

# Minimally Invasive Intervention for Primary Caries Lesions: Are Dentists Implementing This Concept?

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## Keywords

Minimally invasive dentistry · Primary caries · Questionnaire · Restorative dentistry · Treatment planning

## Abstract

Contemporary minimally invasive treatment concepts for restorative treatment of primary caries lesions include both delayed intervention and smaller-sized preparations restricted to removal of carious tissue. The aim of this study was to investigate whether these concepts have resulted in a trend towards a more conservative choice made by dentists regarding treatment thresholds and restorative techniques. The results from previously conducted, precoded questionnaires developed by Espelid and Tveit, as well as from a recent Dutch questionnaire, were collected and analysed. A worldwide trend towards more minimally invasive strategies in the operative treatment of caries lesions could not be observed, neither for the initiation of operative treatment nor for the preparation techniques. However, in some countries, changes over time could be assessed, especially in Norway, where a reduction in the proportion of interventions is visible for both occlusal and approximal lesions, indicating that more dentists are postponing interventions until

the lesions have progressed to a deeper level. From the Dutch national survey, it could be concluded that operators that intervene at an earlier stage of approximal lesioning (stage  $\leq 4$ ) also intervene at an earlier stage of occlusal caries (stage  $\leq 3$ ) ( $p = 0.012$ ; OR = 2.52; 95% CI: 1.22–5.22). Generally, it can be concluded that dentists worldwide still tend to operatively intervene at a too early stage of caries, although variations exist between countries. A worldwide shift could be observed in the restorative material applied, since composite resin has almost completely replaced amalgam for restoring primary caries lesions.

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## Introduction

Despite the fact that the prevalence of dental caries has decreased over the past decades, it still remains one of the most prevalent diseases worldwide [Marcenes et al., 2013]. Dental caries has a great impact on the global clinical and economical burden [Kassebaum et al., 2015; Listl et al., 2015] and caries management is a main issue in oral healthcare.

Prior to the late 1970s, caries progression in dentin was considered to be a rapid and irreversible process, and the concept of arresting caries lesions was not well adopted yet [Vidnes-Kopperud et al., 2011]. In the early 1980s, studies first showed that caries was indeed a slowly progressing disease, which initiated a more preventive, non-operative concept for its treatment [Pitts, 1983; Gröndahl et al., 1984]. Nowadays, it is commonly accepted that a low-cariogenic diet and adequate oral hygiene by brushing with fluoride-containing toothpaste can control or arrest progressive demineralization and caries lesion progression [Frencken et al., 2012]. As a result, increased emphasis is placed on the concept that caries should be managed using non-invasive preventive methods as much as possible [Vidnes-Kopperud et al., 2011; Schwen-dicke et al., 2016].

However, absence or failure of preventive management will still lead to a need for operative intervention. During the last decades, a minimally invasive treatment concept for caries lesions has been introduced. This includes both delayed intervention [Meyer-Lueckel and Paris, 2016] and smaller-sized preparations restricted to removal of carious tissue only, instead of the “extension-for-prevention” treatment concept. Moreover, the choice of restorative material for restoring caries lesions has changed too, from amalgam towards adhesive tooth-coloured materials, mainly composite resin. The use of adhesive techniques made it possible to use less invasive preparation designs, restricted to removing only carious tissue; traditional retentive amalgam preparation forms were abandoned, while for proximal lesions saucer-shaped preparations were introduced. Tunnel restorations for proximal lesions were explored too, but they have been proven to be unsuccessful [Nicolaisen et al., 2000; Strand et al., 2000; Hörsted-Bindslev et al., 2005].

The decision to intervene operatively in the treatment of carious lesions is based on diagnosis by visual and tactile inspection for occlusal caries, while bitewing radiography is mainly employed for the diagnosis of approximal caries [Kidd and Pitts, 1990; Lussi, 1991; Penning et al., 1992]. Based on the presence of discoloured or cavitated fissures and translucencies on radiographs, dentists decide when and how to treat a caries lesion. Espelid et al. [1985, 2001] developed questionnaires to investigate dental restorative treatment thresholds and strategies, which since then have been employed in several countries showing a wide variation of outcomes [Innes and Schwen-dicke, 2017]. There seems to be a tendency towards a more minimally invasive strategy for the treatment of primary caries lesions, but this has not been established

yet. The outcomes of surveys should be compared over time – and, if possible, within countries – since tendencies might be different around the world.

The only available results regarding decision-making on the restorative treatment of primary caries lesions from the Netherlands date back to 1983, and they focused on approximal lesions only [Mileman and Espelid, 1988]. To investigate current Dutch decision-making by general practitioners on the treatment of occlusal and approximal caries lesions, the survey was repeated. The aim of this study was to investigate if there are trends towards a more conservative, minimally invasive treatment concept for primary caries as measured by treatment thresholds and the choice of restorative techniques made by dentists.

## Materials and Methods

### *Study Population and Design*

The precoded questionnaires developed by Espelid et al. [1985, 2001] have been used in several previous studies around the world. These questionnaires include figures or photographs of different stages of approximal [Espelid et al., 1985] and occlusal lesions [Espelid et al., 2001] and questions about restorative treatment criteria, preparation techniques and the use of restorative material.









Approximal caries progression was divided into 6 stages: (1) outer half of the enamel, (2) inner half of the enamel, (3) enamel-dentin border, (4) outer third of the dentin, (5) outer half of the dentin and (6) inner half of the dentin. Traditional black class II preparation, tunnel preparation or saucer-shaped preparation were the options for approximal preparation. Occlusal caries progression was divided into 5 stages: (1) white or discoloured enamel, (2) small cavitation clinically, (3) moderate-sized loss of tooth structure, (4) large-sized loss of tooth structure and (5) extensive loss of tooth structure. For occlusal preparations, only carious tissue removal, opening the whole fissure or another preparation of preference could be chosen.

