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# Radiographic Yield for Clinical Caries Diagnosis in Young Adults: Indicators for Radiographic Examination

Joana Christina Carvalho[a] Heliana D. Mestrinho[b] Alain Guillet[c] Marisa Maltz[d]

[a]Faculty of Medicine and Dentistry, UCLouvain, Brussels, Belgium; [b]Faculty of Health Sciences, University of Brasília, Brasília, Brazil; [c]Multidisciplinary Institute for Modelling and Quantitative Analysis, UCLouvain, Louvain-la-Neuve, Belgium; [d]Department of Preventive and Social Dentistry, Federal University of Rio Grande do Sul, Porto Alegre, Brazil

**Keywords**
Dental caries · DMF index · Diagnostic tests · Radiographs · Clinical decision making · Diagnostic accuracy · Risk indicator

**Abstract**
This prospective cohort study investigated the distribution pattern of carious lesions diagnosed by visual tactile and radiographic examinations, assessed the radiographic yield for clinical caries diagnosis, and estimated how accurately commonly used indicators for caries identified young adults who would benefit from radiographs at different thresholds. Overall, 576 patients aged 16–32 years seeking a first consultation were included. Patients were examined for caries and answered a validated questionnaire on sociodemographics and oral health behavior. Almost 10% of clinically sound approximal surfaces presented radiolucency in enamel/dentine. Of the clinically diagnosed noncavitated approximal and occlusal lesions, 22.5 and 17.7%, respectively, presented radiolucency reaching dentine at the radiographic examination. Noncavitated/enamel lesions detected radiographically were mainly at approximal surfaces (73.2%), while at occlusal surfaces these were negligible (0.7%). More than half of approximal dentine lesions were only detected radiographically (61.3%), while more than half of occlusal dentine lesions were only clinically diagnosed (57.1%). The hierarchical logistic regression analysis showed that patient's caries activity, $D_1$MFS scores ≥17, and frequent consumption of soft drinks were significantly associated with detection of approximal enamel/dentine lesions. Also, patient's caries activity and frequent consumption of soft drinks were significantly associated with occlusal dentine caries ($p \leq 0.05$). The indicator power of grouping these indicators as a predictor for the presence of radiographically detected lesions showed high sensitivity (0.84–0.91) and moderate specificity (0.64–0.73) for all surfaces and thresholds tested. In conclusion, radiographs increased significantly the number of approximal enamel/dentine and occlusal dentine lesions diagnosed. The ability to identify young adults with approximal lesions from the predictor was satisfactory. Bearing in mind that an essential contribution of bitewing radiographs to clinical examination is the detection of approximal noncavitated/enamel lesions that can be inactivated by nonoperative interventions, our results support the prescription of radiographs in young adults seeking a first consultation. Updating of current guidelines' recommendation of radiographs is warranted.


KARGER

karger@karger.com
www.karger.com/cre



Prof. Joana Christina Carvalho
Faculty of Medicine and Dentistry
UCLouvain, Av. Hippocrate 10
BE–1200 Brussels (Belgium)
Joana.carvalho@uclouvain.be

## Introduction

Studies on oral health status of young adults are limited in number [Hugoson et al., 2005; Holmlund and Mejàre, 2006; Skudutyte-Rysstad and Eriksen, 2007; Kirkevang et al., 2009; Bottenberg et al., 2015; Carvalho et al., 2015; Norderyd et al., 2015; Nørrisgaard et al., 2016], in particular studies dealing with caries incidence and progression in adulthood [Mejàre et al., 2014; Ridell et al., 2008; Kirkevang et al., 2009, 2011]. From adolescence to adulthood, the percentage of individuals with no caries experience is dramatically reduced [Kirkevang et al., 2011; Carvalho et al., 2015]. There is indication that during adulthood the proportion of approximal surfaces with caries experience approaches that of occlusal surfaces with due consideration to their severity [Ridell and al., 2008, Nørrisgaard et al., 2016; Carvalho 2016]. The prescription of bitewing radiographs has been considered a state-of-the-art adjunct method in diagnosing caries lesions in clinically inaccessible approximal surfaces and dentine occlusal caries [Wenzel, 2014].

In adolescents with high caries prevalence, the yield of clinical examination for diagnosis of approximal caries lesions was reported as being almost twice as that of the radiographs for noncavitated and enamel lesions, whereas the yield of radiographs was more than two thirds for approximal cavitated and dentine lesions [Machiulskiene et al., 1999, 2004]. Nevertheless, a recent meta-analysis showed a moderate accuracy of visual methods for diagnosing approximal and occlusal carious lesions. While the pooled sensitivity was low, the pooled specificity was high [Gimenez et al., 2015]. Similar results were observed for the accuracy of radiographic examination in another meta-analysis [Schwendicke et al., 2015]. In young adults, the yield of radiographs for clinical examination is known to be >50% [Poorterman et al., 1999, Hopcraft and Morgan, 2005, Galcerá Civera et al., 2007, Chu et al., 2008, Ritter et al., 2013], leading to an increase of sensitivity of the clinical examination.

