THE EFFECTIVENESS OF TELEDENTISTRY VERSUS IN-PERSON EXAMINATION ON DENTAL CARIES EVALUATION

A Thesis
Submitted to
the Temple University Graduate Board

In Partial Fulfillment
of the Requirements for the Degree
MASTER'S OF ORAL HEALTH SCIENCES

---

by
Kalina Casas
May 2023

Examining Committee Members:

Dr. Chukwuebuka Ogwo, Advisory Chair, Department of Oral Health Sciences
Dr. Louis DiPede, TU Department of Restorative Dentistry
Dr. Sara Toema, TU Department of Pediatric Dentistry

ABSTRACT

Objective: To determine the effectiveness of teledentistry versus in-person examination for dental caries diagnosis.

Methods: This is a systematic review and meta-analysis studies comparing the effectiveness of teledentistry versus in-person examination for dental caries diagnosis. The eligibility criteria were peer-reviewed studies published in English between January 2013 through December 2021 that reported diagnostic parameters (specificity and sensitivity) for caries detection in primary and permanent dentition. Articles were extracted using search strategies from PubMed and CINAHL databases. Articles were screened using PRISMA guidelines, following a review for quality assessment using the JBI Critical Appraisal Checklists. Meta-analysis was conducted in R using the mada package. A descriptive analysis of the sensitivity, specificity, DOR, and confidence intervals were performed with respective forest plots. Heterogeneity was assessed using Cochrane Q and Higgin's I2 tests. Univariate measures of diagnostic accuracy were performed based on the DerSimonian-Laird random effect, and the summary diagnostic odds ratio reported.

Results: A total of 12 studies met the inclusion criteria and were reviewed and meta-analyzed. The range of diagnostic parameter were sensitivity (45.6-88.3%), specificity (55.2-98.3%), PPV (79-92%), NPV (48-97%), accuracy (70-96%), and kappa (0.46-0.89) in teledentistry modalities. Test for equality of sensitivities and specificities were significant (p-value = <2e-16). The studies were not heterogenous with Cochran's Q: 14.502 (p = 0.206) and Higgins' I2 of 24% The multivariable analysis of the univariate measures showed a diagnostic odds ratio based on DerSimonian-Laird random effect t was 35.14. This implies that the odds of caries detected via tele dentistry is 35 times true positive than the odds that it is false positive.

Conclusions: Diagnosis of caries via teledentistry effective and comparable to in-person diagnosis. Remote assessments are consistent in diagnostic accuracy for caries. Further research should establish a definitive threshold for the diagnostic parameters in detecting caries.

TABLE OF CONTENTS

LIST OF TABLES

Table Page

LIST OF FIGURES

CHAPTER 1

BACKGROUND

Dental caries is the most prevalent oral infectious disease. If early diagnosis and treatment planning are carried out, dental caries can be prevented (Kopycka & Billings, 2013). Carious lesions are formed by demineralization, where the pH of plaque decreases and is undersaturated with calcium and phosphates (Touger-Decker & van Loveren, 2003). Highly preventable, carious lesions that are prolonged and left untreated can cause acute morbidity and costly treatment (Estai et al., 2016). In addition, prolonged carious lesions can ultimately decrease an individual's quality of life. Specifically, causing pain, low self-esteem, and tooth loss (Kale et al., 2019). Although the traditional diagnosis method of dental caries has been done in-person through clinical and radiographic examinations, teledentistry has made its advancement to provide access for remote dental care.

The COVID-19 pandemic has drastically altered the diagnostic approaches within dentistry, adapting to a more virtual approach in access to dental care. In accordance with the American Dental Association (ADA), 76% of dental offices closed except for emergencies during the pandemic (ADA, 2021). The rise in teledentistry modalities has the potential to release resources from the practice level, to provide remote care to those who need it (Park et al., 2019). The pandemic has affected the quality of dental care among the remote rural, highly populated urban regions, and in economically disadvantaged areas. Due to the evolving technological advances within healthcare, modalities like telehealth have been rapidly adopted and can be seen as revolutionary in the delivery of quality dental healthcare. In a dental setting, teledentistry forwards a patient's electronic data to other health care providers for review and diagnosis (Park et al., 2019). Teledentistry also allows patients to receive medical opinions from clinicians via video conferencing. In addition to remote examinations, the store-and-forward approach in teledentistry allows examiners to store radiographs, intraoral images, and scans to provide additional references for remote examiners (Estai et al., 2016). The integration of images with teledentistry assessments can ultimately improve tooth-by-tooth assessments, to measure caries through the parameters of specificity, sensitivity, and accuracy. However, using three-dimensional images can provide a greater benefit for teledentistry examiners to detect caries using the decayed, missing, and filled teeth (DMFT) and International Caries Detection and Assessment System (ICDAS) indices.

Current evidence shows the validity in teledentistry using radiographic and smartphone images for dental caries diagnosis (Park et al., 2019 & Wosik et al., 2020). Some existing literatures have compared the accuracies of teledentistry versus in-person examination using smartphone and radiographic imaging for dental caries detection (Park et al., 2019 & Wosik et al., 2020). Existing literature has also shown comparisons between dentists and non-dentist for examiners, to further understand the effectiveness of teledentistry within remote areas or places without easy access to dental care (Wosik et al., 2020).

However, there is no recent consensus on the effectiveness of teledentistry versus in-person examination in the diagnosis of dental caries, especially after the COVID-19 pandemic. In 2016, Estai et al. published a systematic review of evidence for the accuracy of dental caries detection, using teledentistry. Caries measured by DMFT and ICDAS indices were variables that compared the accuracy of teledentistry (remote) examinations to in-person clinical examinations (Estai et al., 2016). Since the recent COVID-19 pandemic in 2020, the goal of this study was to establish the accuracy, specificity, and sensitivity of caries diagnosis in teledentistry. The purpose of this meta-analysis was to find the effectiveness of teledentistry versus in-person examination for dental caries diagnosis.

CHAPTER 2

METHODS

Search Strategy

A comprehensive systematic search was conducted with articles published from January 2013, when teledentistry was first introduced by the American Dental Association (ADA), to December 2021. The PubMed and CINAHL databases were used to find articles that implemented the use of teledentistry approaches in detecting dental caries using the Boolean OR/AND terms. MeSh terms for search 1 (S1) relative terms for teledentistry, search 2 (S2) for dental caries, search 3 (S3) for dentistry, and search 4 (S4) included the combination of terms founded for S1, S2, and S3. The PubMed (NLM) database included 447 results from the last search on April 13, 2022, and the CINAHL (EBSCOHost) database included 152 results from the last search on April 13, 2022. Table 6 describes the search strategy for both the PubMed and CINAHL databases.

