

# Assessing the Acceptability of Less Invasive Caries Removal Techniques for treating Deep Carious Lesions: A Conjoint Survey among Dentists Practicing in a Midwestern American State

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## Keywords

Selective caries removal · Stepwise removal · Dentists' decision-making · Conjoint analysis survey

## Abstract

This study identified factors that influence dentists' decisions regarding less invasive caries removal techniques such as stepwise removal (SW) and selective removal (SE) using a marketing research technique, conjoint analysis. A survey was sent to 1,434 dentists practicing in Iowa. Dentists were randomly assigned to receive a questionnaire to rate the likelihood they would use either SW/SE in hypothetical clinical scenarios. The scenarios were carefully created by conjoint design and included three relevant attributes: *depth of lesion*, *hardness of carious dentin*, and *patient age*. Descriptive and conjoint analyses were performed to assess trade-offs between these attributes, using SPSS. The study revealed that *depth of lesion* was the most important factor in the dentists' decisions (49 importance value) when choosing a SW to treat

a deep carious lesion, followed by *hardness* of carious dentin and *patient age* (21 importance value). For the SE group, *depth of the lesion* was also the predominant factor when selecting a treatment. The study also identified that a high proportion of dentists (24.9%) indicated they would never consider using SW or SE under any circumstances. Our survey showed that *depth of lesion* was the most important reason to select a less invasive caries removal method. The high proportion of dentists indicating they would never consider selective caries removal (SE) techniques suggests that these less invasive options are underutilized.

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## Introduction

In recent years, the cost of dental care has increased. According to the Centers for Medicare and Medicaid Services, spending for dental services in 2020 in the USA reached \$146 billion, up to \$162 billion in 2021, representing an 11 percent increase. These increased costs

increase the financial burdens on individuals, communities, public programs, and insurance carriers. Thus, there is a need for better understanding of cost-saving treatment options in dentistry. This is especially important in the case of the treatment of deep caries lesions (DCLs) defined as lesions that reach the pulpal quarter of dentin with a narrow zone separating the lesion from the pulp [Bjørndal et al., 2019]. The standard caries removal approach for these lesions often results in a significantly higher likelihood of having a pulp exposure that can result in more expensive dental treatments [Schwendicke et al., 2013a; Innes et al., 2016]. Fortunately, less invasive caries removal treatments, such as stepwise removal (SW) and selective caries removal (SE), can be used for the management of deep carious lesions. The histological changes that take place in the natural deep carious lesion progression provide the basis for the management of DCLs and their less invasive treatment choices. Considering this, the purpose of SW is to arrest the carious lesion progression by enhancing the defensive pulp-dentinal complex reactions and secondary by allowing formation of tertiary dentin prior to the final removal of carious tissue [Galler et al., 2021]. Therefore, after the first step, the dentinal tissue next to the pulp becomes thicker, and pulp exposure is avoided [Kidd, 2004]. The main difference between SW and SE (one step), however, is that reentry is not required with SE, whereas SW involves a second step [Schwendicke et al., 2013a]. Supporting this point, in a Danish study, 68 teeth that were classified with DCLs showed that in these lesions, bacteria were generally limited to dentin, whereas in extremely deep lesions, the bacteria were also reaching the pulp associated with the presence of an inflammatory infiltrate and partial pulp necrosis [Demant et al., 2021], indicating that these lesions are not candidates for treatments avoiding pulp exposure.

SW is currently defined as carious tissue removal in two steps that is based on the internal-lesion changes in DCLs. The environmental change that takes place during the first stage of soft carious tissue removal aims to arrest the lesion, by placing a provisional restoration, usually a glass ionomer material, on top of the carious dentin. The second step's main purpose is to optimize the final restoration, as potential shrinkage of the remaining carious dentin may occur during the period of carious dentin arrestment [Bjørndal et al., 2019]. While SE is also defined as a selective removal to soft dentin, the main difference with SW is that SE leaves soft carious dentin beneath the restoration. Both caries removal approaches aim to preserve the health of the pulp; both techniques have been shown to have a high percentage of success,

and both offer a cost-saving method compared to traditional caries removal methods [Schwendicke et al., 2021]. However, recent studies have shown that only a small proportion of clinicians select one of the more conservative treatments when treating a DCL [Kassebaum et al., 2015; Koopaei et al., 2017]. In some countries, such as Norway, Denmark [Bjørndal et al., 1997, 2010, 2017], and Brazil [Maltz et al., 2012, 2018], these techniques are well accepted by most clinicians for the management of DCLs. However, in the USA, less invasive caries treatments such as SW and SE have not been widely adopted in clinical practice. Recently, a web-based survey carried out in the USA showed that most respondents (>48%) reported they perform complete caries removal when treating DCLs in asymptomatic permanent teeth [Koopaei et al., 2017]. The erroneous belief that leaving carious dentin or bacteria in the cavity can harm the pulp or allow further carious lesion progression is common among US clinicians and shapes clinical decision-making [Stangvaltaite et al., 2017]. The recent evidence on the effectiveness of less invasive caries removal methods suggests the need for improved understanding of what influences dentists' treatment decisions regarding extensive carious lesions [Schwendicke et al., 2017].