Amalgam, glass ionomer, composite resin, compomer or another material of preference could be chosen as the approximal or occlusal restorative material. All of the included studies had the same design and were based on an identical questionnaire, which, due to translation into other languages, showed different descriptions of the stages of caries, although the figures were identical in all cases. The questionnaires were sent to general practitioners, presenting an identical outcome: the decision taken by the dentist.

To compare them through time and between different countries, the results of the current Dutch questionnaire and of all previously published articles based on these questionnaires were collected and analysed.

### *Dutch Survey*

The questionnaire, based on the questionnaires by Espelid and Tveit [Espelid et al., 1985, 2001], was sent electronically to a sample of 1,050 Dutch dentists in June 2015. Based on the size of the dentist population in the Netherlands of around 8,500 dentists, a desired level of confidence of 95% and an estimated degree of dispersion of 30% require a sample size of 311. Taking into account the

				Total (n)
 	4	8	1	13 (0 / 13)
	41	130	32	203
 	7	16	15	38 (38 / 0)
Total (n)	52 (0 / 7 / 45)	154	48 (46 / 2)	254

**Fig. 1.** Cross table of the number of Dutch respondents selecting specific thresholds for operative treatment in occlusal and approximal caries cases. As the stages at either end of the spectrum were very rarely chosen, these were merged with the adjoining stages for the table. However, the individual numbers are shown in parentheses in the cells showing the total numbers.

circumstance that a number of email addresses are not reachable (bouncing) and the experience that about 25–30% respond to Web surveys, 1,050 Dutch dentists were approached. The sample was drawn randomly by the Royal Dutch Dental Association (KNMT) from the national population of registered dentists aged 64 years or younger with a known address in the Netherlands. Participation was voluntary and anonymous, and no compensation was offered to the respondents. Reminders were sent after 1 week, 3 weeks and 13 weeks. Dentists who were not involved in patient treatment and respondents who did not complete the questionnaire were excluded. Information on the respondents regarding gender, years of experience (divided into groups of 1–5, 6–15, 16–30 and ≥31 years) and place of graduation was collected. The questions from the questionnaire that were included in the national survey and the international studies are shown in Appendix 1.

Statistical analyses were performed with IBM SPSS Statistics version 22.0 (Statistical Package for the Social Sciences; SPSS, Chicago, IL, USA). Descriptive statistics, analyses with  $\chi^2$  testing and logistic regression analyses were performed to characterize the respondent population and present the collected information on occlusal and approximal treatment thresholds and restorative management. The significance level was set at 5%. Logistic regression analyses were performed, with restoring lesions confined to the outer third of the dentin operatively, up to and including stage 3 in occlusal lesions and stage 4 in approximal lesions, as a dependent variable. Dentists' experience, gender, place of graduation, preparation technique and restorative material were set as independent variables. Variables with a *p* value ≤0.3 in the unadjusted analyses were to be entered into the adjusted logistic regression.

#### National and International Trends

The results of all previously published studies based on the questionnaire of Espelid and Tveit [Espelid et al., 1985, 2001] were gathered. The following background data were extracted from the included studies: year the survey was conducted, year of publica-

tion, authors, country, target audience (general dental practitioners or teachers at university) and number of respondents. The evaluated outcomes were: preferred stage of caries intervention (stage 1–5 or 1–6 for occlusal and approximal lesions, respectively); preferred preparation technique (for occlusal lesions: only caries removal, opening the whole fissure or other; for approximal lesions: traditional class II preparation, tunnel preparation or saucer-shaped preparation); and preferred restorative material (amalgam, composite, glass ionomer, composite combined with glass ionomer or other).

To evaluate trends regarding decision-making on minimally invasive restorative treatment across countries and time, the proportion of dentists intervening at or before stage 3 (occlusal) or stage 4 (approximal), preferring limited preparation techniques (only caries removal for occlusal and saucer-shaped preparations for approximal), and preferring composite or amalgam restoration material was plotted against the year of the study.

To evaluate possible correlations between countries regarding occlusal and approximal intervention thresholds, preparation techniques and the preferred restorative material, Spearman's correlation coefficient was calculated and scatterplots were drawn.

## Results

### Dutch Survey

In total, 280 dentists responded after 3 reminders. The response rate was 27%. Dentists not involved in patient treatment and those who did not complete the questionnaire were excluded from the statistical analyses (*n* = 26). The mean age of the included dentists (*n* = 254) was 47.69 years (SD = 12.3); 34.3% were female and 65.7% male. The

individual background characteristics of the respondents and non-respondents are shown in Appendix 2.

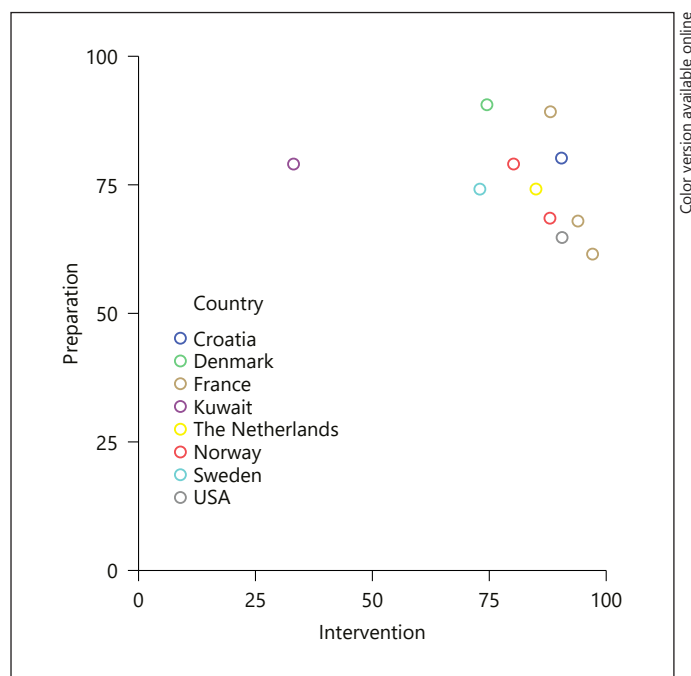
As shown in Figure 1, most dentists would initiate operative treatment in lesions that had progressed into the outer third of the dentin (79.9% for occlusal lesions and 60.6% for approximal lesions). None of the respondents would intervene at stage 1 or wait until stage 5 for occlusal lesions, and only 2 respondents reported waiting until stage 6 for approximal lesions. For approximal lesions, 20.5% of the dentists would intervene already in enamel lesions, and 15% would wait until progression had reached the middle third of the dentin. Operators that would intervene at an earlier stage of approximal lesions (stage  $\leq 4$ ) would also intervene at an earlier stage of occlusal caries (stage  $\leq 3$ ) ( $p = 0.012$ ; OR = 2.52; 95% CI: 1.22–5.22).