Current guidelines recommend prescription of radiographs on an individual basis and preceded by a thorough clinical examination, consideration of the dental history and risk assessment of the patient. The routine or screening use of radiographs is considered unacceptable [European Commission, 2004; American Dental Association 2012]. However, dental practitioners find it challenging to comply with these recommendations since radiographs increase sensitivity of the clinical examination and evidence for indicators for radiographically detectable lesions in young adults is lacking.

The present study investigated the distribution pattern of carious lesions diagnosed by visual-tactile and by radiographic examinations, assessed the radiographic yield for clinical caries diagnosis, and estimated how accurately commonly used indicators for caries identified young adults who would benefit from radiographs at different thresholds. The null hypothesis was that indicators for radiographs in young adults seeking a first consultation would not be identified.

## Subjects and Methods

### *Ethics, Study Design, and Sample*

The study conformed to STROBE guidelines [Vandenbroucke et al., 2014]. The study was designed as a prospective cohort study and the sample size, estimated to 560 participants, was calculated on the basis of the following: if caries experience in young adults at the clinical examination would be 80 and 90% when the radiographic examination was added, and assuming a power of 80, 95% confidence interval, 219 participants would be required. This number was doubled ($n = 438$) taking into account the clustering of the observations, and finally the sample was increased by 30% to account for any loss in further follow-up examinations. Participants were recruited among patients seeking a first consultation at the Saint-Luc University Hospital in Brussels in 2010–2011.

### *Inclusion and Exclusion Criteria*

Inclusion criteria were being a young adult, that is, between the age of 16 and 35 years [United Nations, 2014], ability to understand and fill in questionnaires, willingness to participate in the study, and accepting to be called for a control visit in the future. The matching criteria were dental status clinically assessed only (unexposed to radiographs) and clinically and radiographically assessed (exposed to radiographs). Participants with serious chronic illness were excluded. Participants were informed about the study and signed written consent at their enrollment.

### *Examinations, Reliability, Instrument, and Outcome*

Patients from all over the country seek consultation and treatment at the University Hospital in Brussels. Routine procedures for patients seeking a first consultation include anamnesis, clinical, and radiographic examinations for elaboration of treatment plan and further treatment according to individual needs. Participants in the study were clinically examined for dental and periodontal conditions in addition to radiographic examination. Patients might bring radiographs taken previously to this first consultation at the University Hospital or refuse the radiographic examination.

Prior to the clinical examination for caries, the participants received dental prophylaxis including flossing. The complete dentition of patients was considered, but excluding third molars. Dental caries lesions were diagnosed according to their activity and severity. The surface was classified as sound when it showed normal enamel translucency after air drying. Active noncavitated lesion was defined as an opaque area with a dull-whitish surface without loss of surface continuity. Active cavitated lesion was identified as a cavity in dentine with soft consistency. A lesion was considered inactive when it was seen on an enamel/dentine area which ap-

**Table 1.** Theoretical hierarchical model for nonbiological and biological indicators for presence/absence of approximal caries in radiographs, corresponding criteria, number and percentage of young adults ($n$ = 576) in each category

| Indicators | Criteria | *n* (%) |
|---|---|---|
| *Level 1: Patient's demographics* | | |
| Gender | Male (ref.) | 323 (56.1) |
| | Female | 253 (43.9) |
| *Level 2: Socioeconomic status of parents* | | |
| Mother's educational level | ≥ Technical (ref.) | 355 (61.6) |
| | ≤ Secondary | 221 (38.4) |
| *Level 3: Patient's oral health care habits* | | |
| Brushing frequency | ≥1/day (ref.) | 388 (67.4) |
| | <1/day | 188 (32.6) |
| Last visit to the dentist | ≥3 years (ref.) | 104 (18.1) |
| | >1–2 years | 172 (29.8) |
| | ≤1 year | 300 (52.1) |
| Reason for visiting a dentist | Regular control (ref.) | 395 (68.6) |
| | Other | 181 (31.4) |
| Consumption of soft drinks | ≥1 daily (ref.) | 258 (44.8) |
| | Several times per week | 240 (41.7) |
| | Never or seldom | 78 (13.5) |
| *Level 4: Patients' oral health condition* | | |
| Dental status at $D_1$MFS level* | ≥17 (ref.) | 91 (15.8) |
| | ≤16 | 485 (84.2) |
| Caries lesions | 0 | 1,293 (38.8) |
| (noncavitated and cavitated)* | ≥1 | 2,043 (61.2) |
| Patient's caries activity | No (ref.) | 304 (52.8) |
| | Yes | 272 (47.2) |

* Either variable was used in the model.

peared shiny, smooth, of hard consistency and different degrees of brownish discoloration. Dental probe was used to differentiate between soft consistency and hard consistency of cavitated lesions. A tooth was considered extracted due to caries when there were clear indications of it; otherwise, it was considered as missing due to reasons other than caries [Carvalho et al., 2015]. Patients' caries activity was defined as the presence of at least one active lesion within the dentition, either noncavitated or cavitated [Maltz et al., 2003].