The main purpose of the present study was to determine dentists' willingness to use less invasive caries removal techniques when they were presented with a designed set of DCL scenarios. Conjoint analysis helps to understand how people make complex choices, as it is a tool that allows determination of the importance of each factor or attribute (characteristic) in decision-making [Birch and Ismail, 2002] and can be applied to factors that dentists consider when deciding to perform non-invasive caries removal. In the USA, this decision-making tool has been used in dental research in a conjoint survey completed by 723 members of the American Academy of Pediatric Dentistry to evaluate if they were willing to use the atraumatic restorative treatment (ART) and the main factors that influenced the decision to use ART [Kateeb et al., 2014]. However, there is limited information on the factors that influence clinicians' decision to select less invasive caries removal methods in permanent teeth, particularly regarding extensive caries lesions. Moreover, clinical studies have usually focused on efficacy as the outcome and have not taken into consideration the views and priorities of other stakeholders, such as general dentists and dental educators. Thus, the present study used conjoint analysis to assess the relative importance of several factors that influence dentists to use less invasive techniques for deep carious lesions.

## Materials and Methods

This study used a mail survey among dentists in Iowa, a Midwestern state in the USA, to collect information about their willingness to use less invasive caries removal techniques when they were presented with a carefully designed set of DCL scenarios. First, two pilot surveys (SW and SE) were designed by four experts: one specialist on preventive and community dentistry (J.J.W.), two specialists on operative dentistry (J.L.K. and P.O.-V.), and cariology (J.L.K.), and one expert on marketing research (G.J.G.). After the pilot was created, the surveys were conducted among faculty and graduate students ( $n = 20$ ) from the Department of Operative Dentistry at the University of Iowa during the spring of 2018. Each survey contained exactly the same questions and sections that the survey department mailed at the University of Iowa. With the pilot surveys, we confirmed the feasibility of the survey and adjusted the questions based on the feedback obtained from the pilot study.

A list of all practicing dentists in Iowa was obtained from the Iowa Dentist Tracking System (IDTS). The IDTS is a dataset maintained by the University of Iowa Carver College of Medicine, available for commercial and research purposes. Practicing dentists that were faculty members of the dental school were excluded from the study. An invitation letter was sent to all dentists in the tracking system dataset, which included an explanation of the study, but subjects were not required to formally consent to study participation. Dentists were randomly assigned to one of the two groups (Fig. 1). In September 2018, dentists ( $n = 1,434$ ) received a questionnaire with 18 clinical scenarios regarding deep carious lesion treatment. One group (SW group) was asked to rate how likely they would be to use SW in a clinical scenario. The second group (SE group) was presented with the exact same scenarios and asked how to rate their likelihood of using SE. The questionnaire was constructed using a 5-point Likert scale with 18 hypothetical DCL patient scenarios (these included one holdout scenario) using a balanced and orthogonal fractional factorial design plan created using the “Conjoint” procedure in SPSS® Statistics. The holdout case scenario was a case that was answered by respondents but was not used to estimate utilities; the main purpose of the holdout case was to test the predictive validity of the model. Dentists were asked to read each of the clinical scenarios and then rate the likelihood of using a SW/SE approach, on a scale ranging from 1 = “very likely to use SW/SE” to 5 = “very unlikely to use SW/SE”, as shown in the survey question example (Fig. 2). There was a group of dentists (*non-traders*) that did not show variation on their responses, such as always answering “very likely to use” or always answering “very unlikely to use” in all presented scenarios. Thus, *non-traders* were those dentist-responders who did participate in the survey; however, they answered with the same response for all of the questions. Thus, they could not be included in the analysis as to be effective the conjoint analysis technique requires variability in the responders’ choices.

In addition to the 18 conjoint questions about the clinical scenarios, participants were asked to answer seven questions about their clinical practice (see the survey instrument used in study in online suppl. material; for all online suppl. material, see <https://doi.org/10.1159/000533658>). Data collected in the questionnaire were organized using Excel, and statistical analyses were performed using SPSS 27 statistical package (IBM, NY, USA). Data were stored under a password secured server, and the University of Iowa Institutional Review Board approval was obtained before collection of data.