For occlusal lesions, 188 dentists (74.0%) reported that they would only remove carious tissue, while 62 dentists (24.4%) reported they would use the traditional whole-fissure preparation. Saucer-shaped preparation was the most preferred type (59.1%) for preparing approximal lesions, followed by traditional class II preparation (36.2%). Tunnel preparation was only rarely reported (4.7%). Composite resin was preferred by a vast majority of the respondents for both occlusal (92.5%) and approximal (96.5%) restorations. Amalgam was never reported to be the preferred material, and glass ionomer cement and other restorative materials were only rarely preferred.

The results of the regression analyses are shown in Appendices 3 and 4. None of the independent variables was found to have a significant impact ( $p < 0.05$ ) on the restorative threshold for stage 3 occlusal caries lesions and stage 4 approximal caries lesions, and wide confidence intervals were seen. An adjusted analysis was therefore not performed. ORs for place of graduation could not be calculated, due to the fact that the  $2 \times 2$  tables contain a 0. Therefore, this variable could not be used, and the  $p$  value from the  $\chi^2$  test was recorded.

#### International Comparison

The results of all published studies based on the questionnaire [Espelid et al., 2001] on occlusal caries lesion restorative treatment thresholds, preparation techniques and proposed restorative materials are shown in Table 1. The results of all published studies based on the questionnaire [Espelid et al., 1985] on approximal caries lesion restorative treatment thresholds, preparation techniques and proposed restorative materials are shown in Table 2. The stages of lesion depth were described differently in some studies marked with an asterisk (\*). In the study



**Fig. 2.** Scatterplot of the percentage of respondents intervening at stage 3 occlusal caries ( $x$  axis) and the percentage of respondents choosing only caries removal as the preparation technique ( $y$  axis).

from Iran [Ghasemi et al., 2008], it was impossible to choose stage 4 in the questionnaire, and this study was therefore difficult to compare with the other studies. The studies by Kakudate et al. [2012], Gordan et al. [2009] and Heaven et al. [2013] divided the treatment thresholds for low- and high-caries-risk patients. These studies are marked with a plus sign (+), and the results for low-risk patients were selected for this study.

Figure 2 shows the correlation between the restoration threshold (stage 3) and the only-caries-removal preparation for occlusal caries lesions. This plot suggests that there is a strong tendency that when dentists are intervening at a later stage of the caries process, they are also more likely to use a minimally invasive preparation technique. However, this result is not statistically significant, as the Spearman correlation coefficient ( $-0.579$ ,  $p = 0.062$ ) did not achieve the significance level set for this study (5%). No association between the stage of intervention and the preparation technique was observed.

#### Thresholds for Initiating Operative Treatment

Figure 3a and b shows for each study the proportion of dentists reporting a restorative intervention at or before stage 3 occlusal caries lesions and stage 4 approximal car-

**Table 1.** Results of all published studies based on the questionnaire [Espelid et al., 2001] on occlusal caries lesion restorative treatment thresholds, preparation techniques and proposed restorative materials

Year of question-naire	Year of publication	Authors	Country	Target of questionnaire	N	Stage 1, %	Stage 2, %	Stage 3, %	Stage 4, %	Stage 5, %	Only caries removal	Opening whole fissure	Other	Amalgam	Composite	GIC	Composite/GIC	Other
1995	2001	Espelid et al.	Norway	General	640	0.5	17.3	70.2	11.5	0.5	68.3	31.7	0	19.9	39.1	22.2	16.1	2.7
1995	2001	Espelid et al.	Denmark	General	173	0	4.6	69.9	24.3	1.2	90.3	9.7	0	52.4	29.2	2.4	14.3	1.8
1996	1999	Mejäre et al.	Sweden	General	590	0.1	5.9	67.0	26.7	0.3	74	26	0	2.9	71.6	11.4	12.6	1.5
2002	2004	Doméjean-Orliaguet et al.	France	General	793	2.1	47.8	47.2	2.9	0	61.4	36	2.6	17.3	74.3	7.0	0	1.4
2003	2004	Tubert-Jeannin et al.	France	University	86	0.6	20.1	67.4	11.9	0	89	8	3	8	92	0	0	0
2009	2016	Kopperud et al.	Norway	General	2,375	0.3	12	68	19	0.8	78.8	21.2	0	0	91.9	4.8	1.6	1.7
2012	2013	Heaven et al. <sup>a</sup>	USA	General	479	1.3	9.4	34.2	47.8	7.3	–	–	–	–	–	–	–	–
2012	2015	Doméjean et al.	France	General	770	2.1	37.2	54.7	6.0	0	67.8	30	2.2	7.3	81.6	11.0	0	0.1
NA	2012	Baraba et al.	Croatia	University	59	1.5	20	69	8	1.5	80	20	0	2	81	7	10	0
2013	2014	Khalaf et al.	Kuwait	General	185	0	4.3	28.1	43.8	23.8	78.9	21.1	0	9.7	68.7	14.6	5.4	1.6
2013	2016	Rechmann et al. <sup>a</sup>	USA	General	1,922	1.8	38.9	49.9	7.7	1.7	64.6	31.5	3.9	4.7	94.6	5.1	0	0.7
2015	2017	Laske et al.	The Netherlands	General	254	0	5.1	79.9	15.0	0	74.0	24.4	1.6	0	92.5	5.1	0	2.4