Eligibility and Study Selection

The articles that were included have the following criteria: comparing teledentistry to in-person examination on dental caries evaluation, primary and permanent teeth, studies involving patients with implants and crowns, ICDAS and/or DMFT/S or dmft/s scores used to detect caries via teledentistry and in- person examination, caries diagnostic parameters using specificity and sensitivity, radiographic examination, non-randomized and randomized control trials, thesis and dissertation studies, and other types of studies published during January 2013 to December 2021. Exclusion criteria include if the studies include edentulous patients, the full text is unavailable, the articles are published before January 2013, and the articles are not provided in English. The articles were screened using the Preferred Reporting Systems for Systematic Reviews and Meta-Analyses (PRISMA) guidelines. The screening process included reviewing articles that were duplicates, were part of the inclusion criteria, and had a full-text readily available which are shown in Figure 1.

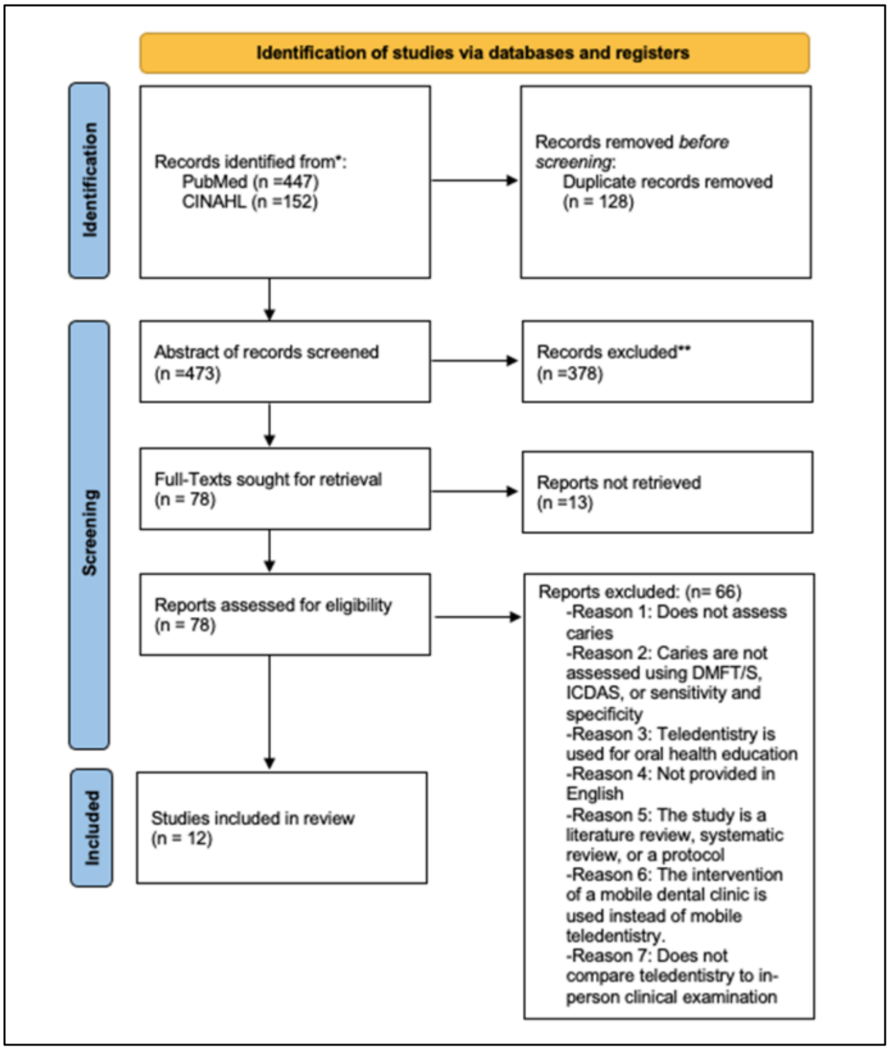

Figure 1. PRISMA Flow Diagram

Quality Assessment

Each article was reviewed for quality assessment using the Joanna Briggs Institute (JBI) Critical Appraisal Checklists. The Quasi-Experimental Checklist and the Randomized Control Checklist were used to properly assess the bias, quality, and validity of each study. Table 7 described the quality of each article, obtaining the randomization, attrition, type of blinding, and follow-up schedules for each experimental group.

Quantitative Analysis

The true positive rate (TP), true negative (TN), false positive rate (FPR), and false negative rate (FNR) values were determined for each study. The sample size and effect size of each study was recorded in an Excel sheet. The metanalyses (pooled and random effect estimation and heterogeneity assessment) for this study was performed in R using the MADA package (Sousa-Pinto Bernado, 2022). The descriptive analysis of the sensitivity, specificity, Diagnostic Odds Ratio (DOR) and their respective confidence intervals were performed, and their forest plots provided. Also, the correlation of the sensitivities, FPR's, and the chi-square test of equality of sensitivities and specificities were measured. The metanalysis of the diagnostic accuracy of remote caries assessment was done by pooling the univariate measures of accuracy (DOR) using the DerSimonian-Laird random effect estimator and the summary DOR forest plot provided (DerSimonian, R. and Laird, N., 1986). The Cochran's Q and Higgins' I2 measures of heterogeneity were assessed.

CHAPTER 3

RESULTS

Table 1. *Extraction Table*

Author	**Publication Year & Study Location**	**Objective**	**Population Parameter & Sample Size**	**Variables of Interest**	**Statistical Analysis**	**Outcomes**
Steinmeir et al.	Year: 2019 Location: Zurich, Switzerland	Assessing the relationship between intraoral true color scans with remote examination and conventional clinical examinations.	Study Design: Cross- Sectional Population: Recruited patients in need of prosthetic rehabilitation Sample size: 10 patients total	Caries measured by dentition for decayed, missing, or crowned teeth (DMFT) and accuracy.	Statistical software R and package ggplot2.	Accuracy for DMFT in clinical assessment: 73% of cases correctly assessed the presence and absence of decayed teeth. Accuracy for DMFT for remote assessment: 70% of cases correctly assess the presence or absence of decayed teeth.

