	1,194.18	682.84	49.69	38.73	28.80	89.68	2,483,187.44	1,935,262.00	1,438,693.80	4,483,404.30
97.5%	1,943.34	1,353.15	1,300.41	741.79	52.69	44.71	31.21	95.19	2,632,831.02	2,234,457.21	1,558,905.69	4,758,767.87
Maximum	2,202.44	1,576.22	1,505.00	853.73	56.08	54.09	33.97	102.12	2,802,081.17	2,703,266.12	1,697,551.50	5,105,460.34
Sum	1,657,275.00	867,915.97	969,452.30	572,823.20	44,765.17	29,388.02	23,462.51	79,647.41	2,236,601,207.59	1,468,532,852.10	1,172,156,174.12	3,981,797,553.65
Size (n)	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000
Variance	22,931.69	55,263.10	29,410.66	6,702.78	14.93	49.31	17.39	61.46	37,320,807,002.95	123,121,062,658.94	43,412,429,298.24	153,642,615,602.25
Variance/Size	22.93	55.26	29.41	6.70	0.01	0.05	0.02	0.06	37,320,807.00	123,121,062.66	43,412,429.30	153,642,615.60
SQRT[Variance/Size]	4.79	7.43	5.42	2.59	0.12	0.22	0.13	0.25	6,109.08	11,095.99	6,588.81	12,395.27
CI-	**1,647.89**	**853.35**	**958.82**	**567.75**	**44.53**	**28.95**	**23.20**	**79.16**	**2,224,628**	**1,446,785**	**1,159,242**	**3,957,503**
CI+	**1,666.66**	**882.49**	**980.08**	**577.90**	**45.00**	**29.82**	**23.72**	**80.13**	**2,248,575**	**1,490,281**	**1,185,070**	**4,006,092**

Rollback analysis showed similar results compared to the Monte Carlo simulation. For example, in the rollback analysis, the cost and effectiveness for RCT were 1621.87 and 43.87 respectively, while the Monte Carlo simulation showed 1657.27 and 44.77 for the same parameters respectively. The same pattern was found for all four strategies of interest. Table 6 shows results for the C/E ratio on all four treatments of interest.

TABLE 6. Net cost-effectiveness ratio

Decision Strategy	Cost*	Effectiveness*	C/E ratio
Rollback			
RCT	1621.87	43.87	36.97
DPC	837.00	28.61	29.25
FP	560.73	79.71	7.03
PP	1006.67	24.42	41.22
Monte Carlo			
RCT	1657.27	44.77	37.02
DPC	867.92	29.39	29.53
FP	572.82	79.65	7.19
PP	969.45	23.46	41.32

*Net cost and effectiveness values from the results of each decision strategy

Figure 2 represents a cost-effectiveness scatterplot from the results of the Monte Carlo simulation. The horizontal axis represents effectiveness in tooth life years and the vertical axis represents cost in U.S. dollars. FP was found to be significantly more cost-effective than RCT, DPC and PP.