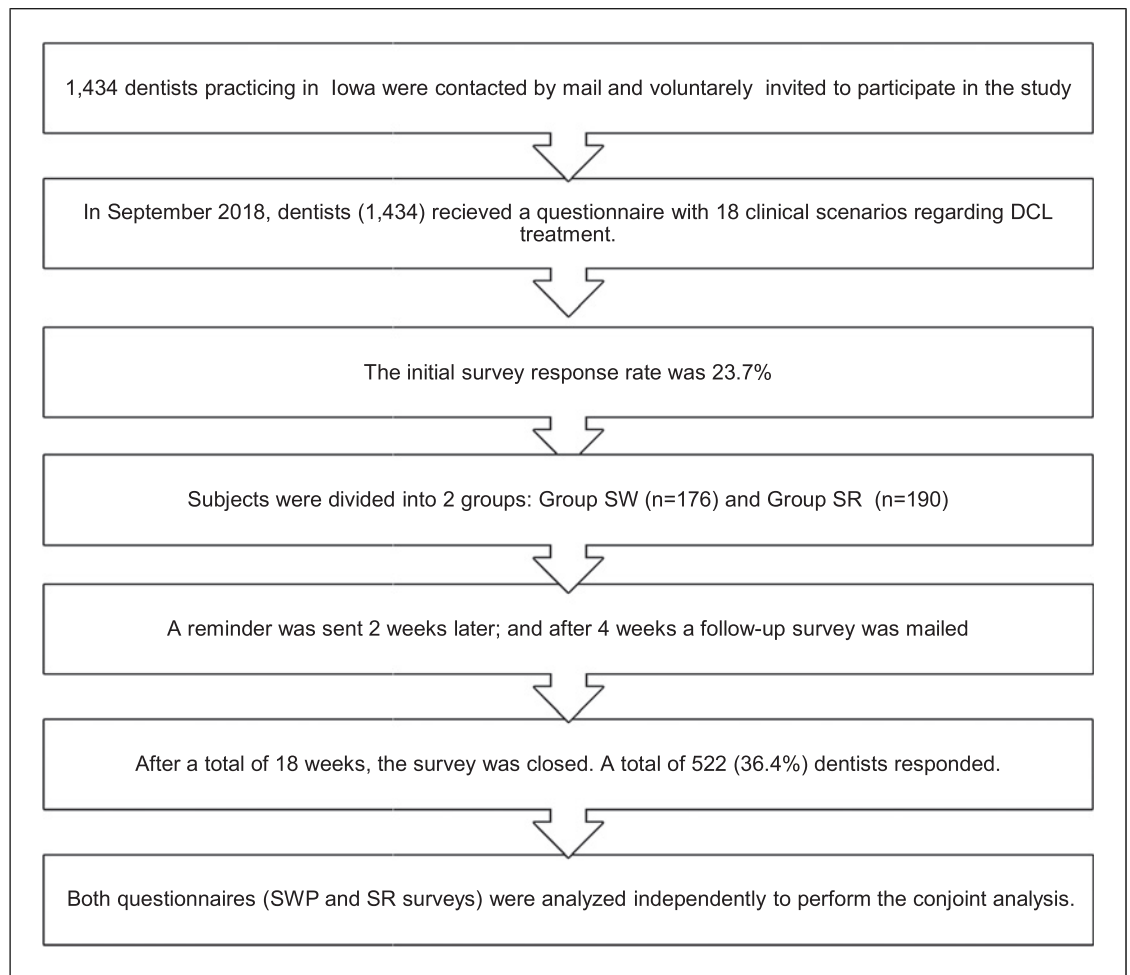
## Conjoint Model

Based on the literature, input from dental school faculty, and a pilot study, three attributes were selected for the conjoint model, as shown in Figure 3: *patient’s age* (divided into three levels of age: 18–29, 30–40, and 41–55 years old), *depth of the lesion* (attribute levels: carious lesion progression is limited to the outer third of dentin, lesion progression extended to middle third of dentin, and lesion extended to the inner third of dentin), and *hardness of carious dentin* (hard, firm, leathery, and soft dentin). *Hardness of carious dentin* was included in the conjoint model as a characteristic of the consistency of the carious tissue and thus was not defined as the endpoint for caries removal. Different levels of these attributes were used in various combinations to create the 18 scenarios presented to the participating dentists. In this way, using conjoint analysis, we categorized the influence of each attribute on dentists’ clinical decisions to determine the impact of each decision level within an attribute.

## Conjoint Analysis of the Decision-Making Process

Following standard conjoint analysis techniques, a general linear model was used to derive, for each participant, the individual Partworths for each attribute level and the overall relative importance of each attribute. This allowed us to determine how the dentists made treatment choices related to deep carious lesions based on characteristics presented in the scenarios. After this, cluster analyses were performed on the individual attribute importance value to derive homogenous groups of dentists who share similar preferences; that is, dentists who share similar attribute importance values and are therefore likely to have similar decision-making styles. Cases were matched based on the values of key variables and number of study subjects. To do this, we used a hierarchical cluster method to define the number of clusters using JMP®. We then used cluster distance history results obtained in JMP® from the Hierarchical clustering, to look for a large decrease in average distance between clusters which occurred with four clusters (online suppl. Fig. 1). Following this, we used a K-means cluster analysis specifying a four-cluster solution. Finally, we used Analysis of Variance to determine if cluster membership was related to any of the demographic variables, using a significance level of 0.05 and where the assumption was that the responses for each group had a normal population distribution.

Descriptive analysis was also performed to assess differences among subjects participating in this study. As discussed earlier, those participants who showed no variability in their responses (typically called *non-traders*) did not contribute to the conjoint analysis and thus were removed (25% of total respondents). Because of the high percentage of *non-traders* in the study, we decided to analyze the groups separately and assess their differences regarding educational experience and practicing characteristics, in order to investigate potential differences in the traders’ and *non-traders*’ characteristics. Bivariate analyses were performed to evaluate the difference between the two groups with regard to their demographic characteristics. A standard  $\chi^2$  test was used for categorical variables, and a  $p$  value of less than 0.05 was used as a criterion for statistical significance. Variables that were included in the comparison were number of years practicing, postgraduate education (yes or no), type of postgraduate program, nature of practice, public versus private insurance, and population of the county where they were practicing.



**Fig. 1.** Sequential order of the survey procedure.

**Please check your response:**

**1. How likely are you to use the SWP in an 18–29-year-old patient who presents with a soft caries lesion that extends to the inner third of dentin?**