Table 1. *Extraction Table* (Continued)

Kale et al	Year: 2019 Location: Pune, Maharashtra, India	Determine a mother's ability in caries diagnosis, using a smartphone photographic approach.	Study Design: Cohort (Retrospective) Population: Children ages 3-5 years of age Sample Size: 100 mothers and 100 children	Caries measured by accuracy, sensitivity, specificity, positive predictive value (PPV), and negative predictive value (NPV).	Inter-rater reliability using the kappa value and chi-square test was used to indicate any significant difference in caries diagnosis between the dentist and mothers.	Accuracy and reliability measures for mothers: Sensitivity =88.3% Specificity =9 8.3% PPV = 92% NPV = 97% Accuracy = 96% Kappa = 0.87 *Strong agreement with mother's diagnosis to dentist.
Park et al.	Year: 2018 Location: Subiaco, Australia	Comparing the detectability of intra-oral photographic methods to comprehensive dental examination (CDE) on children.	Study Design: Cohort (Retrospective) Population: Children ages 2-18 years old Sample Size: 77 patients	Caries measured by the decay filled teeth (dft/DMFT) index, sensitivity, specificity, PPV, and NPV.	Landis and Koch measurement of agreement and one-way ANOVA.	CDE vs Photo: Kappa score =0.62 Specificity= 95% Sensitivity= 61.5% PPV=79 NPV=88

Table 1. *Extraction Table* (Continued)

Alshaya et al	Year: 2018 Location: Saudi, Arabia	Reliability of mobile phone teledentistry for dental caries diagnosis of children with mixed dentition	Study Design: Cross Sectional Population: Children 6-12 years Sample Size: 57 cases, yielding 342 comparisons	Caries measured by DMFT, sensitivity, and specificity.	Cohen's kappa: measured the accuracy of the diagnosis Cronback's alpha: measured the inter-rater reliability using the intraclass correlation coefficient (ICC)	Overall Agreement between the examiners (teledentistry) and control (clinical) Sensitivity Mean of E1-E6 = 79.1% Specificity Mean of E1-E6 = 85.9% Kappa Mean of E1-E6 = 0.824
Kohara et al.	Year: 2018 Location: Sao Paulo, Brazil	Comparing two different camera modalities, a smartphone and conventional camera, with traditional direct examination in detecting carious lesions at different stages in deciduous molars.	Study Design: Cohort (Retrospective) Population: In-vivo: Children aged 3-6 years & primary teeth Sample Size: *In-vitro* 11 first molars and 9 second molars *In-vivo* 15 children	Caries measured by ICDAS score, sensitivity, and specificity.	*In-vivo group:* inter-rater reliability was calculated with weighted kappa test to understand the accuracy with each device and reference standard. Confidence intervals for sensitivity, and specificity for initial, moderate, and extensive carious lesion thresholds were calculated	In-vivo: Macro (clinical) means between E1 & E2: Kappa mean = 0.602 Sensitivity mean = 45.6 Specificity mean = 93.3 iPhone & Nexus (remote) means between E1 & E2: Kappa mean = 0.603 Sensitivity mean = 56.8 Specificity mean = 95.9

Table 1. *Extraction Table* (Continued)						
Estai et al.	Year: 2017 Location: Australia	To evaluate the efficacy of teledentistry to screen dental caries remotely.	Study Design: Cross-Sectional Population: Patients who attend a routine check-up of any age. Sample Size: 100 participants	Caries measured by accuracy, specificity and sensitivity.	Weighted kappa (k): inter-rater and intra-rater reliability of photographic and face-to-face caries assessments.	Face-to-Face (Benchmark) Screening vs Teledentistry Dentist 1 & 2: Sensitivity mean = 69 Specificity mean = 97 Accuracy mean = 96 Kappa Statistic mean = 0.63 Intra-rater agreement for photographic assessment: K=0.84
Pentapati et al.	Year: 2017 Location: Manipal, India	To evaluate the application of an intraoral camera within Teledentistry on comprehensive screening of oral conditions.	Study Design: Cohort (retrospective) Population: Children ages 7-16 years Sample Size: 62 children	Caries measured by DMFT/dmft values, sensitivity, specificity, PPV, and NPV.	Spearman's rho correlation coefficient: measured differences in clinical and intraoral camera DMFT/dmft values. Wilcoxon signed rank test: compared means of DMFT/dmft within clinical and intraoral camera examinations. Kappa coefficient: compared the presence of calculus, stains, tooth wear, and fluorosis within clinical and intraoral camera examinations.	***p-value <0.05 was statistically significant Caries Experience (kappa-coefficient) between intraoral and clinical examination: Sensitivity = 98.1% Specificity = 66.7% % agreement = 93.55% Kappa = 0.714

Table 1. *Extraction Table* (Continued)						
Purohit et al.	Year: 2016 Location: Bhopal, India	To assess the reliability of remote examination to screen dental caries within 12-year-old school children living in a rural geographical area of India.	Study Design: Cross-Sectional Population: 12-year-old school children living in the outreach health centers of the Bhopal district. Sample Size: 139 children.	Caries measured by DMFT index, sensitivity, specificity, PPV, and NPV	Intra-class Correlation Coefficient (ICC): compared the variability between the two assessments. Bland-Altman plot: used linear regression analysis to measure the agreement and proportional bias between the two modalities for caries assessment. Student's t-test: compared quantitative variables. Likelihood ratio (LR) and a receiver-operating characteristic (ROC) curve: measured the predictive accuracy for videographic analysis.	***significance was set at less than 0.05 Clinical: Inter-examiner mean score for E1 & E2 = 0.95 Intra-examiner score for E1 vs. E2 = 0.93 Remote: Inter-examiner mean score for E1 & E2 = 0.85 Intra-examiner score for E1 vs. E2 = 0.84 Sensitivity= 0.86 Specificity= 0.58 PPV= 0.90 NPV= 0.48
Estai et al.	Year: 2016 Location: Australia	Compared the validity and reliability of dental caries screening between different levels of dental practitioners using photographic methods.	Study Design: Cohort (retrospective) Population: Children 2-18 years Sample Size: 126 children	Caries measured by DFT/dft, accuracy, sensitivity, and specificity.	Cohen's kappa: inter-rater examiner reliability for the benchmark (clinical) examination and photographic examination.	Benchmark panel vs. MLDP & Dentist: Sensitivity mean = 84% Specificity mean = 97% Accuracy mean = 94% Kappa mean = 0.83