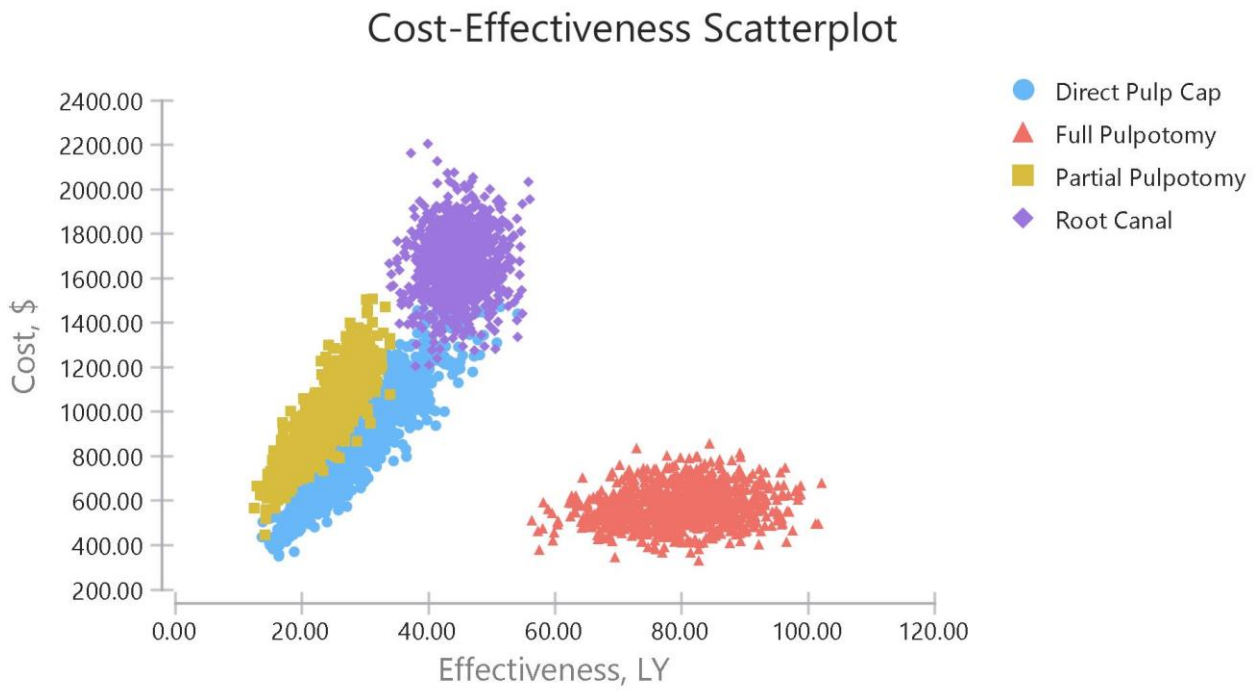

Figure 2. Scatterplot showing results from Monte Carlo simulation comparing cost ($) and effectiveness (LY). FP was significantly more cost-effective than all other treatment strategies.

Results from the univariate sensitivity analysis can be found in Table 7.

TABLE 7. Univariate Sensitivity analysis

Treatment	Cost	Effectiveness	C/E ratio
Actual			
RCT	1372.15	37.50	36.59
DPC	325.09	13.58	23.94
FP	435.20	76.62	5.68
PP	490.53	11.64	42.14
	-50%		
RCT	686.08	37.50	18.29
DPC	162.55	13.58	11.97
FP	217.60	76.62	2.84
PP	245.27	11.64	21.05
	+50%		
RCT	2058.23	37.50	54.87
DPC	487.64	13.58	35.91
FP	652.80	76.62	8.52
PP	735.80	11.64	63.21
		0.50	
RCT	1372.15	37.50	36.59
DPC	325.09	13.58	23.94
FP	435.20	76.62	5.68
PP	490.53	11.64	42.14
		0.99	
RCT	1372.15	46.22	29.69
DPC	325.09	16.74	19.42
FP	435.20	94.44	4.61
PP	490.53	14.35	34.18

DISCUSSION

CEAs compare treatments over a lifetime. This type of study can help patients, clinicians and organizations in finding the best use of limited amounts of resources. While previous publications have opted for the use of a Markov model for this type of study (19), our study was conducted using a decision tree. This model was chosen for its ability to map all possible options of treatment for our simulated patient without the need for cycling recurrent events over time.

The present study found that FP was significantly more cost-effective than RCT, DPC and PP on an adult tooth. We also found RCT to be less cost-effective than all VPT procedures. This results coincide with that of a previous CEA conducted between RCT and DPC in the German healthcare system (19). While DPC and PP were found to be a viable option in the case of carious asymptomatic exposures in adult teeth, our study found that full pulpotomy fared much better.

Several limitations were encountered. Since VPT procedures have been reserved for the pediatric patient in the past, few studies were found to include adult patients. Often times, those studies found to include adults, did not separate their results between adult and

pediatric patients. We assumed that the inclusion of pediatric patients also meant the inclusion of open apices, which some studies have found to favor better in some VPT procedures (32). Another area of concern was the inclusion of symptoms. Not all studies found would report on patients' symptoms, and again, those that did, would not always report separate results for symptomatic vs asymptomatic patients. There were also differences in studies found between treatments. Only one study could be found using our initial inclusion criteria for each pulpotomy procedure (8). On the other hand, six articles were found for DPC (2-7). This favored PP significantly as the study found 100% success after one year of follow-up (8). The results would translate to 0% AMR and a tooth that would last forever in our model. To offset this bias, we decided to include studies with symptomatic patients only for pulpotomies, thus increasing the amount of studies available. Several articles were found that compared a bioceramic material with another type of material, like calcium hydroxide or Endocem (2, 3, 4, 9). Of these studies, only the numbers associated with the bioceramic material were considered.