Caries experience was considered according to the following case status: (1) decayed, missing, and filled teeth and surfaces ($D_1$MFT/S) level ($D_1$: the decayed component represented both active and inactive noncavitated as well as cavitated lesions, M: missing due to caries, F: filled, T: tooth, S: surface) and (2) $D_3$MFT/S level ($D_3$: the decayed component represented active and inactive cavitated lesions, M: missing due to caries, F: filled, T: tooth, S: surface). The following indices were also used: $D_1$Sappr = number of noncavitated/enamel lesions on approximal surfaces, $D_3$Sappr = number of dentine lesions on approximal surfaces, $D_1$Soccl = number of noncavitated/enamel lesions on occlusal surfaces, $D_3$Soccl = number of dentine lesions on occlusal surfaces [Mejàre et al., 2014].

Five percent of the sample ($n$ = 31) was examined twice by 2 independent observers (S.S. and J.C.C.). Inter-examiner reliability was 0.86 (95% CI 0.84–0.89, nonweighted kappa). The radiographic examination for caries concerns posterior teeth, excluding third molars. A protocol to standardize the taking of radiographs was established using a Kwik-Bite™ holder (Kerr). Two or four bitewing radiographs were taken for each patient (Siemens, Germany, 60 KV and 7 mA). The phosphor plate was scanned by using VistaScan (Dürr Dental, Germany, 60 KV and 7 mA). A surface was scored as: (0) sound: no visible radiolucency, (1) radiolucency in enamel, and (2) radiolucency in dentine [Mejàre et al., 2014]. Filled and missing surfaces were also recorded. The assessment of radiographs was carried out by one examiner (HDM), and the intra-examiner reliability in 10% of the sample was 0.91 (95% CI 0.90–0.94, weighted kappa).

A correspondence with the caries diagnostic criteria applied in the clinical and radiographic examinations, respectively, was established for data analyses as follows: (1) sound (normal enamel translucency after air drying; no radiolucency), (2) enamel lesion (active/inactive noncavitated lesion; radiolucency in enamel), and (3) dentine lesion (active/inactive cavitated lesion; radiolucency in dentine).

The patients answered a questionnaire about sociodemographics and indicators of oral health behavior. Sociodemographic indicators were reported in terms of patient's age in years; gender (female; male); mother's level of education (technical or university completed; high school completed and primary completed or less). Patient's oral health behavior determinants were measured as brushing frequency (≥ once per day; < once per day); reason(s) for visiting a dentist (regular control; other); last dental attendance (≤1 year; >1 year up to 2 years; ≥3 years); and consumption of soft drink (≥ once per day; several times per week, seldom or never).

**Table 2.** Distribution of caries lesions in posterior teeth according to diagnostic method, tooth surface, and threshold

| | Approximal lesions | | | Occlusal lesions | | |
|---|---|---|---|---|---|---|
| | noncavitated/ enamel* | cavitated/ dentine** | total | noncavitated/ enamel | cavitated/ dentine | total |
| Total of examined surfaces | 16,128 | 16,128 | 16,128 | 9,216 | 9,216 | 9,216 |
| Lesions diagnosed clinically only | 237 | 523 | 796 | 407 | 395 | 802 |
| Lesions detected radiographically only | 646 | 828 | 1,474 | 3 | 297 | 300 |
| Lesions diagnosed by either methods | 883 | 1,351 | 2,234 | 410 | 692 | 1,102 |
| Percent of lesions diagnosed clinically only | 26.8% | 38.7% | 35.6% | 99.3% | 57.1% | 72.8% |
| Percent of lesions detected radiographically only | 73.2% | 61.3% | 66.0% | 0.7% | 42.9% | 27.2% |

* Non cavitated lesion/enamel, diagnosed clinically noncavitated lesions/radiolucent area restricted to enamel.
** Cavitated/dentine, diagnosed clinically cavitated lesions/radiolucent area reaching dentine.

**Table 3.** Mean number ± SD of DMFT and DMFS clinically diagnosed, diagnosed by either methods and average gain from radiographs

| | Clinically diagnosed | Diagnosed by either methods | Average gain from radiographs |
|---|---|---|---|
| $D_1$MFT level | 7.1±5.5 | 8.6±5.8 | 1.6±1.9 |
| $D_3$MFT level | 5.3±4.7 | 8.0±6.4 | 2.7±2.6 |
| $D_1$MFS level* | 13.5±13.9 | 17.0±15.4 | 3.5±3.8 |
| $D_3$MFS level** | 10.7±12.2 | 13.4±13.3 | 2.7±3.1 |
| $D_1$S approximal level* (posterior teeth) | 1.32±2.5 | 3.8±4.3 | 2.5±3.0 |
| $D_3$S approximal level** (posterior teeth) | 0.9±2.0 | 3.5±4.2 | 2.6±3.2 |
| $D_1$S occlusal level* | 1.4±2.0 | 1.8±2.2 | 0.4±0.9 |
| $D_3$S occlusal level** | 0.7±1.4 | 1.2±1.8 | 0.5±1.0 |
| $D_1$S approximal*** | 0.4±1.2 | 1.6±2.4 | 1.2±1.8 |
| $D_1$S occlusal*** | 0.7±1.2 | 0.7±1.2 | 0.0±1.0 |
| $D_1$S approximal + occlusal | 1.1±1.8 | 2.3±2.8 | 1.2±1.8 |