Table 1. *Extraction Table* (Continued)						
Estai et al.	Year: 2016 Location: Australia	To evaluate remote screenings for dental caries by MLDPs, using a store-and-forward telemedicine modality.	Study Design: Cross-sectional Population: Patients of regular attendance at a dental clinic Sample Size: 100 patients	Caries measured by accuracy, sensitivity, and specificity.	Kappa statistics: inter-rater and intra-rater reliability of visual and photographic assessments. Landis and Koch: measured rater agreement in categorical data.	Benchmark vs Screener 1 & 2: Sensitivity mean = 63% Specificity mean = 85% Accuracy mean = 96% Kappa mean = 0.60 Intra-rater reliability for photographic assessment: K=0.89
Morosini et al.	Year: 2014 Location: Parana, Brazil	To determine the validity of a store-and-forward teledentistry method to screen dental caries in digital photographs, within juvenile offenders	Study Design: Cross-sectional Population: Male juvenile offenders 15-19 years Sample Size: 102 males	Caries measured by DMFT, accuracy, sensitivity, and specificity.	Kappa coefficient: measured the agreement between clinical and teledentistry consultants.	Traditional Examination vs. Teledentistry Consultant 1 & 2: Sensitivity mean = 64% Specificity mean = 98% Accuracy mean = 94% Kappa mean = 0.83

Table 1. *Extraction Table* (Continued)

Van Hilsen et al	Year: 2013 Location: Minnesota	To determine the reliability of caries diagnosis between clinical and teledentistry methods, while using a stimulated ex vivo extracted tooth model that could be histologically validated. Additionally, comparing the reliability of caries assessment using Midwest Caries ID (MID), visual photographic examination (CAM), and Cross Polarization Optical Coherence Tomography (CP-OCT).	Study Design: RCT Population: Extracted permanent posterior teeth that were collected at local oral surgery offices without patient identifiers Sample Size: 43	Caries measured by ICDAS- II (score 0-2), sensitivity, and specificity. Sensitivity and specificity scores 1,2: first threshold differentiating any type of demineralization. Sensitivity and specificity scores 2: second threshold of demineralization into the enamel or outer dentin.	Unweighted Kappa Statistic: measured the intra-examiner reliability agreement of each examiner between the 1st and 2nd attempt. ICC: measured the absolute agreement of all 4 readings.	Clinical Examination with CAM: Kappa mean = 0.60 Sensitivity mean = 64.3 Specificity mean = 55.2 Remote Examination with MID & CP-OCT: Kappa mean = 0.70 Sensitivity mean = 48.0 Specificity mean = 72.7

Characteristics of Included Studies

There was only one RCT that was examined within this study. The remaining included studies consisted of a cross-sectional or cohort (retrospective) study design. There were two articles that were published during the years 2019-2020, within the rise of the COVID-19 pandemic. Two included studies used mid-level dental providers (MLDPs) in comparison to dentists for both clinical and teledentistry modalities. The smallest sample size was recorded by Steinmeir et al. (2020) with only 10 patients, compared to the largest sample size of 139 patients in Purohit et al. (2016). However, when assessing TP, TN, FP, and FN, the largest sample size consisted of N=3815 total teeth assessed for caries prevalence in Estai et al. (2016).

Demographic Variables

Out of all the included studies, 7 articles were focused on children. There was a wide range of ages 1-18 years with studies that included mixed dentition. Within the articles that included children, there was one study which included a population group from school children, two studies that demonstrated children who regularly see a dentist, one study from an urban setting, one study from a rural setting, and one study within a juvenile detention center. There was only one other study that did not focus on children, where the sample population consisted of routine patients recruited from a clinic.

Diagnostic Outcomes

Accuracy, specificity, sensitivity, PPV, NPV, and kappa parameters were the most common diagnostic outcomes used throughout all 12 studies. The included studies and their outcomes show the diagnostic accuracies and reliability for both remote and clinical examinations (Table 3). A total of six studies measured the accuracy of detecting carious lesions. The remote assessment accuracy scores ranged from 70-96%. All studies measured both sensitivity and specificity values, where sensitivity scores in remote assessments ranged from 45.6-88.3%. Specificity scores in remote assessments ranged from 55.2-98.3% Only three studies measured PPV and NPV values. PPV values within remote assessments ranged from 79-92% and NPV values ranged from 48-97%. Eleven studies were measured using kappa as an inter-rater reliability of both remote and clinical assessments which ranged from 0.84-0.89. Kappa used as an intra-rater reliability for remote assessments ranged from 0.46-0.89.

Types of Cameras

Within this review, the most common types of cameras included smartphone, digital single lens reflex (DSLR), intraoral (IOS) two-dimensional, and IOS three-dimensional. Six studies involved smartphone cameras that ranged in Apple iPhone generations 5 and 7, LG Google Nexus 4, Motorola MotoG, and Sony Xperia.

Risk of Bias Assessment for Included Studies

The quality assessment of all 12 studies were included in Table 7. There was a total of six cross-sectional studies, seven retrospective cohort studies, and one randomized control trial (RCT) used within this review. Steinmeier et al., 2019 and Estai et al., 2016 failed to identify the clear definition of inclusion criteria and sample selection. All the seven retrospective cohort studies did not complete a follow-up examination time. Kohara et al., 2018 was the only retrospective cohort study that did not use two groups from the same population, since this study included both in-vitro and in-vivo experiments. However, all studies included a comparison of teledentistry modalities to clinical gold standard examinations.

CHAPTER 4

ANALYSIS

Table 2. *R values to find TP/FPR, TN/FNR, and Prevalence Using Sensitivity, Specificity, and Sample Size*

Author and Year	Specificity	Sensitivity	TP	TN	FPR	FNR	Prevalence	N
Kale et al., 2019	98.30%	88.30%	1373	431	9	187	0.78	2000
Park et al., 2018	95%	61.50%	254	1659	87	156	0.19	2156
Alshaya et al, 2018	85.90%	79.10%	428	699	114	114	0.4	1354
Kohara et al., 2018	95.90%	56.80%	11	96	4	8	0.16	119
Estai et al., 2017	97%	69.00%	564	1474	46	253	0.35	2338
Pentapati et al., 2017	66.70%	98.10%	52	6	3	1		62
Purohit et al., 2016	58%	86%	97	15	11	16	0.81	139
Estai et al., 2016	97%	84%	2884	370	11	549	0.9	3815
Estai et al., 2016	85%	63%	520	1305	230	305	0.35	2362
Morosini et al., 2014	98%	64%	376	2622	54	212	0.18	3264
Van Hilsen et al., 2013	72.70%	48%	6	23	9	7	0.29	45
Steinmeir et al., 2019	97%	79%	4	5	0	1	0.5	10