Percentages in a column may not equal 100 due to rounding. Year of questionnaire: the year the questionnaire was administered. GIC, glass ionomer cement; –, not asked in the questionnaire. \* Stages differently described compared to Espelid et al. [2001].  
<sup>a</sup> Results based on inclusion of low-carries-risk patients.

**Table 2.** Results of all published studies based on the questionnaire [Espelid et al., 1985] on approximal caries lesion restorative treatment thresholds, preparation techniques and proposed restorative materials

Year of question-naire	Year of publication	Authors	Country	Target of questionnaire	N	Stage 1, %	Stage 2, %	Stage 3, %	Stage 4, %	Stage 5, %	Stage 6, %	Class II preparation	Tunnel preparation	Saucer-shaped preparation	Amalgam	Composite	GIC	Composite/GIC	Other
1983	1985	Espelid et al.	Norway	General	616	2.3	19.1	44.2	30.0	3.9	0.5	–	–	–	–	–	–	–	–
1983	1988	Mileman and Espelid <sup>a</sup>	Holland	General	325	10	44	38	8	–	–	–	–	–	–	–	–	–	–
1987	1990	Nataf and Pitts <sup>a</sup>	Scotland	General	1,127	2.4	3.0	15.6	19.8	47.2	12.0	–	–	–	–	–	–	–	–
1990	1991	Riordan et al.	Australia	General	45	2.2	8.9	28.9	40.0	11.1	8.9	–	–	–	–	–	–	–	–
1992	1994	el-Mowafy and Lewis <sup>a</sup>	Canada	General	1,276	1	27	67	5	0	–	–	–	–	–	–	–	–	–
1995	1999	Tveit et al. <sup>a</sup>	Norway	General	640	3.6	14.7	62.0	19.2	0.5	28.2	47.5	24.3	15.5	15.8	46.3	22.4	0	–
1996	1999	Mejäre et al.	Sweden	General	590	0.2	2.0	4.5	41.0	51.8	1.5	20.3	47.7	32.0	2.9	56.9	13.7	24.7	1.8
1999	2005	Træbert et al. <sup>a</sup>	Brazil	General	840	31.5	23.0	24.5	17.9	2.8	0	–	–	–	–	–	–	–	–
2002	2004	Doméjean-Orliaguet et al.	France	General	793	20.5	35.5	32	11.5	0.5	0	12.0	33.3	54.7	20.5	58.4	12.3	5.5	3.3
2003	2004	Tubert-Jeannin et al.	France	University	86	2.4	19.5	39.1	31	6.5	1.5	2.4	60.7	36.9	8.3	78.6	11.9	1.2	0
2005	2008	Ghasemi et al. <sup>a</sup>	Iran	General	870	7	24	57	11	–	–	–	–	–	–	–	–	–	–
2005–2006	2009	Gordan et al. <sup>a</sup>	USA	General	500	1.8	39	54	5	0.2	–	–	–	–	–	–	–	–	–
NA	2010	Baraba et al.	Croatia	General	307	10	32	39	18	1	0	32	46	22	4	66	13	17	0
2009	2011	Vidnes-Kopperud et al. <sup>a</sup>	Norway	General	2,026	0.2	6.8	35.8	35.8	0.7	27.8	3.8	68.4	0	94.9	3.3	1.8	0	–
2011	2012	Kakudate et al. <sup>a,a</sup>	Japan	General	189	3.7	42.8	42.8	9.1	1.6	–	–	–	–	–	–	–	–	–
NA	2012	Baraba et al.	Croatia	University	59	14.5	19.5	34	30	1	17	47	36	0	65	17	6	12	–
2012	2013	Heaven et al. <sup>a,a</sup>	USA	General	479	1.9	41.8	53.7	2.5	0.1	–	–	–	–	–	–	–	–	–
2013	2014	Khalaf et al.	Kuwait	General	185	2.2	8.1	7.0	40.0	18.9	23.8	49.2	24.9	11.4	61.0	14.6	13.0	0	–
2013	2016	Rechmann et al. <sup>b</sup>	USA	General	1,922	2.9	15.1	42.6	33.4	4	2	54.1	0	45.9	6.4	92.6	0.8	1	–
2015	2017	Laske et al.	The Netherlands	General	254	0	2.8	17.7	60.6	18.1	0.8	36.2	4.7	59.1	0	96.5	0.8	0	2.8

Percentages in a column may not equal 100 due to rounding. Year of questionnaire: the year the questionnaire was administered. GIC, glass ionomer cement; –, not asked in the questionnaire. \* Stages differently described compared to Espelid et al. [1985].  
<sup>a</sup> Results based on inclusion of low-carries-risk patients. <sup>b</sup> No distinction was made between composite resin, GIC or a combination of both. These choices were gathered under "tooth-coloured restorations."

ies lesions. Data from time points at least 10 years apart were available for Norway (1983, 1995 and 2009), France (2002 and 2012) and the Netherlands (1983 and results from the present Dutch survey). In Norway, a reduction in the proportion of dentists is visible for both occlusal lesions (from 88.0% in 1995 to 80.2% in 2009) and approximal lesions (from 95.6% in 1983 over 80.3% in 1995 to 63.5% in 2009), indicating that more dentists are postponing interventions until the lesions have progressed to a deeper level. In France, a similar but weaker trend could be observed for occlusal lesions (from 97% in 2002 to 94% in 2012). For approximal caries lesions, in the Netherlands a similar trend could also be observed (from 92% in 1983 to 81.1% in 2015). Relative outliers are visible in studies from 2012 (USA) and 2013 (Kuwait) and in studies from 1987 (Scotland) and 1996 (Sweden), where occlusal and approximal interventions, respectively, were predominantly postponed until frank cavitation.