* $D_1$S approximal/occlusal level: the decayed component represented non- and cavitated lesions.
** $D_3$S approximal/occlusal level: the decayed component represented cavitated /dentine lesions.
*** $D_1$S approximal/occlusal: the decayed component represented noncavitated/enamel lesions.
DMFT, decayed, missing and filled teeth; DMFS, decayed, missing and filled surfaces.

The reliability of the self-applied questionnaire was assessed using a test-retest procedure. Thirty-nine patients filled in the questionnaire twice with a minimal interval of 1 week. Reliability was excellent ($\kappa > 0.8$) for 28.3% of the surveyed items, good ($\kappa$ = 0.6–0.8) for 40.0%, fair ($\kappa$ = 0.4–0.59) for 22.5%, and poor ($\kappa < 0.4$) for 9.2% of the items.

The outcomes were the diagnostic yields of clinical and radiographic caries examinations at different thresholds and the indicators for identification of patients who would benefit from radiographic examination.

*Missing Data*

Only patients with complete clinical and radiographic data were included. A limited number of missing answers ($n$ = 21) in the questionnaire applied did not show an apparent pattern and therefore none of them were removed from the study.

*Statistical Analysis*

Descriptive statistics in terms of percentage were used to describe the distribution of sociodemographic and oral health behavior indicators together with oral health conditions. The occurrence of caries lesions was described by mean ± SD. Clinically diagnosed noncavitated lesions were grouped together with radiograph radiolucent areas restricted to enamel (noncavitated/enamel), whereas clinically diagnosed cavitated lesions were grouped with radiograph radiolucent areas reaching dentine (cavitated/dentine) [Machiulskiene et al., 2004].

In the Hierarchical Logistic Regression Model applied, the independent variables were categorized into 4 blocks and forced into the model (Table 1). In the first block, gender was entered. In the second block, the effect of adding mother's sociodemographic indicator was evaluated. In the third block, indicators of oral health-related behavior were entered. Finally, in the fourth block, oral

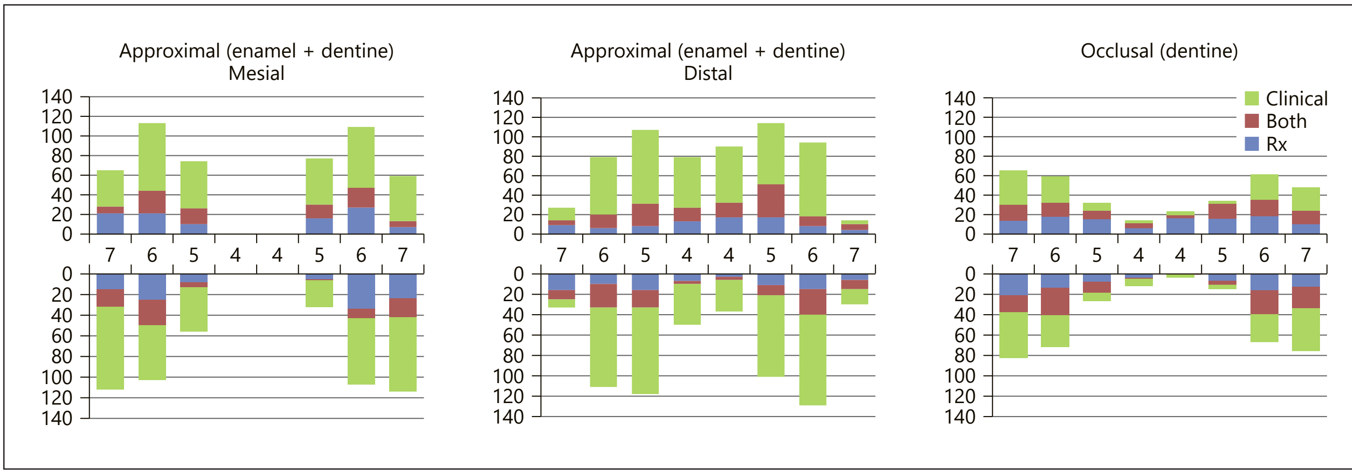


**Fig. 1.** Number of lesions diagnosed clinically only (Clinical), detected radiographically only (Rx), and diagnosed by either methods (Both), by threshold, tooth, and surface.



health conditions were selected using the forward LR method (it only enters when significant at the 0.05 level). Additional hierarchical logistic regression was performed replacing the $D_1$MFS scores for the decayed component (noncavitated [$D_1$] and cavitated [$D_3$] = $D_1$ score). Sensitivity, specificity, positive predictive value, negative predictive value, and Youden's index were calculated for variables in block 4 and separately for the grouping of patient's caries activity, $D_1$MFS scores ≥17 and frequent consumption of soft drink variables. Data analyses were carried out using R Statistics [R Core Team, 2017].