Table 3. *Descriptive Analysis for Sensitivity, Specificity, and CI*				
Author and Year	**Sensitivity**	**CI**	**Specificity**	**CI**
Kale et al., 2019	0.88	0.86-0.90	0.98	0.96-0.99
Park et al., 2018	0.62	0.57-0.66	0.95	0.94-0.96
Alshaya et al., 2018	0.79	0.75-0.82	0.86	0.83-0.88
Kohara et al., 2018	0.58	0.36 -0.76	0.96	0.90-0.98
Estai et al., 2017	0.69	0.66-0.72	0.97	0.96-0.98
Pentapati et al., 2018	0.97	0.89-0.99	0.65	0.35-0.86
Purohit et al., 2016	0.86	0.78-0.91	0.57	0.39-0.74
Estai et al., 2016	0.84	0.830.85	0.97	0.95-0.98
Estai et al., 2016	0.63	0.60-0.66	0.85	0.83-0.87
Morosini et al., 2014	0.64	0.60-0.68	0.98	0.97-0.98
Van Hilsen et al., 2013	0.46	0.24-0.70	0.71	0.54-0.84
Steinmeir et al., 2019	0.75	0.36-0.94	0.92	0.52-0.99
Test for equality of sensitivities: X-squared = 473.0828, df= 11, p-value < 2e-16 Test for equality of specificities: X-squared = 519.1442, df= 11, p-value < 2e-16				

Table 4. *Descriptive Analysis for DOR, Positive LR, and Negative LR*						
Author and Year	**DOR**	**CI**	**Pos LR**	**CI**	**Neg LR**	**CI**
Kale et al., 2019	332.72	171.85-644.22	40.85	21.77-76.64	0.12	0.11-0.14
Park et al., 2018	30.84	23.01-41.34	12.36	9.94-15.37	0.4	0.35-0.45
Alshaya et al., 2018	22.86	17.18-30.42	5.61	4.71-6.68	0.25	0.21-0.29
Kohara et al., 2018	29.01	7.94-106.03	12.91	4.85-34.34	0.44	0.27-0.74
Estai et al., 2017	70.61	50.90-97.96	22.57	16.95-30.07	0.32	0.29-0.35
Pentapati et al., 2018	65	8.13-519.83	2.78	1.19-6.47	0.04	0.01-0.22
Purohit et al., 20116	7.96	3.16-20.07	2.01	1.29-3.13	0.25	0.15-0.44
Estai et al., 2016	169.12	93.38-306.38	27.9	15.79-49.31	0.16	0.15-0.18
Estai et al., 2016	9,65	7.91-11.77	4.2	3.69-4.78	0.44	0.40-0.48
Morosini et al., 2014	85.26	62.12-117.01	31.4	23.98-41.12	0.37	0.33-0.41
Van Hilsen et al., 2013	2.14	0.59-7.81	1.61	0.74-3.51	0.75	0.44-1.28
Steinmeir et al., 2019	33	1.06-1023.56	9	0.61-133.08	0.27	0.07-1.11
Correlation of Sensitivities and FPR: rho= 0.24, CI = - 0.39 to 0.72						