We found there to be a deficit in CEA studies in dentistry, especially in the endodontics field. As we experienced, the challenge of informing the model with homogenous, high-level data is currently insurmountable. There is a noticeable deficiency of well-controlled, randomized trials evaluating specific VPTs. Most studies comparing DPC, PP, and FP are not randomized. Rather, the decision regarding the specific VPT chosen is made based on the clinical presentation.

In the past, some studies have proposed ways to determine parameters needed for constructing dental CEAs (19, 33). The Quality Adjusted Life Years (QALY) parameter is one used in the medical literature to determine the effectiveness of treatment - i.e. how many more quality years of life a patient gained after a certain treatment was provided. In dentistry, this has been translated to Quality Adjusted Tooth Years (QATY), or the years a tooth has gained from our treatment before extraction (34). The QATY is a product of the ATLY and the utility of a health state (utility). Utility is a parameter obtained from surveys to patients and their assessment on how they value a certain treatment and the results obtained from it (26). Another way to obtain the quality of life parameter is with the inclusion of an expert panel. For our study, we included experts from fields other than endodontics due to their surgical and restorative expertise. The questionnaire provided a way to assess utility but it also presented with several limitations. Our expertise as specialized clinicians could have biased our answers, as opposed to answers taken from the general public. In a previous study that analyzed responses from both patients and clinicians, dentists were generally found to value utilities higher than the general public but still ranked in the same order for both groups (26). Also, all VPT states were considered to be of equal utility by the expert panel due to the assumed lack of appreciable difference for the patient experience. Future survey studies are needed to determine patients' perceptions of utility for these specific states.

Some assumptions had to be made while conducting this study. If a study included patients younger than 18 years old, it was assumed that some of the teeth would have an

immature apex, and such, were excluded. For studies reporting a follow-up time longer than 12 months, a linear AMR was assumed. This provided a fair and convenient way to calculate AMR since there is no way to determine if AMR was higher or lower in a particular year. Another assumption made was while adding ATLY for each branch. We assumed that all treatments would last to the end of their calculated ATLY, thus accumulating years of tooth life for all steps at the end of the branch. Also, we were unable to factor in different perceived utilities regarding the types of treatment failure. For instance, it can be assumed that a symptomatic failure would have significantly less utility than an asymptomatic failure. Future research can provide further evidence to determine these values.

The costs of treatment were extracted from the ADA Survey of Dental Fees 2018 (25). Most procedure costs were obtained from the general practitioner's national average while RETX and S-RETX were obtained from the endodontists' national average under the assumption that most of these procedures would be performed by specialists. Some costs were avoided due to the inherit complexity of their addition – i.e. initial appointments, follow-ups, posts, crown lengthening, healing or interim abutments, provisional crowns, and complications. Certain costs were added to specific treatment steps with the assumption that these were more than likely always needed – i.e. core build-up was added to RCT and RETX, resin-based composite was added to VPT procedures, and crown and abutment were added to implants. The addition of these procedures was used only to add costs and were not considered in the for the transition probability of each step.

Univariate sensitivity analysis was conducted for cost and QATY variables. With changes in cost or effectiveness, FP is still the most cost effective treatment. However, if the cost for DPC would drop -50%, and all other variables would remain the same, this treatment is almost as cost effective as FP. On the other hand, PP is still significantly less cost-effective than other strategies, regardless of the changes in variables.

CONCLUSIONS

Our study found that FP is more cost-effective when compared to NSRCT, DPC and FP. RCT was found to have higher costs and higher effectiveness, while DPC and PP were found to have lower cost and lower effectiveness. Only FP was found to have significantly better effectiveness at a lower cost. With the limitations of this study, we found the CEA type of analysis, combined with the decision tree methodology to provide a good way to simulate scenarios in order to predict results. This results should help patients, clinicians and corporations to make informed, rational decisions in the placement of resources. More research is needed in assessing and defining parameters for future CEAs in endodontics and dentistry in general.