#### *Preparation Techniques*

Figure 3c and d shows for each study the proportion of dentists preferring minimally invasive preparation techniques. In Norway (between 1995 and 2009) and France (between 2002 and 2012), a clear increase (from 10 to 20%) in use of the carious-tissue-removal-only method was observed for occlusal lesions. For approximal lesions, a very strong trend was observed in Norway, with the reported use of the saucer-shaped preparation increasing from 24.3% in 1995 to 68.4% in 2009. In contrast, Table 1 reveals that the standard class II preparation was still the most favoured preparation design reported for California and Kuwait even in 2013.

#### *Use of Restorative Materials*

Figure 3e and f shows the preferred restorative material reported in all studies. A linear trend line was drawn for the use of composite resin and amalgam. Across countries, a clear increase in the use of composite can be observed, with amalgam becoming almost extinct. Glass ionomer cement use (alone or in combination with composite) was only substantially reported between 1995 and 1999 in Scandinavia.

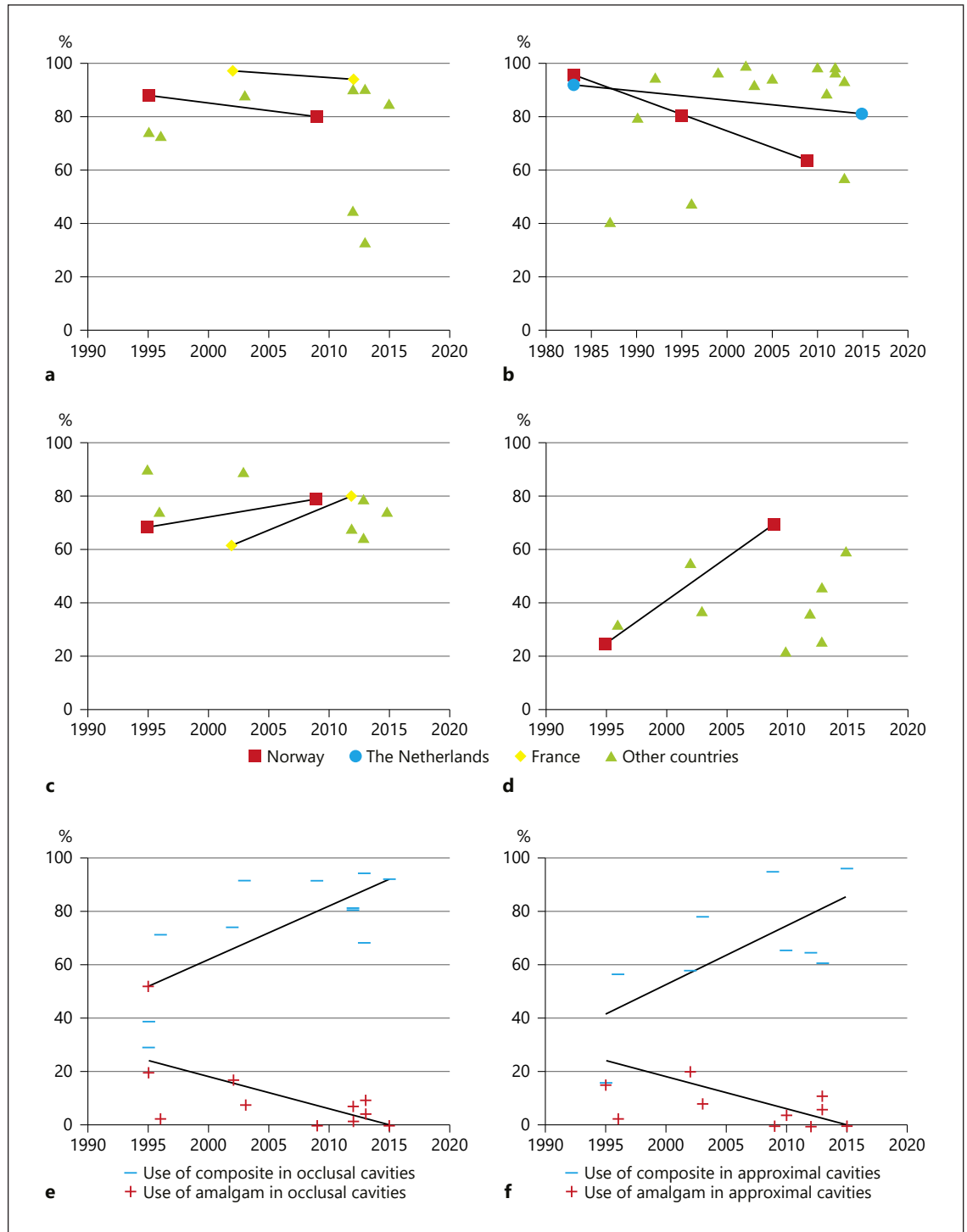
## **Discussion**

The present study aimed to explore a possible worldwide trend towards a more minimally invasive strategy concerning operative interventions in primary caries lesions. For this purpose, the results from questionnaires

designed by Espelid and Tveit [Espelid et al., 1985, 2001] were used. However, as the dates of the surveys vary considerably, differences in caries experience and social culture occur between countries and only for a limited number of countries two questionnaires could be compared across an interval of at least 10 years, it is difficult to draw any conclusions about worldwide trends. Within these limitations, we can clearly state that an international trend towards more minimally invasive strategies in the operative treatment of caries lesions could not be observed, neither regarding the initiation of operative treatment nor concerning preparation techniques. Figure 3a–d shows a scattered landscape, mainly due to remarkable differences between countries. In the few cases in which we were able to compare results within the same country over time, some trends could be observed that will be discussed.