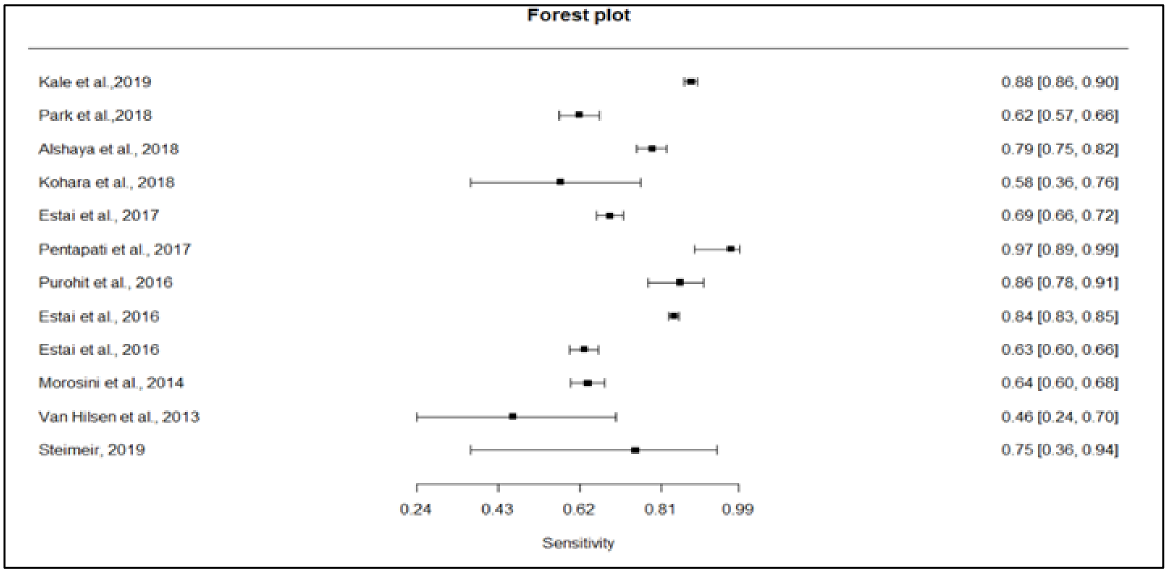

Figure 2. Descriptive Analysis for Sensitivity Forest Plot

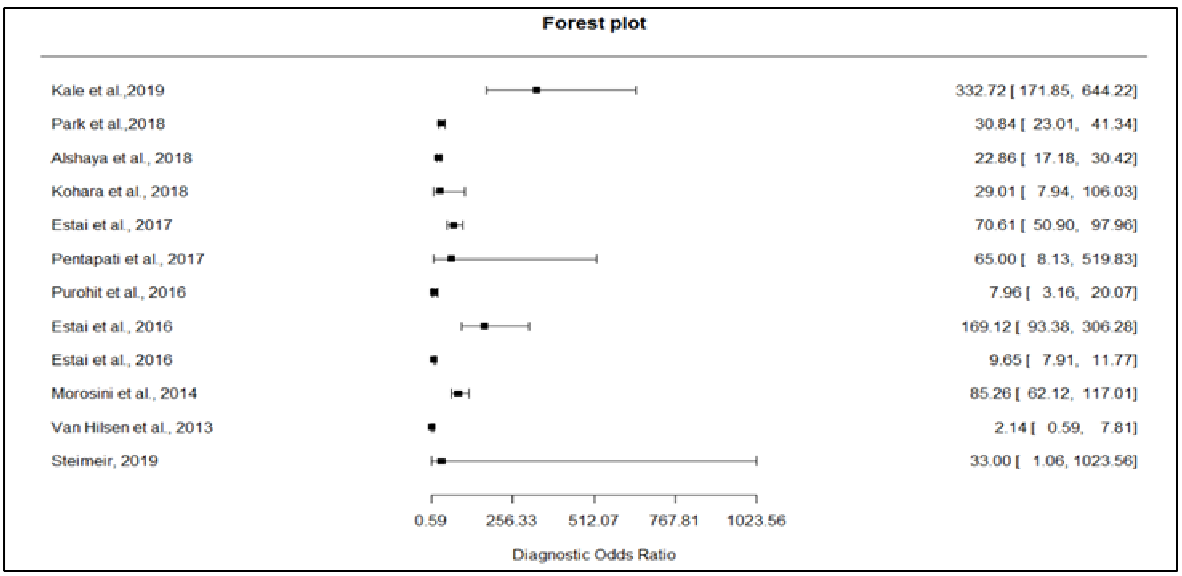

Figure 3. Descriptive Analysis for Specificity Forest Plot

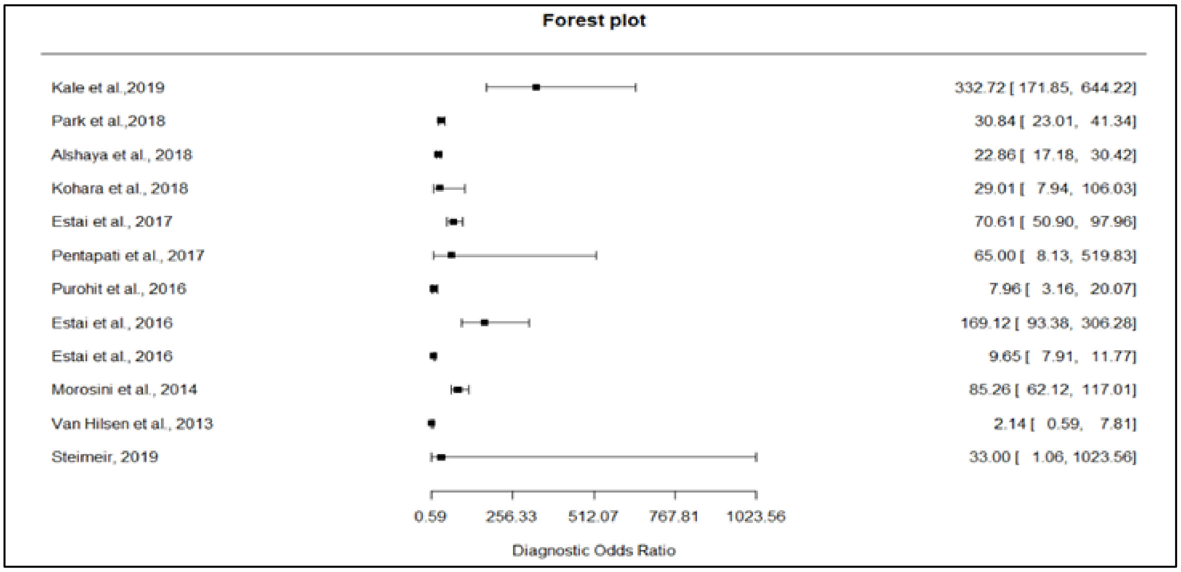

Figure 4. Descriptive Analysis for DOR Forest Plot

Table 5. *Random Effect Estimation Based on Univariate Measures of Diagnostic Accuracy using DerSimonian-Laird Random Effect Estimator*

	DSL Estimate	**CI**
DOR	35.409	17.721-70.753
lnDOR	3.567	2.875-4.259
tau^2	1.234	0- 4.060
tau	1.111	0- 2.015
Cochran's Q: 14.502, df = 11, p = 0.206 Higgins' I^2 = 24.15%		