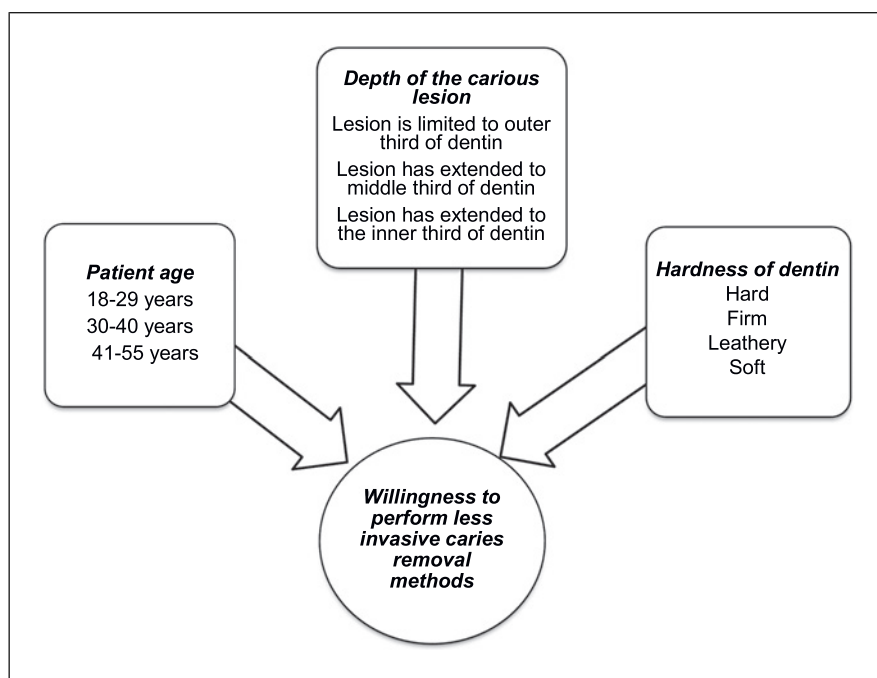
Very likely to use SWP  
 Somewhat likely to use SWP  
 Neither unlikely nor likely to use SWP  
 Somewhat unlikely to use SWP  
 Very unlikely to use SWP

**Fig. 2.** Questionnaire-question example (SWP group).

## Results

The survey had a 36% response rate; 522 of 1,434 dentists who were mailed questionnaires during 2019 responded in some way (Fig. 1). From the total ( $n = 522$ ), 130 (25%) respondents showed zero variation among their ratings (*non-traders*) and were excluded from the conjoint

analysis, 25 were blank surveys (19 surveys were returned without answers, and 6 surveys were returned incomplete) and 1 dentist was excluded because she was not currently practicing. Thus, our final sample ( $n = 366$ ) that was used in the conjoint analysis included 75% of the responders, 190 respondents for the SE group, and 176 respondents for the SW group (Table 1).



**Fig. 3.** Study conjoint model including the three attributes and main outcome.

### Sample Characteristics

The dentists in our sample were mainly general dentists (79%), the majority of respondents worked in group practice (54%), and the sample represented a diverse number of years of professional experience as displayed in Table 2. Regarding the practice urbanicity, most dentists worked in counties with a 20,000 or more population (78.8%). The data also showed that most dentists (62.9%) reported working mainly with patients from the “middle class” (Table 2).

### Comparison between Traders and Non-Traders

Among the 522 respondents who submitted the mailed survey, 24% answered that they were “very unlikely to use SW/SE” for all of the clinical scenarios. An additional 0.8% answered that they were “very likely to use SW/SE” for all of the eighteen clinical scenarios presented. Additional analyses were performed to compare non-traders with those respondents that were included in the conjoint model. Non-traders differed significantly from traders only by the type of postgraduate education, where traders had more postgraduate education (Fisher’s exact test = 28.10,  $p = 0.000$ ), as shown in Table 3. The groups did not significantly differ when compared on other characteristics (Table 3). Similarly, there were no significant differences between traders and non-traders based on public or private insurance statuses (data shown in <https://osf.io/f67dt/>).

**Table 1.** All survey respondents

	N	Mean
Non-traders	131	0.25
Traders	390	0.75
Total respondents	521	100

### Conjoint Analysis

The results for the SW and SE groups showed that overall, the *depth of the lesion* had the most influence on overall dentists’ preference to select SW as a choice, followed by *hardness of the carious dentin* (31 importance value). *Patient age* was identified as the least important factor in determining dentists’ overall preference (21 importance value) to select SW as caries removal treatment. For the SE group, for SE, dentists were strongly inclined by the *depth of the lesion* (47 importance value), followed by *hardness of the carious dentin* (32 importance value). Similar to the SW group, *patient age* was identified as the least important factor in determining dentists’ overall preference (21.2 importance value).

### Conjoint Analysis for Stepwise Removal Group

We also obtained an estimate for each attribute level (Partworth) as shown in Table 4. The results revealed that dentists were more strongly inclined to indicate SW in a

**Table 2.** Demographic and practice characteristics of survey respondents

Categorical variable	Category	Survey respondents, N (%)
Number		496*
Years of practicing dentistry	Less than or equal to 5 years	77 (15.5)
	6–15 years	131 (26.4)
	16–25 years	94 (19.0)
	26–30 years	112 (22.6)
	>35 years	82 (16.5)
Type of postgraduate education	Dental public health	3 (0.6)
	Endodontics	9 (1.8)
	GPR/AEGD	56 (11.3)
	Operative dentistry	4 (0.8)
	Oral surgery	2 (0.4)
	Orthodontics	2 (0.4)
	Pediatric dentistry	19 (3.8)
	Periodontics	2 (0.4)
	Prosthodontics	6 (1.2)
Special needs	1 (0.2)	
Type of practice	Community	24 (4.8)
	Group private practice	267 (53.8)
	Hospital	2 (0.4)
	Public health service	10 (2.0)
	Solo private practice	193 (38.9)
Population size where practicing	Completely rural or less than 2,500 urban population	1 (0.2)
	Urban population of 2,500 to 19,999	105 (21.2)
	Urban population of 20,000 or more	391 (78.8)
“What best describes the patient population in your practice?”	Below poverty	6 (1.2)
	Below middle class	48 (9.7)
	Middle class	312 (62.9)
	Affluent	130 (26.2)

\*Total respondents ( $n = 496$ ) included traders who were included in the survey ( $n = 366$ ) and non-traders ( $n = 130$ ) who were excluded from the conjoint analysis.

patient who had a carious lesion reaching the inner third of dentin as this attribute level showed a higher importance score (utility estimate = 0.879) compared to the other two attribute levels. This means that when deciding to use SW to treat a DCL, dentists more strongly preferred to apply SW in patients who presented deeper carious lesions (also shown in Fig. 4c). When considering the attribute levels of *hardness of carious dentin*, among the four levels (hard, firm, leathery, and soft), a patient that had a *soft carious lesion* was rated as more likely to receive SW treatment (utility = 0.375). Regarding *patient age*, dentists were more likely to indicate less invasive caries methods for the 30–40-year-old group (utility estimate = 0.158) than using it for either the 18–29 or 41–55-year-old groups (Fig. 4a).