## Results

A total of 623 patients were eligible for the study. Seven potential participants refused to participate due to lack of interest and 4 others, under treatment for serious health conditions, were excluded. Overall, 612 patients were examined and answered the self-applied questionnaire. One patient was excluded because of double and different records in the database. Thirty-five other patients were removed either due to missing radiographs or contradictory notation between clinical and radiographic examinations such as remaining roots covered by gingiva present at the radiographic examination recorded as absent teeth in the clinical examination, teeth recorded absent due to other reasons than caries in the clinical examination and absent due to caries in the radiographic examination, inverted notation of neighboring teeth in the clinical examination. Thus, 576 patients aged from 16 to 32 years and resident in 148 different municipalities (25% of Belgian municipalities) in Belgium were included in the study.

Table 2 shows the distribution of caries lesions according to diagnostic method, tooth surface, and threshold. Globally, 9,216 teeth and 25,344 surfaces were examined. Of the examined surfaces, 9,216 were occlusal surfaces, and 16,128 approximal surfaces were eligible for the analyses.

In this population of young individuals 13% of the surfaces at risk were diagnosed as carious; 13.9% of approximal surfaces and 12.0% of occlusal surfaces. Regarding lesion severity, the majority of the lesions diagnosed by either clinical or radiographic examinations were cavitated/dentine (15.9% cavitated/dentine lesions and 9.9% noncavitated/enamel lesions). Cavitated/dentine lesions amounted 60.5 and 62.8% of the approximal and occlusal caries, respectively. Most enamel and dentine approximal lesions were detected radiographically only. Noncavitated/enamel lesions were mainly detected radiographically at approximal surfaces ($n = 646$, 73.2%), while at occlusal surfaces these were not detected at all ($n = 3$, 0.7%). More than half of approximal dentine lesions were detected radiographically only (61.3%), whereas more than half of occlusal dentine lesions were clinically diagnosed (57.1%).

A total of 2.6% of clinically sound occlusal surfaces and 17.7% of noncavitated occlusal lesions presented radiolucency in dentine at the radiographic examination. Regarding sound approximal surfaces, 9.9% presented radiolucency either in enamel (4.9%) or dentine (5.0%). Moreover, 37% of clinically noncavitated approximal lesions presented radiolucency, 14.5% in enamel and 22.5% in dentine.

**Table 4.** OR (95% CI) of indicators that remained significant in the hierarchical logistic regression model for the association between nonbiological as well as biological indicators and the radiographically detected approximal (enamel + dentine) and occlusal (dentine) caries lesions (outcome) in young adults