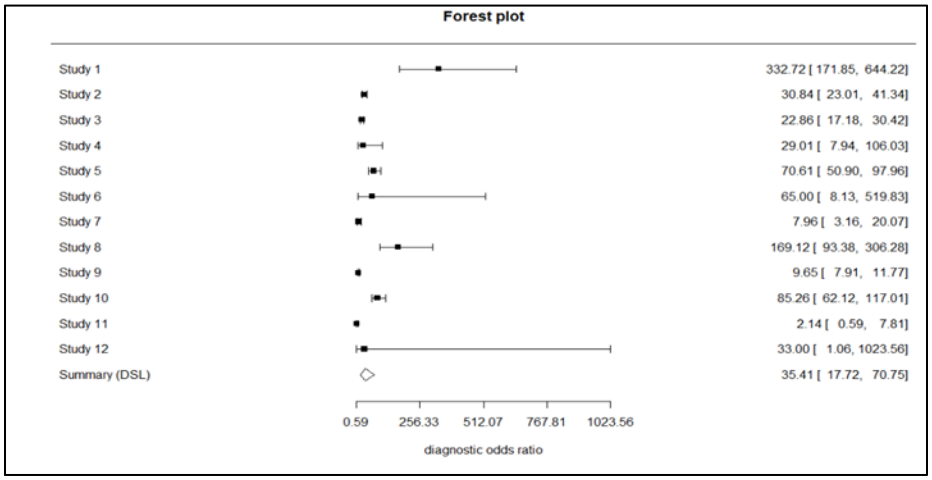

Figure 5. Univariate Measures of Diagnostic Accuracy Forest Plot

CHAPTER 5

DISCUSSION

This systematic review and meta-analysis assessed the effectiveness of teledentistry versus in person clinical examinations in the diagnosis of dental caries. The articles included in this study used dentists, mid-level dental providers (MLDP's), and mothers for remote examiners. Four of the articles which included MLDP's, and mothers established calibration methods by dentists, before proceeding with remote examinations. In Kale et al., 2019, calibration methods involved a dentist adjusting the focus on Motorola smartphones to obtain quality and clear images with the inbuilt flash. Similarly, Estai et al., 2016 established a baseline where intraoral photographs were reviewed by an expert panel to formulate a standard screening. Another study using MLDP's integrated a numeric record system for each participant, who were assigned a code that was linked to benchmark charting (Estai et al., 2016). Lastly, MLDP's in Park et al., 2019 conducted calibration methods through comprehensive dental examinations (CDE) through visual-tactile examinations, bitewing and periapical radiographs, and intra-oral camera photographs taken under optimal lighting. Calibration efforts for remote examiners who are not dentists, are critical to ensure accurate measurements. The random effect estimation from this review showed a high diagnostic odds ratio of true positives, ultimately supporting those individuals with adequate dental knowledge, teledentistry assessors can vary and can contribute to delivering dental care. The integration of teledentistry and remote examiners, like MLDP's or mothers, can be implemented in remote settings for early caries screening and triaging for preventative care (Park et al., 2019). A variation in remote examiners for teledentistry assessment can optimize the accessibility of dental and oral healthcare, by addressing the shortage of dental practices within rural populations, initiating continuity of care and follow up cases, and reducing patient wait times.

Further, the most common imaging modalities used within the teledentistry assessments were digital single-lens reflex (DSLR), smartphone, and intra-oral cameras. All the studies were homogeneous, which portrayed consistent diagnostic accuracy for dental caries. Six out of the twelve studies used smartphone imaging for teledentistry approaches. A study in 2022 stated that there were high rates of smartphone usage specifically for platform access like telehealth (Broffman et al., 2022). During the COVID-19 pandemic, Washington state provided high-speed hotspots in communities with slow internet connection speeds, also known as broadband, to help this population seek telehealth resources (Broffman et al., 2022). The adoption of smartphones is increasing as time advances, specifically within the younger generation (Broffman et al., 2022). Smartphone camera advancements can contribute higher quality imaging for teledentistry examinations, while detecting carious lesions.

The descriptive analysis showed the sensitivity, specificity, and DOR for each of the twelve studies, with the respective confidence intervals. The significant chi-squared test for equality for both sensitivity and specificity indicated that there were no significant differences in sensitivity and specificity across the studies reviewed. In addition, FPR and sensitivities from each study showed no correlation (rho = 0.24). The sensitivity and specificity values throughout all the twelve studies, suggested a moderate to high agreement for remote modalities. The outcomes of the descriptive analysis within this review, provides a foundational agreement for sensitivity and specificity values for future teledentistry examinations.

The random effect estimation of univariate measures using the DerSimonian-Laird estimator showed the DOR of 35.14. This demonstrated that the odds of detecting true positive cases of dental caries via teledentistry is 35 times the odds of detecting false positive cases of dental caries. This clearly indicates that the use of teledentistry or remote assessment is highly accurate and precise in caries diagnosis when compared to the gold standard. Remote assessments via teledentistry are likely to identify present caries, or true positive cases, rather than falsely detecting dental caries. Our study findings showed no heterogeneity of the articles reviewed (Cochran's Q: 14.502 ($p = 0.206$) and Higgins' I2 test = 24%). This indicates that our studies were homogeneous with little variations. This means that all 12 studies were consistent in accurately diagnosing dental caries via teledentistry examination.

The strength of this study included the homogeneous measures throughout the studies, and consistent in diagnostic accuracies for detecting caries. These measures indicate that remote modalities are as good as clinical examinations in detecting dental caries. This study is the only meta-analysis that measured the diagnostic accuracy of teledentistry examinations. The random effect estimator implied a higher diagnostic odds ratio for true positives. The univariate measures analyzed within this study provides a great foundation in the diagnostic accuracy in detecting caries for the future of teledentistry and remote examiners.

The articles reviewed in this study, provided diagnostic parameters only for remote examinations, which were compared to gold-standard clinical examinations. Diagnostic parameters for clinical examinations were referenced to the WHO dentition status, resulting to the decision to proceed with a univariate analysis for remote diagnosis. Future teledentistry studies should include a bivariate analysis to compare the diagnostic parameters from both clinical and remote assessments. The studies included in this review ranged from January 2013-December 2021, many of these studies had limitations in quality of images sent into a store-and-forward system. Technology is consistently evolving, especially within the advancements within smartphone cameras, which can greatly affect the quality of images in future teledentistry examinations. The teledentistry store and forward system has yet to maximize security efforts for patient information. Further research should explore a dependable system to make patient data more secure. Lastly, a definitive threshold for diagnostic parameters should be established for detecting caries and will be resourceful for future teledentistry assessments and the remote examiners.

CHAPTER 6

CONCLUSION

Despite the limitations of this review, the results from this study established a baseline for diagnostic accuracy in detecting caries via teledentistry modalities. The outcomes from the univariate measures within this review supports the diagnostic accuracy for true positive outcomes when using remote examinations for dental caries diagnosis. It can be concluded that teledentistry assessment is an accurate tool to detect dental caries, and diagnosing dental caries via teledentistry is effective and comparable to in-person diagnosis.

BIBLIOGRAPHY

Ada releases updated covid-19 dental office procedures emphasizing need for hazard assessments. American Dental Association. (n.d.). Retrieved April 19, 2023, from https://www.ada.org/publications/ada-news/2021/july/ada-releases-updated-covid-19-dental-office-procedures-emphasizing-need-for-hazard-assessmentsAlShaya, M. S., Assery, M. K., & Pani, S. C. (2020). Reliability of mobile phone teledentistry in dental diagnosis and treatment planning in mixed dentition. Journal of telemedicine and telecare, 26(1-2), 45-52.

Broffman, L., Harrison, S., Zhao, M., Goldman, A., Patnaik, I., & Zhou, M. (2022). The relationship between broadband speeds, device type, demographic characteristics, and care-seeking via telehealth. Telemedicine and e-Health.

Daniel, S. J., & Kumar, S. (2017). Comparison of dental hygienists and dentists: clinical and teledentistry identification of dental caries in children. International journal of dental hygiene, 15(4), e143-e148.

DerSimonian, R. and Laird, N. (1986). “Meta-analysis in clinical trials.” Controlled clinical trials, 7, 177–188.

Estai, M., Kanagasingam, Y., Huang, B., Shiikha, J., Kruger, E., Bunt, S., & Tennant, M. (2017). Comparison of a smartphone-based photographic method with face-to-face caries assessment: a mobile teledentistry model. Telemedicine and e-Health, 23(5), 435-440.

Estai, M., Winters, J., Kanagasingam, Y., Shiikha, J., Checker, H., Kruger, E., & Tennant, M. (2016). Validity and reliability of remote dental screening by different oral health professionals using a store-and-forward telehealth model. British dental journal, 221(7), 411-414.