Figure 4a, c, and e show how strongly the different level attributes affect dentists’ choices. Figure 4c shows that regarding *depth of the lesion*, a lesion reaching the inner third

would likely become higher in importance in dentists’ decision to select a SW. The bottom plot (Fig. 4e) clearly shows that dentists would be more likely to select SW for “a soft carious lesion” than for a hard, firm or leathery carious lesion.

#### Conjoint Analyses for the Selective Removal Group

Similarly, to the SW group, considering relative importance of factors, the most important factor encouraging dentists to use a less invasive caries removal technique when treating a DCL was the *depth of the lesion*, followed by *hardness of the carious dentin*, and lastly, the *patient age* which was the least important factor for the respondents. And different from the SW group, dentists were more likely to indicate a SE for the 18–29-year-old group (utility estimate = 0.088) than using it for either the 30–40- or 41–55-year-old groups. The findings also showed that dentists were more strongly inclined to

**Table 3.** Comparison between traders and non-traders

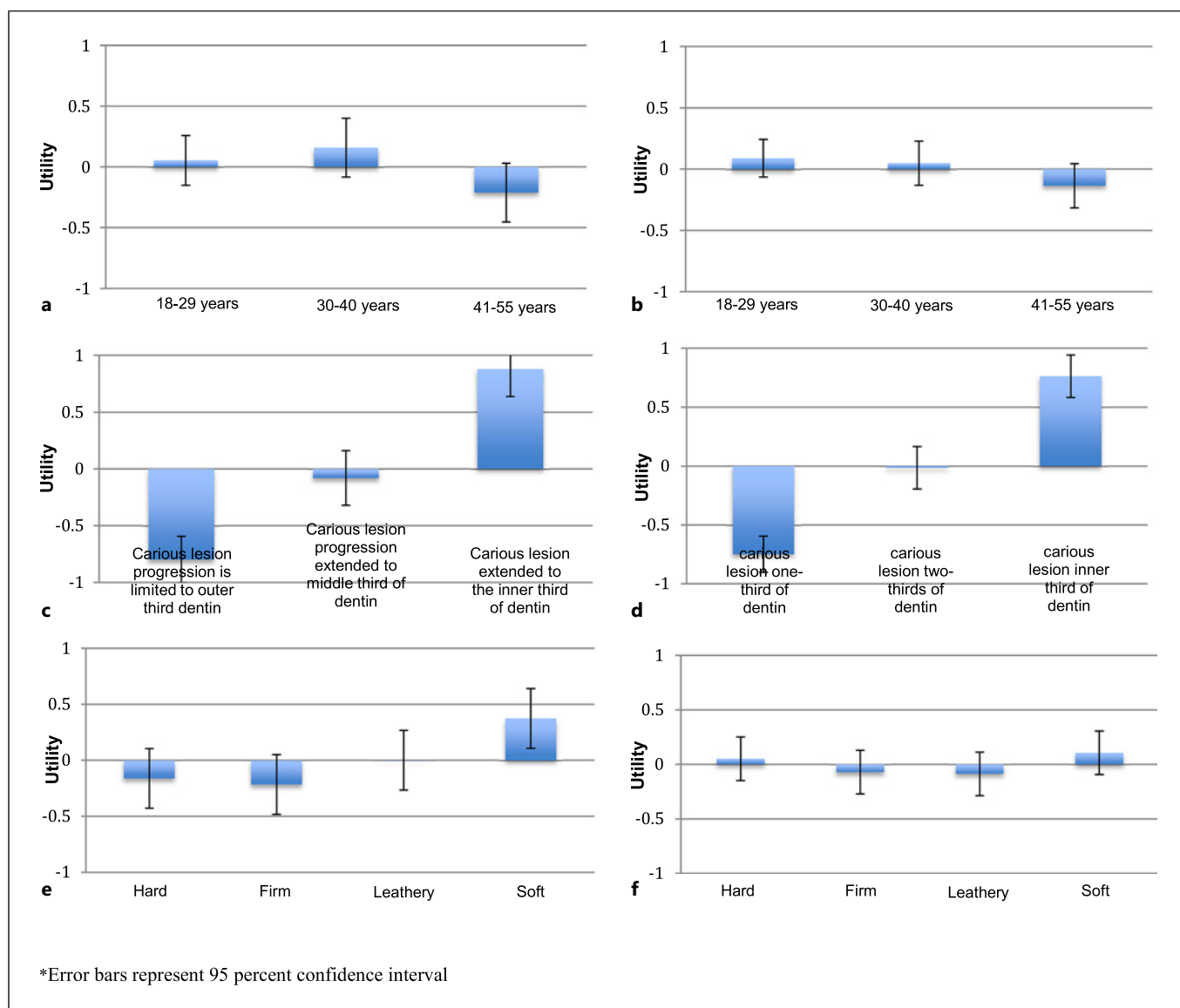
Categorical variable	Category	Traders	Non-traders**	p value
Years of practicing dentistry	Less than or equal to 5 years	63	15	0.281
	6–15 years	88	43	
	16–25 years	70	24	
	26–30 years	84	27	
	>35 years	61	21	
Postgraduate education or not	No	293	99	0.348
	Yes	73	31	
Type of postgraduate education	Dental public health	2	1	0.000* (+)
	Endodontics	2	7	
	GPR/AEGD	39	17	
	Operative dentistry	4	0	
	Oral surgery	1	1	
	Orthodontics	1	1	
	Pediatric dentistry	19	0	
	Periodontics	2	0	
	Prosthodontics	2	4	
	Special needs	1	0	
Type of practice	Community	20	4	0.240
	Group private practice	194	73	
	Hospital	1	1	
	Public health service	10	0	
	Solo private practice	141	52	
Population size where practicing	Completely rural or less than 2,500 urban population	0	0	0.379
	Urban population of 20,000 or more	81	24	
	Urban population of 2,500 to 19,999 population	285	106	