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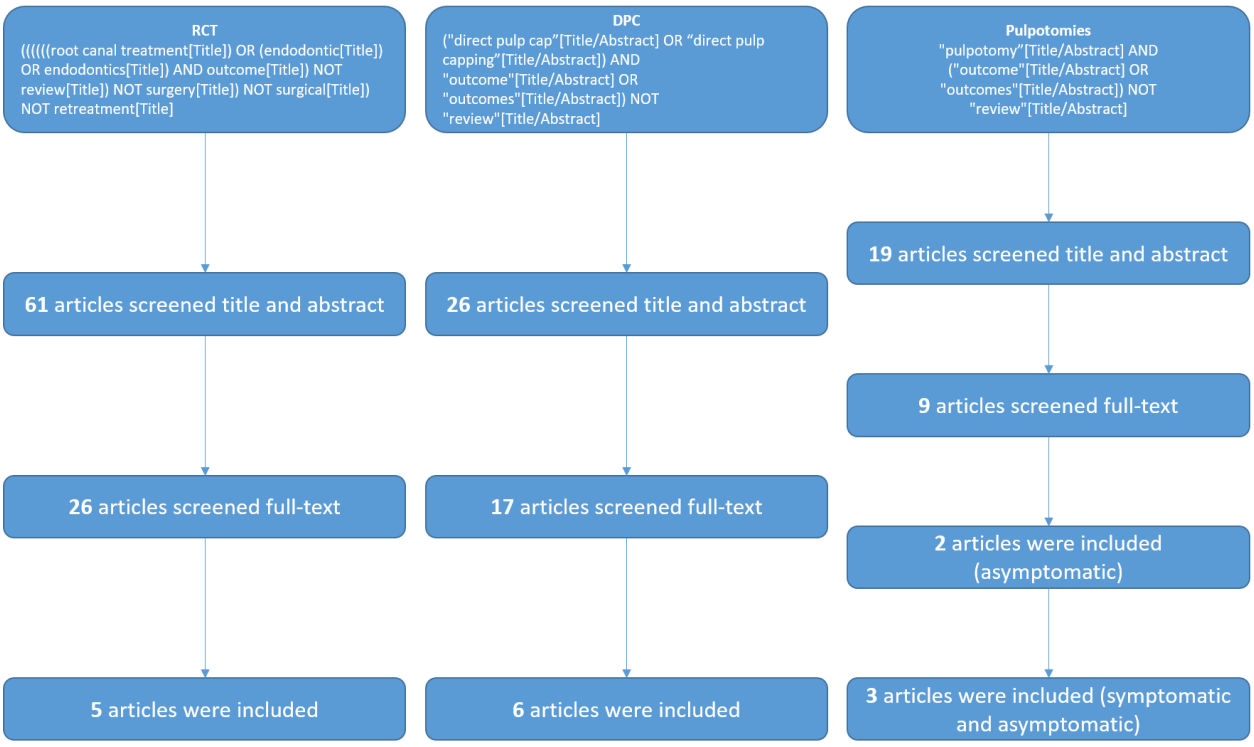
Supplemental



Supplemental Figure 1. Boolean search for the four primary treatments of interest: RCT, DPC, PP and FO.

Inclusion Criteria	Exclusion Criteria
• Year of publication 2000 or newer • Humans only • Adult patients included • Use of bioceramic material • Reported success rate • Reported follow-up time • Use of rubber dam and sodium hypochlorite	• Unrelated studies • Systematic reviews • Inclusion of patients with systemic diseases • Necrotic teeth or teeth with apical radiolucencies

Supplemental Figure 2. Inclusion and exclusion criteria for literature review.

SUPPLEMENTAL TABLE 1. Included Studies

Author	Population	12 months F/U (%)	Up to 24 months F/U (%)	Up to 36 months F/U (%)	Up to 48 months F/U (%)	AMR (%)
Root Canal Therapy (Vital)						
Chugal	104				89.70	2.56
Imura	956		94.90			2.55
Root Canal (Necrotic)						
Chugal	123				98.7	0.325
Penesis	33	85				15
Penesis	30	80				20
Saini	129	75				25
Verma	86	100				0
Direct Pulp Cap						
Awawdeh	16	100				0
Awawdeh	16		100			0
Awawdeh	15			93.30		2.23
Çalışkan	68		93			3.5
Çalışkan	47				89	2.75
Jang	23	86.96				13.04
Kundzina	33			85		5
Linu	26	88.50				11.5
Lipski	42	73.80				26.2
Partial Pulpotomy						
Kang	23	100				0
Taha (S)	24	83				17
Taha (S)	26		85			7.5
Full Pulpotomy						
Awawdeh	37	97.3				2.7
Awawdeh	35		100			0
Awawdeh	34			94.1		1.97
Taha (S)	59	98.4				1.6
Taha (S)	40	100				100
Taha (S)	41			92.7		2.43