| Indicators for radiographic examination | Block I | | Block II | | Block III | | Block IV | |
|---|---|---|---|---|---|---|---|---|
| | OR (95% CI) | *p* value | OR (95% CI) | *p* value | OR (95% CI) | *p* value | OR (95% CI) | *p* value |
| **Approximal (enamel + dentine)** | | | | | | | | |
| **Occlusal (dentine)** | | | | | | | | |
| Visit to a dentist | | | | | | | | |
| Control (ref. *n* = 395) | | | | | 1 | | | |
| Other (*n* = 181) | | | | | 1.71 (1.34–2.20) | <0.001 | **1.35 (1.06–1.72)** | **0.020** |
| Soft drinks | | | | | | | | |
| ≥1daily (ref. *n* = 258) | | | | | 1 | | | |
| >1 per week (*n* = 240) | | | | | 0.71 (0.53–0.95) | 0.020 | **0.75 (0.57–1.00)** | **0.040** |
| Seldom (*n* = 78) | | | | | 0.58 (0.44–0.77) | <0.001 | **0.68 (0.52–0.88)** | **0.003** |
| $D_1$MFS level | | | | | | | | |
| ≥17 (ref. *n* = 91) | | | | | | | 1 | |
| ≤16 (*n* = 485) | | | | | | | **0.49 (0.37–0.66)** | **<0.001** |
| Patient's caries activity | | | | | | | | |
| No (ref. *n* = 304) | | | | | | | 1 | |
| Yes (*n* = 272) | | | | | | | **2.01 (1.63–2.62)** | **<0.001** |
| **Approximal (enamel)** | | | | | | | | |
| Soft drinks | | | | | | | | |
| ≥1daily (ref. *n* = 258) | | | | | 1 | | | |
| >1 per week (*n* = 240) | | | | | 0.57 (0.40–0.81) | 0.002 | **0.58 (0.41–0.83)** | **<0.001** |
| Seldom (*n* = 78) | | | | | 0.66 (0.47–0.92) | 0.013 | **0.72 (0.52–1.00)** | **0.050** |
| $D_1$MFS level | | | | | | | | |
| ≥17 (ref. *n* = 91) | | | | | | | 1 | |
| ≤16 (*n* = 485) | | | | | | | **0.62 (0.43–0.89)** | **0.009** |
| Patient's caries activity | | | | | | | | |
| No (ref. *n* = 304) | | | | | | | 1 | |
| Yes (*n* = 272) | | | | | | | **1.56 (1.25–2.28)** | **0.001** |
| **Approximal (dentine)** | | | | | | | | |
| Soft drinks | | | | | | | | |
| ≥1daily (ref. *n* = 258) | | | | | 1 | | 1 | |
| >1 per week (*n* = 240) | | | | | 0.87 (0.60–1.27) | 0.480 | 0.94 (0.66–1.34) | 0.700 |
| Seldom (*n* = 78) | | | | | 0.54 (0.37–0.78) | 0.001 | **0.62 (0.44–0.88)** | **0.008** |
| $D_1$MFS level | | | | | | | | |
| ≥17 (ref. *n* = 91) | | | | | | | 1 | |
| ≤16 (*n* = 485) | | | | | | | **0.36 (0.25–0.52** | **<0.001** |
| Patient's caries activity | | | | | | | | |
| No (ref. *n* = 304) | | | | | | | 1 | |
| Yes (*n* = 272) | | | | | | | **2.35 (1.71–3.21)** | **<0.001** |
| **Occlusal (dentine)** | | | | | | | | |
| Gender | | | | | | | | |
| Male (ref. *n* = 323) | 1 | | 1 | | 1 | | 1 | |
| Female (*n* = 253) | 0.67 (0.53–0.84) | 0.001 | 0.66 (0.52–0.83) | 0.001 | 0.69 (0.54–0.88) | 0.003 | **0.71 (0.55–0.90)** | **0.005** |
| Visit to a dentist | | | | | | | | |
| Control (ref. *n* = 395) | | | | | 1 | | 1 | |
| Other (*n* = 181) | | | | | 1.82 (1.43–2.31) | <0.001 | **1.61 (1.26–2.07)** | **<0.001** |
| Soft drinks | | | | | | | | |
| ≥1daily (ref. *n* = 258) | | | | | | | | |
| >1 per week (*n* = 240) | | | | | 0.82 (0.61–1.10) | 0.199 | 0.85 (0.63–1.13) | 0.300 |
| Seldom (*n* = 78) | | | | | 0.59 (0.43–0.80) | 0.001 | **0.63 (0.46–0.85)** | |
| Patient's caries activity | | | | | | | | |
| No (ref. *n* = 304) | | | | | | | 1 | |
| Yes (*n* = 272) | | | | | | | **1.56 (1.20–2.05)** | **0.001** |

**Table 4** (continued)

| Indicators for radiographic examination | Block I | | Block II | | Block III | | Block IV | |
|---|---|---|---|---|---|---|---|---|
| | OR (95% CI) | *p* value | OR (95% CI) | *p* value | OR (95% CI) | *p* value | OR (95% CI) | *p* value |
| **Approximal (enamel + dentine)** | | | | | | | | |
| Visit to a dentist | | | | | | | | |
| Control (ref. *n* = 395) | | | | | 1 | | 1 | |
| Other (*n* = 181) | | | | | 1.75 (1.31–2.32) | <0.001 | **1.34 (1.01–1.78)** | **0.040** |
| Soft drinks | | | | | | | | |
| ≥1daily (ref. *n* = 258) | | | | | 1 | | 1 | |
| >1 per week (*n* = 240) | | | | | 0.67 (0.47–0.93) | 0.020 | **0.75 (0.65–0.86)** | **0.040** |
| Seldom (*n* = 78) | | | | | 0.57 (0.42–0.79) | 0.001 | **0.71 (0.61–0.81)** | **0.010** |
| $D_1$MFS level | | | | | | | | |
| ≥17 (ref. *n* = 91) | | | | | | – | 1 | |
| ≤16 (*n* = 485) | | | | | | | **0.42 (0.30–0.59)** | **<0.001** |
| Patient's caries activity | | | | | | | | |
| No (ref. *n* = 304) | | | | | | | 1 | |
| Yes (*n* = 272) | | | | | | | **2.20 (1.67–2.90)** | **<0.001** |

$D_1$MFS, decayed, missing, and filled surfaces.

Table 3 shows the mean number of DMFT and DMFS diagnosed by clinical examination, diagnosed by either clinical and radiographic examinations and the average gain of carious surfaces from radiographs. The mean ± SD average gain at $D_1$FMS level was 3.5 ± 3.8. The radiographic examination increased the detection of the noncavitated approximal decayed component by about 3/4.

Figure 1 describes the frequency distribution of caries lesions (approximal enamel/dentine and occlusal dentine) diagnosed clinically only, detected radiographically only, and diagnosed by either methods. The radiographic examination was particularly important for the overall diagnosis of approximal lesions. The percentage of caries lesions which was only detected by the radiographic examination varied from 48 to 83% of the enamel/dentine lesions depending on the surface. Enamel occlusal lesions were not detected by the radiographic examination. Increased detection of approximal dentine lesions was observed in molars and premolars, whereas occlusal dentine lesions were mainly detected in molars.