+, Fisher's exact test. \* $p < 0.05$ . \*\*Non-traders, respondents who showed zero variation among their ratings and were excluded from the conjoint analysis.

**Table 4.** Partworth utilities of attribute levels for SW group and SE group treatment

Partworth utilities	Partworth utilities SW treatment (SW)	95% CI SW-group	Partworth utilities SE group treatment (SE)	95% CI SE group
Patient age				
18–29 years	0.054 (0.105)	(–0.151, 0.259)	0.088 (0.078)	(–0.064, 0.240)
30–40 years	0.158 (0.123)	(–0.083, 0.399)	0.048 (0.092)	(–0.132, 0.228)
41–55 years	–0.211 (0.123)	(–0.452, 0.030)	–0.1369 (0.092)	(–0.316, 0.044)
Depth of the lesion				
Carious lesion progression is limited to the outer third dentin	–0.8 (0.105)	(–1.005, –0.594)	–0.749 (0.078)	(–0.901, –0.596)
Carious lesion progression extended to the middle third of dentin	–0.080 (0.123)	(–0.321, 0.161)	–0.014 (0.092)	(–0.194, 0.166)
Carious lesion extended to the inner third of dentin	0.879 (0.123)	(0.637, 1.120)	0.762 (0.092)	(0.582, 0.943)
Hardness of carious dentin				
Hard	–0.161 (0.136)	(–0.427, 0.105)	0.052 (0.102)	(–0.147, 0.251)
Firm	–0.215 (0.136)	(–0.481, 0.051)	–0.071 (0.102)	(–0.270, 0.128)
Leathery	0.001 (0.136)	(–0.265, 0.267)	–0.087 (0.102)	(–0.286, 0.112)
Soft	0.375 (0.136)	(0.108, 0.641)	0.106 (0.102)	(–0.093, 0.305)

SE, standard error.



**Fig. 4. a, c, e** Summary plots of Partworth utilities group SW treatment for patient age (**a**), depth of lesion (**c**), and hardness (**e**). **b, d, f** Plots of Partworth utilities of group SE treatment for patient age (**b**), depth of lesion (**d**), and hardness (**f**).

indicate SE in a patient who had a carious lesion reaching the inner third of dentin as this attribute level showed a higher importance score (utility estimate = 0.763) compared to the other two attribute levels, as shown in Table 4. Figure 4d shows that regarding depth of the lesion, a lesion reaching the inner third is of the greatest importance in dentists' decision to use a SE.

#### Clustering Results for the Stepwise Removal Group

Researchers in the present study were interested in investigating whether there were subgroups of dentists who had similar decision-making preferences and, if

so, how did the groups differ from one another. To do this, a K-means four-cluster analysis showed that cluster 2 represented the largest group of dentists ( $n = 62$ ) characterized by choosing a less invasive caries removal method in patients that had a carious lesion extending to the inner dentin (online suppl. Table 1). Cluster 3 ( $n = 51$ ) showed a similar pattern to cluster 2, characterized for dentists who strongly considered a treatment based on if the patient had a carious lesion compromising inner dentin. Cluster 1 contained 36 subjects and represented those for whom the most important factor to consider when indicating a SW was mainly that the carious lesion

was soft. Cluster 4 was the smallest group, containing only 27 subjects and represents dentists who weigh a carious lesion that was soft, but also extending to the inner dentin as the significant factors when selecting a treatment for a DCL.

#### *Clustering Results for the Selective Removal Group*

We performed an identical two-step cluster analyses for the SE group as we conducted for the SW group, and again based on the same criteria decided to use the 4-cluster solution in the SE group, followed by K-means. The data showed that dentists in cluster 1 ( $n = 109$ ) would be likely more willing to indicate less invasive caries removal for patients who have larger carious lesions that reach the inner third of dentin (thus the deepest carious lesions). Dentists in cluster 2 ( $n = 34$ ) tend to give more weight to the situation where there is a “soft carious lesion” when selecting a less invasive caries removal. In contrast, dentists in cluster 3 ( $n = 24$ ) tend to care more about if the carious lesion presents hard dentin (online suppl; Table 2).

Finally, to validate these differences, we performed a multivariate analysis for both survey groups, the results showed that all the attributes were significantly different and confirmed that “lesion extended to the inner third of dentin” had the higher  $F$  test among the other attribute levels in both groups, SW ( $p < 0.0001$ ) and SE ( $p < 0.0001$ ). These results confirmed that there was a distinct group of dentists who were more likely to consider less invasive caries removal methods when the carious lesion reaches the inner third of dentin. Additional analysis with the Shapiro-Wilkin test (online suppl. Table 3) to test normality among groups showed that the data were not normally distributed and showed that most variables had a  $p$  value  $< 0.05$ .