Include studies up to 48 months of follow-up. Several studies were used more than once if they included more than once follow-up time. AMR was calculated as a linear loss according to follow-up time.
*(S) = studies including symptomatic patients

SUPPLEMENTAL TABLE 2. Excluded Studies after Full Text Screening

Authors	Reason for exclusion
Root Canal Therapy	
Azim	No report on maturation status or patient age, includes medically compromised patients
Bołtacz-Rzepkowska	No success numbers reported
Castelot-Enkel	No preop diagnosis reported
Chatzopoulos	Includes patients w. systemic disease, does not separate success between vital and necrotic
Cheung	No preop diagnosis reported
Chu	No preop diagnosis reported
Chugal	Restorative outcome study. No info on age or preop diagnosis
Chugal	Study on working length and apical size outcome
de Chevigny	No preop diagnosis reported
Farzaneh	No preop diagnosis reported
Fernández	No specific information on age (only average age of 52)
Friedman	Results not separated between pediatric and adult, vital and necrotic
Hoskinson	Includes retreatments (15% of cases)
Liang	No age range or apex maturity status reported
Marquis	No apex maturity status reported. No separate outcome between <45 y/o group and >45 y/o group
McGuigan	Review article
Ørstavik	No preop diagnosis or apex maturation status reported. No sodium hypochlorite used
Peak	No preop diagnosis reported
Direct Pulp Cap	
Al-Hiyasat	CaOH study
Asgary	Case series
Bogen	Pediatric patients included, includes open apices
Cho	Patient's age and apex maturity status not specifically disclosed
Dammaschke	CaOH study
Dube	Pediatric patients included, periapical status not assessed
Hilton	Pediatric patients included, periapical status not assessed
Marques	does not assess PA maturity status
Mente	Pediatric patients included, periapical status not assessed
Mente	Pediatric patients included, periapical status not assessed
Raedel	Success was defined as not undergoing root canal treatment (survival)
Pulpotomies (partial and full)	
Asgary	Only CEM material used
Asgary	Follow up time exceeds 48 months
Asgary	Pediatric patients included, periapical status not assessed
Asgary	Retracted article
Bakhtiar	Histologic study, teeth extracted after 8 weeks
Bakhtiar	Histologic study, teeth extracted after 8 weeks
Bjørndal	Step-wise caries removal study
Bołtacz-Rzepkowska	Recall study, initial treatment completed prior to study
Ebeleseder	Reports for perforation repair using CaOH
Jackson	Unrelated study in pediatric population
Kérourédan	unrelated study, short term pain assessment
Kunert	Only CaOH used
Linsuwanont	Pediatric patients and periapical radiolucency included, periapical status not assessed
Miyashita	Review article

Which of the following gambles would you prefer INSTEAD of having _____ which will then last for the rest of your life?

- 100% chance of having a sound tooth for the rest of your life. 0% chance of immediate extraction
- 99% chance of having a sound tooth for the rest of your life. 1% chance of immediate extraction
- 95% chance of having a sound tooth for the rest of your life. 5% chance of immediate extraction
- 90% chance of having a sound tooth for the rest of your life. 10% chance of immediate extraction
- 80% chance of having a sound tooth for the rest of your life. 20% chance of immediate extraction
- 70% chance of having a sound tooth for the rest of your life. 30% chance of immediate extraction
- 60% chance of having a sound tooth for the rest of your life. 40% chance of immediate extraction
- 50% chance of having a sound tooth for the rest of your life. 50% chance of immediate extraction
- 40% chance of having a sound tooth for the rest of your life. 60% chance of immediate extraction
- 30% chance of having a sound tooth for the rest of your life. 70% chance of immediate extraction
- 20% chance of having a sound tooth for the rest of your life. 80% chance of immediate extraction
- 10% chance of having a sound tooth for the rest of your life. 90% chance of immediate extraction
- 0% chance of having a sound tooth for the rest of your life. 100% chance of immediate extraction`

Supplemental Figure 3. Utility questionnaire utilized with our expert panel. Blank _____ was replaced in each scenario with the scenario in question.