The hierarchical logistic regression analysis is shown in Table 4. A total of 21 answers were missing in the self-applied questionnaire being 14 (2.4%) regarding mother's education level, 4 (0.7%) last visit to the dentist, and 3 (0.5%) frequency of soft drink consumption. The missing data for mother's education level were replaced by the median value, whereas the last visit to the dentist and the frequency of soft drink consumption were replaced by values corresponding to the worst scenario.

Young adults with caries activity (OR 2.01, 95% CI 1.63–2.62) and those who paid irregular visit to the dentist (OR 1.35, 95% CI 1.06–1.72) presented lesions that were significantly more likely to be detected by the radiographic examination when all enamel and dentine lesions were considered. Individuals having absolute $D_1$MFS scores ≥17 (OR 2.04, 95% CI 1.51–2.70) and frequent consumption of soft drinks (OR 1.47, 95% CI 1.14–1.92) were likely to present lesions detected by the radiographic examination when all enamel and dentine lesions were considered. Two indicators, patient's caries activity and consumption of soft drink several times per week, were significantly associated with the detection of lesions in all types of surfaces and at all thresholds studied. $D_1$MFS scores ≥17 were significantly associated with the detection of approximal enamel and dentine lesions but not to occlusal dentine lesions.

An additional hierarchical regression analysis, in which the mean $D_1$MFS was replaced by $D_1$ scores, highlighted that the decayed component was not a determinant for radiographic examination at both surfaces and thresholds. Sensitivity, specificity, positive, and negative predictive values were calculated for each indicator. The indicators that showed high SE (ability to correctly identify individuals with caries) also showed low SP (ability to correctly identify individuals without caries) for all surfaces and thresholds studied. No single best indicator for the presence of approximal (either enamel and/or dentine caries) or occlusal caries (dentine) could be identified. None of the indicators showed values for SE + SP ≥1.

**Table 5.** Predictive power of significant indicators detected in the mixed-effects model when all enamel and dentine lesions were considered (patient's caries activity, dental status at $D_1$MFS level, and consumption of soft drinks) for presence/absence of radiographically detected caries lesion in young adults (*n* = 576)

| | SE | SP | PV+ | PV- | Youden's index |
|---|---|---|---|---|---|
| Approximal enamel | 0.84 | 0.73 | 0.11 | 0.99 | 0.56 |
| Approximal dentine | 0.91 | 0.67 | 0.13 | 0.992 | 0.58 |
| Approximal enamel and dentine | 0.87 | 0.65 | 0.19 | 0.98 | 0.53 |
| Occlusal dentine: patient's caries activity + $D_1$MFS + soft drinks | 0.95 | 0.72 | 0.10 | 1.00 | 0.68 |
| Approximal (enamel + dentine) and occlusal (dentine) | 0.85 | 0.64 | 0.14 | 0.98 | 0.48 |

SE, sensitivity; SP, specificity; PV+, predictive positive value; PV–, predictive negative value. Youden's index, 1 – (1 – SP) + (1 – SE)/100; $D_1$MFS, decayed, missing and filled surfaces.

Yuoden's index was very low, none of the individual variables reached values higher than 0.02.

Table 5 shows the predictive power of grouping the significant indicators analyzed in the mixed-effects model when all enamel and dentine lesions were considered (patient's caries activity, dental status at $D_1$MFS level and consumption of soft drinks) for the presence/absence of radiographically detectable caries lesions. The grouping of these significant variables as predictor for the presence of radiographically detectable lesions gave high SE (0.84–0.91) and moderate SP (0.65–0.76) values for all surfaces and thresholds tested. The null hypothesis was rejected. High negative predictive values, but low positive values, were observed applying such a predictor.

## Discussion

To our knowledge, this is the first study that answers the specific question about the appropriateness of prescribing bitewing radiographs to young adults seeking a first consultation in daily practice. According to our findings, bitewing radiographs provided additional diagnostic benefit in the detection of approximal lesions and to some extent to occlusal lesions with radiolucency in dentine. Furthermore, the ability of combined clinical indicators to identify young adults benefiting from radiographs was satisfactory in these young adults with moderate caries experience.

Previous studies analyzing radiograph yields to clinical caries diagnosis in young adults and adults did not perform plaque removal before clinical examination, which could lead to an underestimation of the lesions diagnosed [Hopcraft and Morgan, 2005, Galcerá Civera et al., 2007, Chu et al., 2008; Ritter et al., 2013]. In adults, the study by Ritter et al., [2013] showed additional radiographic yield of 43.0% for noncavitated approximal lesions that were air dried for the clinical examination. In contrast, in adolescents with high caries prevalence, the corresponding contribution of radiographs was limited to 24% for noncavitated/enamel approximal lesions when teeth were isolated with cotton rolls and air dried for examination [Machiulskiene et al., 1999, 2004]. It is believed that plaque removal facilitates the clinical diagnosis, therefore in our study, prophylaxis including flossing was performed and teeth were examined dried. The radiograph yield to clinical diagnosis remained important for noncavitated/enamel approximal lesions (73.2%). In contrast, the radiograph yield for noncavitated/enamel occlusal lesions was negligible (0.7%).