## **Discussion**

Conjoint analyses indicated that depth of the lesion, when limited to the inner third of the dentin had a significant role in dentists’ decisions on using less invasive caries removal methods. These findings in our study contrast with recent evidence that indicated that hardness of the carious lesion was the most important criterion to assess caries removal excavation [Schwendicke et al., 2013b]. However, these previous studies did not investigate factors such as depth of the lesion and the patient age as we included in our study. Our findings also reveal that despite robust evidence supporting less invasive methods for management of carious lesions, these ap-

proaches are still not frequently adopted in many dental practices [Stangvaltaite et al., 2013; Oen et al., 2007].

Our results identified that the clinical profile that dentists would most likely be inclined to use SW for a patient who presents with a soft caries lesion that extends to the inner third of dentin. Likewise, dentists would most likely be inclined to use SE on a patient who presents with a soft caries lesion that extends to the inner third of dentin; however, they would be more likely do this with younger patients. Therefore, based on our findings, we can deduce that dentists would select a SE for younger patients while they would indicate a SW for older patients. Also, it is interesting to speculate that this tendency to use SW for older patients, which might be due to the fact that SW is a two-step clinical procedure that would be more likely successful in older patients who may be more likely to attend a second appointment. This is based on evidence from a previous study, where patients with completed SW re-evaluation tended to be older than those without re-evaluation within 18 months after the SW first appointment [Ortega-Verdugo et al., 2016]. This is supported by a meta-analysis showing that SE showed significantly higher overall clinical success in young permanent teeth compared to SW [Barros et al., 2020]. High-quality studies that included clinical trials, such as Bjørndal et al., [2017], have been clear to show that SW had higher clinical success rates compared to non-SE. However, even after many years of study, there is insufficient evidence showing that SE is significantly better versus SW [Schwendicke and Göstemeyer, 2016; Jeggle et al., 2019]. Schwendicke and Göstemeyer [2016] found SE to be superior or equally successful to SW with regard to both pulpal and restorative outcomes; however, patient’s age was found not being a significant factor on SW and SE success. This is consistent with our findings that showed the patient’s age was the least important factor in the dentists’ decision when selecting between SE and SW.

The present study also identified three distinct groups of dentists with differing preferences for the most important factors regarding less invasive DCLs treatment. In the SW group, there was a large group of dentists (63%) who prioritized the carious lesion reaching the inner dentin when selecting a treatment for a deep carious lesion. For the second group (29%) the most important factor to consider when indicating SW or SE was that the carious lesion would present with soft dentin. The smallest group (with only 8% of the subjects) represented those dentists for whom the most significant factor was that the carious lesion would be hard when selecting the treatment for a DCL. Similarly, for the SE group, there was also a large group of dentists (57%) who selected the

deepest carious lesions reaching the inner dentin when choosing DCL treatment, followed by a smaller group (18%) who believed that the most significant factor to consider when indicating SE was that the carious lesion would present with soft dentin. Our findings are particularly valuable because there have been no previous survey studies in the literature that reported findings related to clinical factors of hardness, depth of the carious lesion, and patient age.

The findings of the present study showing that most dentists preferred less invasive caries removal approaches in the deepest carious lesions are supported by previous evidence. These approaches, such as SW and SE, are supported in the evidence that less invasive caries restorative procedures allow the dental-pulp complex to react to irritation by a combination of inflammation and the promotion of mineralization to repair dentin and reduce incidence of pulpitis [Galler et al., 2021]. These less invasive approaches are also supported by evidence that the removal of infected carious tissue combined with anti-cariogenic restorative materials (e.g., glass ionomer) will resolve the pulp inflammation and reduce levels of pro-inflammatory mediators [Desai et al. 2021]. Evidence also shows that while these processes allow the pulp tissue to heal, stem cells are recruited to the site of injury where they differentiate to form new odontoblast-like cells that secrete tertiary dentin, resulting in dentin bridge formation above an affected pulp [Cooper et al., 2014].

Another caveat in the present study is that the DCL definition used in the questionnaire was the more current definition for deep carious lesions obtained from the International Caries Consensus Collaboration, and the present study and questionnaire were designed in 2018. This definition has been updated to date (2023) and will potentially be changed.

Previous studies have shown that the age of a dentist was a significant factor to more likely to perform SW or SE, as younger dentists were reported to be less invasive than older dentists in most studies [Schwendicke and Göstemeyer, 2016; Doméjean et al., 2017]. We did not include age as demographic variable; instead, we have the “proxy” variable “years of practicing dentistry.” However, the present study did not find any significant association between years of practicing dentistry, type of practice or practice setting (size of population in the county where the practice is found), and a dentist’s willingness to select a less invasive caries removal method. Our findings are in contrast with similar studies that have found associations between failing to perform less invasive caries removal methods and practice size or dental education and experience of the dentist [Oen et al., 2007; Weber

et al., 2011]. Another study [Schwendicke et al., 2013b] found that attitude toward DCL management was not associated with the clinician’s age or gender; however, these factors were not evaluated in the present study.

One major finding in our study worth noting was a quarter of the dentists were not willing to perform less invasive methods for the DCL treatment in any of the clinical scenarios. These findings reveal that considering that there is robust evidence supporting the use of less invasive methods for management of carious lesions, these approaches are still not frequently adopted in many dental practices. Our findings are consistent with previous studies that have found a high proportion of dentists who would not utilize SW or SE for deep lesions in permanent teeth. Whereas in Europe and South America, less invasive caries removal strategies are well accepted among clinicians for the management of DCLs [Bjørndal et al., 2010; Maltz et al., 2012a]; to our knowledge, there is no information about dentists’ clinical decision-making in the USA, particularly regarding DCLs. Finally, strong evidence on what is the best approach to treat DCL in adults has still not been completely defined. Therefore, it is not surprising that there are great treatment variations on deep caries treatment among American general dentists.