With the more recent insight that caries is not an infectious disease and (complete) carious tissue removal is not necessary [Ricketts et al., 2013], the recommended moment of operative intervention is when preventive measures such as biofilm control, remineralisation strategies and sealing are no longer expected to be successful [Marinho et al., 2013; Ricketts et al., 2013; Dorri et al., 2015]. As a current guideline, cavitated lesions are considered appropriate candidates for operative intervention [Meyer-Lueckel and Paris, 2016]. This would also include approximal lesions extending beyond the outer third of the dentine as observed on bitewing radiographs, since these are most likely cavitated, even if cavitation cannot normally be clinically detected [Meyer-Lueckel and Paris, 2016]. Therefore, in terms of the present questionnaire this would mean that stage 4 occlusal caries and stage 5 approximal caries would be the closest to a “gold standard” threshold for minimally invasive operative intervention.

The results reported over the years, as shown in Figure 3a and b, suggest that there is still a gap between this scientific view on caries management and clinical practice, as the majority of dentists would intervene at stages 3 (occlusal) and 4 (proximal), although in some countries a slow shift towards later intervention can be observed. The most pronounced change was observed in Norway. In 1983, 95.6% of the Norwegian dentists would have initiated operative treatment when caries was reaching the outer third of the dentin for approximal lesions. Over the years this percentage decreased to 80.3% in 1995 and 63.5% in 2009, clearly indicating that Norwegian dentists are moving towards later intervention. A less clear trend was found in the Netherlands. In 1983, 92% of the Dutch



**Fig. 3.** Scatterplots from different studies for restorative threshold (%), minimally invasive preparation technique (%) and the preferred restorative material (%) against the year the questionnaire was administered. **a, b** For each study, the proportion of dentists reporting restorative intervention at or before stage 3 occlusal caries lesions (**a**) and approximal stage 4 lesions (**b**) is shown. **c, d** For each study, the proportion of dentists preferring only occlusal caries removal (**c**) and an approximal saucer-shaped preparation (**d**) is shown. **e, f** For occlusal (**e**) and approximal (**f**) cavities, the proportion of dentists preferring a composite resin or amalgam restoration is shown.

dentists would have intervened restoratively in a stage 4 approximal caries lesion, while by 2015 this percentage decreased to 81.1%, indicating that the majority of dentists in the Netherlands still tend to intervene at a too early stage in proximal caries.

As far as interventions for occlusal lesions are concerned, Norway and France both show a slight decrease in early interventions. However, French dentists seem to be more eager to intervene than dentists from the other countries studied, as both in 2002 and 2012 more than 94% of the questioned French dentists would have intervened as soon as caries had reached the dentin. The development of caries management in the USA is more difficult to assess, because the surveys there were conducted in different states and over a shorter time span (2005, 2012 and 2013). However, in all 3 surveys more than 90% of the studied American dentists would have intervened restoratively in caries lesions confined to the outer third of the dentin. The scatter plot in Figure 2 suggests there is a tendency that when dentists are intervening at a later stage of the occlusal caries process, they are also more likely to use a minimally invasive preparation technique. However, this result was not statistically significant, and Kuwait was found as a relative outlier. These results could be related to the fact that almost all countries evaluated present a limited caries experience. Practising dentists in countries with a high caries prevalence are more used to intervening at a later stage of the caries process and have fewer possibilities for controlling progressive demineralization and caries lesion progression.

These results confirm longstanding differences in preventive orientation, with the Scandinavian countries having formed the vanguard for many decades. An explanation for the scattered landscape regarding decision-making especially between countries is difficult to give, as several factors may be responsible that have not been investigated yet. Differences in reimbursement systems, nationwide caries experience, the age of the dentist population, the presence of a dental public health service or the dentist-patient ratio may be responsible for the delayed implementation of novel developments among dentists.

It may be assumed that in the university environment of dental schools, the implementation of new evidence-based treatment is likely to precede its spread in general dental practice, and that therefore a younger population of dentists will more likely have been exposed to these changing guidelines. The Dutch dentist population is relatively old, which matches the observation that they still intervene relatively early, especially in proximal lesions. Rechmann et al. [2016] observed a trend among younger

Californian dentists to intervene at a later stage when compared to their older colleagues, which supports this assumption and may also have played a role in the US results. Differences in occlusal and approximal caries management between teachers at university and general dental practitioners in France and Croatia have been found. The threshold for operative treatment among teachers is at a more advanced stage of caries lesion than among French general dental practitioners [Doméjean-Orliaguet et al., 2004; Tubert-Jeannin et al., 2004]. Also, more minimally invasive preparation techniques and the use of composite are more popular at French universities than in general dental practices. In Croatia, no differences were found regarding restoration thresholds or proposed restorative materials, but the saucer-shaped preparation was more preferred at university (36%) than in private practice (22%) [Baraba et al., 2010, 2012].

The response rate (27%) in the 2015 Dutch national survey was lower than that obtained with a similar questionnaire in 1983 (77%), which can be seen as a limitation to the results of the present national survey. Nevertheless, the current data provide a general demographically representative data set, as shown in Appendix 2. A statistically significant correlation regarding when to intervene in approximal and occlusal caries was shown (Figure 1). This indicates that practitioners who are more eager to intervene at an early stage of approximal caries are also more eager to do so in case of occlusal caries. These findings are in line with previous studies [Mejàre et al., 1999; Espelid et al., 2001; Kopperud et al., 2016].