It has been reported that bitewing radiographs increase the diagnosis accuracy of dentine lesions [Hopcraft and Morgan, 2005, Galcerá Civera et al., 2007, Chu et al., 2008, Ritter et al., 2013]. Hopcraft and Morgan, [2005] documented radiograph yields to clinical diagnosis of cavitated lesions from 67.1 to 77.1% for approximal and from 17.1 to 24.1% for occlusal lesions in 17–30 years old young adults. Chu et al., [2008] showed radiograph yield to clinical diagnosis of cavitated lesions of 51.4% in 18–24-year-olds. A similar tendency was observed in young adults aged 16–32 years old for radiograph yields of cavitated/dentine approximal (61.3%) and occlusal lesions (42.9%).

Regarding the depth of lesions, earlier studies indicated that most of approximal noncavitated lesions presented radiolucency restricted to enamel, whereas 46–79% of lesions with radiolucency reaching the outer third or half of the dentine were cavitated lesions. [Lunder and von der Fehr, 1996; Bille and Thylstrup, 1982; Mejàre and Malmgren, 1986; Thylstrup et al., 1986; Akpata et al., 1996; Mialhe et al., 2009]. However, the relationship between depth of radiolucency and clinical cavitation is not unequivocal [Wenzel, 2014; Sansare et al., 2014].

According to the literature, treatment decisions for clinically and/or radiographically detected lesions restricted to enamel should be nonoperative strategies [Carvalho et al., 2004]. Since radiographic approximal lesions reaching the cutoff point of the outer/middle of the dentine should not automatically lead to a decision of operative treatment [Baelum et al., 2012], temporary tooth separation has been indicated to determine whether there is surface cavitation [Sansare et al., 2014; Urzúa et al., 2019]. Occlusal radiolucency in the outer third of dentine indicates operative treatment only when associated with cavitated lesions not allowing biofilm control [Carvalho et al., 2016].

Two studies carried out in children established indicators for prescription of radiographs [Anderson et al., 2005, Lillehagen et al., 2007]. Their ability to identify children who benefited from radiographs was limited. The best predictor was dentist's judgment, but its accuracy did not reach the combined level of 160% for sensitivity and specificity [Kingman, 1990]. Low accuracy was also observed in our study when the indicators were tested individually. The grouping of patient's caries activity, $D_1$MFS >17 and frequent consumption of soft drink showed significant OR for radiographs when all enamel and dentine lesions were considered. Besides their high sensitivity, these indicators were sensitive enough to identify patients benefiting from radiographs.

The grouping of these significant indicators as a predictor for radiographs was satisfactory showing a high sensitivity, moderate specificity, high negative predictive value, but low positive predictor value for all surfaces and thresholds tested. Thus, this predictor would indicate unnecessary radiographs probably due to the low number of caries lesions observed in the population under study. The high negative predictive value observed shows that patients for whom the predictor indicates no need for radiographs do not need them. The use of this predictor would indicate a high number of radiographs to young adults due to its low positive predictive value which would be contra balanced by a low number of radiographs due to its high negative predictive value.

It can be questioned whether the absence of a gold standard is a limitation of this study. We acknowledge this constraint, but one should consider that our study is centered on the contribution of radiographs to clinical examination and subsequent treatment decisions. A further limitation is the cross-sectional nature of the study design. However, prescription of radiographs for patients seeking a first consultation is assessed by cross-sectional data. Longitudinal data are required for assessing the appropriate interval between radiographs. Finally, at a first consultation, radiographs do not contribute to clinical examination regarding assessment of caries lesions activity, which is an essential aspect of treatment decisions. Radiographs are limited in this aspect and can only contribute to assessment of caries lesions activity when lesions are monitored over time and further images are taken according to individual needs.

In conclusion, bitewing radiographs increased significantly the number of diagnosed approximal enamel/dentine lesions and occlusal lesions with radiolucency in dentine. The ability to identify young adults with approximal lesions from the predictor was satisfactory. Bearing in mind that an essential contribution of bitewing radiographs to clinical examination is the detection of approximal noncavitated/enamel lesions that can be inactivated by nonoperative interventions, our results support the prescription of radiographs in adults seeking a first consultation. This finding contrasts with current guidelines' recommendation of radiographs for young adults seeking a first consultation. Updating of current guidelines' recommendation of radiographs is thus warranted.


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## Statement of Ethics

The study protocol was approved by the Ethical Committee of the Catholic University of Louvain, Belgium (Belgian register number 340320097.77). The participants signed a written informed consent.

## Disclosure Statement

The authors have no conflict of interest to declare.

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## Authors Contributions

J.C.C.: contributed to the conception and design of the study. J.C.C. and H.M.: contributed to data collection. M.M., J.C.C., and A.G.: contributed to statistical analysis and interpretation of data. J.C.C., M.M., and H.M.: wrote the paper. All authors critically revised and approved the final version of the manuscript.

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