One systematic review reported that from four thousand one hundred ninety-nine dentists, around half of all the dentists (53%) rejected these treatments for deep lesions [Schwendicke and Göstemeyer, 2016]. A similar percentage was found in a survey conducted among German dentists [Schwendicke et al., 2013b]. Likewise, systematic reviews and clinical studies from the USA and Brazil have reported that less invasive caries removal methods, such as SW and SE, are not considered by the majority of dentists [Oen et al., 2007; Weber et al., 2011]. One study [Oen et al., 2007] reported that only 21% of dentists would indicate an incomplete caries removal method, while another [Weber et al., 2011] showed that 26% of dentists would consider incomplete excavation when presented with extensive caries lesions. In contrast to the US dentists, in a survey conducted in Northern Norway among private and public health practicing dentists, researchers found that complete caries excavation (49%) and stepwise excavation (45%) were almost equally preferred treatment methods for an asymptomatic deep carious lesion without pulpal exposure [Stangvaltaite et al., 2013].

An interesting finding in this study was that the type of postgraduate education was a significant factor to determine non-trader and trader respondents ( $p = 0.001$ ). For instance, our results showed that there were no dentists with pediatric, operative dentistry, or special care

dentistry training among the respondents who answered “very unlikely to use SW or SE” in all of the presented clinical scenarios. This might suggest that dentists who better understand caries as a dynamic disease process would choose selective caries excavation methods more frequently than those who do not have this orientation. Certainly, these findings indicate that having a better understanding of the caries disease and the associated scientific rationale behind different excavation strategies may influence dentists’ decision-making for deep lesions.

One point to be considered is that the population of the present study only included dentists practicing in Iowa, and the response rate was lower than we had expected (36% of clinicians answered the survey) based on data showing that previous surveys of Iowa dentists yielded response rates of around 50% [McQuistan et al., 2008, 2010]. However, these surveys had an adjusted response rate that only included the University of Iowa College of Dentistry alumni. In our study, we attempted to survey all 1,434 dentists practicing in the state of Iowa. It is likely that the study may have obtained different results if, for instance, we conducted this same survey using dentists from multiple states.

It would also be interesting to perform a nonresponder analysis in a future study to determine the reasons for the relatively low response. This can help us to identify demographic differences among nonresponders and learn more about dentists’ decisions regarding DCLs.

Another issue was our null hypothesis was that the cluster data were normally distributed. Additional analysis to test normality among groups showed that the data were not normally distributed. However, since these analyses were exploratory, further analyses are planned to determine the reason for this issue. Further research could address this by possibly using a larger sample and applying a nonparametric test.

Regardless of the limitations, we feel our research is innovative since it combined conjoint analysis and clustering analyses to identify the degree of association among dentists when requested to select a DCL treatment. Clustering allowed us to identify common decision-making patterns among the clinicians that might not have been evident before, but which provide significant meaning to the data.

This present study provides significant information on dentists’ acceptance of less invasive caries removal methods and deeper understanding of dentists’ decision-making. This will help to direct educational institutions to develop strategies that increase the utilization of less invasive caries removal approaches, such as SW or SE. There are recent and strong pieces of evidence [Schwendicke et al., 2013a; Innes et al., 2016] that selective excavation

and SW reduce the risk of pulp exposure. Because of this low risk of accidental pulp exposure, both approaches are associated with lower costs. Thus, we feel dental schools should keep re-evaluating how less invasive treatment options are currently being taught to new generations of dentists. Moreover, based on reduced costs, it would be helpful if governmental policies and dental insurances companies promoted minimally invasive approaches by modifying reimbursements and incentives for preserving pulp vitality according to the more recent scientific evidence. Finally, future studies should be conducted that compare dentists from different countries, to determine if the trends found in this study are consistent across other states and countries. Such studies could help promote the use of less invasive caries methods for deep lesions that will benefit numerous patients.

## Conclusions

The present study showed that depth of lesion was the most important reason to select a less invasive caries removal method, while hardness of the carious dentin and patient age were not as important in making decisions regarding treatment of DCL. The high proportion of dentists indicating they would never consider SE techniques suggests that dentists have not completely adopted less invasive caries removal methods for the management of DCLs and therefore these methods are underutilized in private and public practice.

## Acknowledgments

The authors thank the Iowa Dentist Tracking System (IDTS), maintained by the University of Iowa Carver College of Medicine, that provided a list of all practicing dentists in Iowa. Also, we greatly thank Dr. Manuel Gomez (Clinical Associate Professor of Endodontics, University of Iowa) for sharing with us his expertise in endodontics.

## Statement of Ethics

Written informed consent to participate was not directly obtained but inferred by completion of the questionnaire/participation in the interview. Ethical approval was obtained from the University of Iowa Institutional Review Board IRB ID # 201307760 before data acquisition.

## Conflict of Interest Statement

The authors have no conflicts of interest to declare.

## Funding Sources

This work was supported by a Delta Dental Foundation Grant.

## Author Contributions

P.O.-V., J.J.W., J.L.K., G.J.G., E.K., K.C., and D.M.S. designed and planned the survey. P.O.-V. collected the survey data and performed the modeling. P.O.-V., J.J.W., G.J.G., and K.C. analyzed the results. P.O.-V. wrote a first draft of the manuscript that was

complemented by J.J.W. and G.J.G. All authors contributed to the development of the survey and contributed to the writing of the manuscript and read and approved the final version of the manuscript.

## Data Availability Statement

All data generated or analyzed during this study are included in this article and its online supplementary material. Further inquiries can be directed to the corresponding author.

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