As far as preparation techniques are concerned, the caries-removal-only technique has generally been preferred for the past 20 years by more than half of the dentists. No overall trend can be observed, although this technical preference increased by 10.5% among dentists over a period of 14 years in Norway and by 17% among dentists over a period of 11 years in France. In Norway, the preference for a saucer-shaped preparation almost tripled to 68.4% between 1995 and 2009. From the results of the last decade, only in Norway and the Netherlands the saucer-shaped preparation design has been the most favoured technique, while overall the traditional class II preparation is still quite popular.

However, a worldwide shift in the restoration of primary caries lesions, i.e., from amalgam towards composite resin, could be observed in the present study, as illustrated in Figure 3e and f. From the data it becomes clear that composite resin has replaced amalgam as the preferred material for the restoration of primary caries lesions in the Netherlands, Norway, France and California

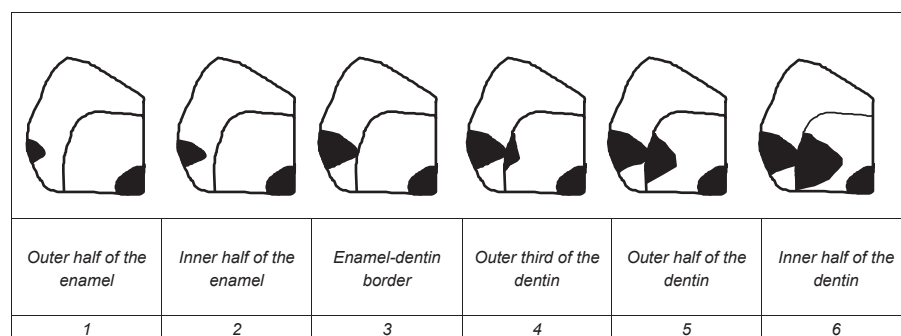


(USA), where tooth-coloured restorations were preferred by more than 90% of the dentists. These findings are in accordance with other studies [Sunnegårdh-Grönberg et al., 2009; Eklund, 2010]. On January 1, 2008, the use of amalgam was banned in Norway, and in the most recent surveys [Vidnes-Kopperud et al., 2011; Kopperud et al., 2016] it was not an option anymore. Glass ionomer cement reached some popularity as the preferred material for restoring primary caries lesions especially in Northern European countries, although its use decreased overtime. However, it is doubtful whether this shift is driven by a more minimally invasive approach of the dentists. It may well be that the WHO recommendation to decrease the use of amalgam and the increased demand of patients for aesthetically pleasing restorations are the reasons for this [FDI World Dental Federation, 2014].

Summarising this overview of the survey results, the following conclusions can be made: Large variations in restorative decisions at which stage to intervene in proximal and occlusal primary caries exist around the world. Generally, dentists decide on operative interventions at too early a stage. In countries where changes over time could be assessed, and especially in Norway, an increasing minimally invasive attitude could be observed. Composite resin has almost completely replaced amalgam for restoring primary caries lesions.

## Appendix 1

### Questionnaire



**Fig. 1.** Illustration of the different stages of approximal caries progression (stages 1–6)

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## Statement of Ethics

The design and the protocol were approved by the local ethics committee (METC; CMO Arnhem-Nijmegen, file Nr. 2016-2556).

## Disclosure Statement

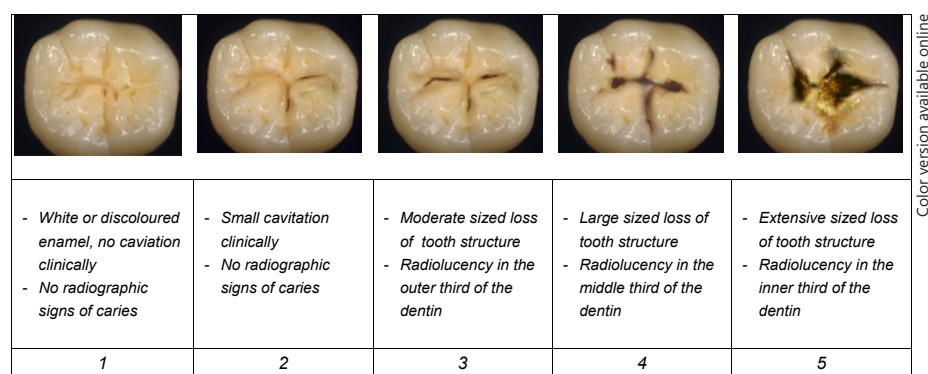
The authors declare no conflict of interest.

## Author Contributions

All the authors had a part in the preparation of the manuscript.

**Table 1.** Questions regarding approximal carious lesions

Case 1 Approximal lesion	These pictures illustrate different stages of caries progression on the distal surface of tooth 15 or 25. Imagine a 20-year-old patient with low caries activity, good oral hygiene, visiting a dentist annually and brushing twice a day with a fluoridated toothpaste
A	Starting at which stage do you think an approximal restoration is indicated? (1–6)
B	Which type of preparation would you prefer for the restoration of the lesion at your chosen stage? (1–3) 1: Traditional black class II preparation, 2: Tunnel preparation, 3: Chamfer preparation, saucer-shaped preparation
C	Which restorative material would you prefer for the restoration of the lesion at your chosen stage? (1–5) 1: Amalgam, 2: Glass ionomer, 3: Composite resin, 4: Compomer, 5: Other



**Fig. 2.** Illustration of the different stages of occlusal caries progression (stages 1–5)

**Table 2.** Questions regarding occlusal carious lesions

Case 2 Occlusal lesion	These pictures illustrate different stages of caries progression on the distal surface of tooth 15 or 25. Imagine a 20-year-old patient with low caries activity, good oral hygiene, visiting a dentist annually and brushing twice a day with a fluoridated toothpaste
A	Starting at which stage do you think an occlusal restoration is indicated? (1–5)
B	Which type of preparation would you prefer for the restoration of the lesion at your chosen stage? (1–3) 1: Only carious tissue removal, 2: Opening whole fissure, 3: Other
C	Which restorative material would you prefer for the restoration of the lesion at your chosen stage? (1–5) 1: Amalgam, 2: Glass ionomer, 3: Composite resin, 4: Compomer, 5: Other

## Appendix 2

*Representativeness of the Collected Data: Individual Background Characteristics of the Non-Respondents and Respondents in the Sample from the Dutch Survey*

	Non-respondents	Respondents	Total sample
<b>Sex (df = 1/p = 0.393/Cramér's V = 0.027)</b>			
Male	63%	66%	64%
Female	37%	34%	36%
<b>Age on January 1, 2015 (df = 4/p = 0.002/Cramér's V = 0.130)</b>			
29 years or younger	6%	10%	10%
30–39 years	18%	25%	25%
40–49 years	15%	19%	19%
50–59 years	41%	30%	30%
60 years or older	20%	16%	16%
Mean age (df = 1/p = 0.000/ $\eta^2$ = 0.009)	44.5 years	47.1 years	45.2 years
<b>Place of graduation (df = 5/p = 0.065/Cramér's V = 0.102)</b>			
Amsterdam	39%	33%	37%
Groningen	15%	16%	16%
Nijmegen	25%	22%	24%
Utrecht	10%	17%	12%
Abroad	11%	12%	11%
<b>Year of graduation (df = 4/p = 0.002/Cramér's V = 0.130)</b>			
1979 or earlier	9%	18%	11%
1980–1989	30%	34%	31%
1990–1999	17%	13%	16%
2000–2009	33%	25%	31%
2010 or later	11%	10%	11%
Mean year of graduation (df = 1/p = 0.003/ $\eta^2$ = 0.013)	1995.1	1992.1	1994.3
<b>Region of establishment (df = 3/p = 0.251/Cramér's V = 0.064)</b>			
North	9%	11%	10%
East	20%	21%	20%
South	20%	22%	21%
West	50%	45%	49%
<b>Participation in postgraduate education programme Iqual (KNMT) (df = 1/p = 0.133/Cramér's V = 0.048)</b>			
Yes	22%	27%	24%
No	78%	73%	76%
<b>Registered in postgraduate education register (df = 1/p = 0.470/Cramér's V = 0.023)</b>			
Yes	52%	55%	53%
No	48%	45%	47%
<b>Total<sup>b</sup></b>	<b>714</b>	<b>227</b>	<b>991</b>
	<b>72%</b>	<b>28%</b>	<b>100%</b>

The sample consisted of 1,050 dentists aged 64 years or younger (January 2014) with a known place of residence and/or work in the Netherlands. Those dentists were asked by email to answer the Web questionnaire. A total of 55 dentists from the sample were not reached (bouncers: autoreply, wrong or unknown email address). The net sample therefore consisted of 995 dentists. <sup>a</sup> The region of establishment is based on the division of the Netherlands into KNMT departments. Here the “south” region is formed by sections 12, 13 and 14, the “west” region by sections 5, 7, 8, 9, 10 and 11, the “east” region by sections 3, 4 and 6, and the “north” region by sections 1 and 2. <sup>b</sup> Four people were found to be unidentifiable (completely anonymous).

### Appendix 3

*Associations between Selected Variables and the Odds of Restoring Stage 3 Occlusal Caries Operatively from the Dutch Survey*

Independent variable	Subjects, n (%)	Unadjusted		p value
		OR	95% CI	
Gender				
Female	87 (34.3)	1.002	0.485–2.073	0.995
Male	167 (65.7)			
Experience				0.309
0–5 years	24 (9.4)	4.351	0.543–34.900	0.166
6–15 years	66 (26.0)	1.372	0.539–3.491	0.507
16–30 years	76 (29.9)	0.769	0.345–1.718	0.522
≥31 years	88 (34.6)			
Graduation				
Abroad	33 (13)	1.882	0.544–6.506	0.318
The Netherlands	221 (87)			
Preparation technique				0.811
Open the whole fissure	92 (36.2)	1.282	0.554–2.965	0.562
Other	12 (4.7)	–	–	0.590*
Removal of carious tissue only	150 (59.1)			
Filling material				
Amalgam, GIC and others	9 (3.5)	0.457	0.155–1.354	0.158
Composite	245 (96.5)			

GIC, glass ionomer cement. \* Calculated from  $\chi^2$  test.

### Appendix 4

*Associations between Selected Variables and the Odds of Restoring Stage 4 Approximal Caries Operatively from the Dutch Survey*

Independent variable	Subjects, n (%)	Unadjusted		p value
		OR	95% CI	
Gender				
Female	87 (34.3)	1.182	0.602–2.320	0.627
Male	167 (65.7)			
Experience				0.120
0–5 years	24 (9.4)	1.567	0.481–5.101	0.456
6–15 years	66 (26.0)	3.134	1.186–8.284	0.021
16–30 years	76 (29.9)	1.088	0.525–2.255	0.821
≥31 years	88 (34.6)			
Graduation				
Abroad	33 (13)	–	–	0.003*
The Netherlands	221 (87)			
Preparation technique				0.055
Traditional class II preparation	92 (36.2)	2.496	1.170–5.324	0.018
Tunnel preparation	12 (4.7)	0.913	0.234–3.559	0.896
Saucer-shaped preparation	150 (59.1)			
Filling material				
Amalgam, GIC and others	9 (3.5)	1.899	0.232–15.555	0.550
Composite	245 (96.5)			

GIC, glass ionomer cement. \* Calculated from the  $\chi^2$  test.

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