Estai, M., Kanagasingam, Y., Huang, B., Checker, H., Steele, L., Kruger, E., & Tennant, M. (2016). The efficacy of remote screening for dental caries by mid-level dental providers using a mobile teledentistry model. Community Dentistry and Oral Epidemiology, 44(5), 435-441.

Estai, M., Bunt, S., Kanagasingam, Y., Kruger, E., & Tennant, M. (2016). Diagnostic accuracy of teledentistry in the detection of dental caries: a systematic review. Journal of Evidence Based Dental Practice, 16(3), 161-172.

Haque, S. N., & Hayden, E. M. (2022). Telehealth. In Clinical Informatics Study Guide: Text and Review (pp. 255-259). Cham: Springer International Publishing.

Kale, S., Kakodkar, P., & Shetiya, S. H. (2019). Assessment of mother's ability in caries diagnosis, utilizing the smartphone photographic method. Journal of Indian Society of Pedodontics and Preventive Dentistry, 37(4), 360.

Kohara, E. K., Abdala, C. G., Novaes, T. F., Braga, M. M., Haddad, A. E., & Mendes, F. M. (2018). Is it feasible to use smartphone images to perform telediagnosis of different stages of occlusal caries lesions?. PloS one, 13(9), e0202116.Kopycka-Kedzierawski, D. T., & Billings, R. J. (2013). Comparative effectiveness study to assess two examination modalities used to detect dental caries in preschool urban children. TELEMEDICINE and e-HEALTH, 19(11), 834-840.

Morosini, I. D. A. C., de Oliveira, D. C., Ferreira, F. D. M., Fraiz, F. C., & Torres-Pereira, C. C. (2014). Performance of distant diagnosis of dental caries by teledentistry in juvenile offenders. Telemedicine and e-Health, 20(6), 584-589.

Park, J. S., Kruger, E., Nicholls, W., Estai, M., Winters, J., & Tennant, M. (2019). Comparing the outcomes of gold-standard dental examinations with photographic screening by mid-level dental providers. Clinical Oral Investigations, 23(5), 2383-2387.

Pentapati, K. C., Mishra, P., Damania, M., Narayanan, S., Sachdeva, G., & Bhalla, G. (2017). Reliability of intra-oral camera using teledentistry in screening of oral diseases–Pilot study. The Saudi dental journal, 29(2), 74-77.

Purohit, B. M., Singh, A., & Dwivedi, A. (2017). Utilization of teledentistry as a tool to screen for dental caries among 12-year-old school children in a rural region of I ndia. Journal of Public Health Dentistry, 77(2), 174-180.

Touger-Decker, R., & Van Loveren, C. (2003). Sugars and dental caries. The American journal of clinical nutrition, 78(4), 881S-892S.

Sousa-Pinto Bernado (2022). mada: Meta-Analysis of Diagnostic Accuracy. R package version 0.5.11,https://CRAN.R-project.org/package=mada.

Steinmeier, S., Wiedemeier, D., Hämmerle, C. H., & Mühlemann, S. (2020). Accuracy of remote diagnoses using intraoral scans captured in approximate true color: a pilot and validation study in teledentistry. BMC Oral Health, 20, 1-8.

Wosik, J., Fudim, M., Cameron, B., Gellad, Z. F., Cho, A., Phinney, D., ... & Tcheng, J. (2020). Telehealth transformation: COVID-19 and the rise of virtual care. Journal of the American Medical Informatics Association, 27(6), 957-962.

Van Hilsen, Z., & Jones, R. S. (2013). Comparing potential early caries assessment methods for teledentistry. BMC Oral Health, 13(1), 1-9

APPENDICIES

Table 6. *Search Strategy*		
Database	**Search Strategy**	**MeSh Terms**
PubMed	S1	("Telemedicine"[Mesh] OR "telehealth*"[tiab] OR "mobile health*"[tiab] OR mhealth*[tiab] OR ehealth*[tiab] OR "tele medic*"[tiab] OR "tele health*"[tiab] OR teled*[tiab] OR "tele health*"[tiab] OR "mobile dent*"[tiab] OR mdent*[tiab] OR “m dent*”[tiab] OR "mobile dentist*"[tiab] OR edent*[tiab] OR "tele dent*"[tiab] OR (phone* AND dent*))
	S2	(cari*[tiab] OR “dental cari*”[tiab] OR "Dental Caries"[Mesh] OR “carious lesion*”[tiab] OR “dental deca*”[tiab] OR “tooth deca*”[tiab] OR “teeth deca*”[tiab] OR “tooth cari*”[tiab] OR “carious dentin*”[tiab] OR “dentin cari*”[tiab])
	S3	dent*[tiab] OR "Dentistry"[Mesh] OR "Oral Medicine"[Mesh] OR “oral medic*”[tiab]
	S4	S1 AND S2 AND S3
CINAHL	S1	((MH "Telehealth+") OR (MH "Telemedicine+")) OR TI (("telehealth*" OR "mobile health*" OR mhealth* OR ehealth* OR "tele medic*" OR "tele health*" OR teled* OR "tele health*" OR "mobile dent*" OR mdent* OR "m dent*" OR "mobile dentist*" OR edent* OR "tele dent*" OR (phone* AND dent*))) OR AB (("telehealth*" OR "mobile health*" OR mhealth* OR ehealth* OR "tele medic*" OR "tele health*" OR teled* OR "tele health*" OR "mobile dent*" OR mdent* OR "m dent*" OR "mobile dentist*" OR edent* OR "tele dent*" OR (phone* AND dent*)))
	S2	((MH "Dental Caries") OR (MH "Tooth Demineralization+")) OR TI (cari* OR "dental cari*" OR "Tooth Demineraliz*" OR "carious lesion*" OR "dental deca*" OR "tooth deca*" OR "teeth deca*" OR "tooth cari*" OR "carious dentin*" OR "dentin cari*") OR AB (cari* OR "dental cari*" OR "Tooth Demineraliz*" OR "carious lesion*" OR "dental deca*" OR "tooth deca*" OR "teeth deca*" OR "tooth cari*" OR "carious dentin*" OR "dentin cari*")
	S3	((MH "Oral Medicine") OR (MH "Dentistry+")) OR TI ((dent* OR "oral medic*")) OR AB ((dent* OR "oral medic*"))
	S4	S1 AND S2 AND S3

Table 7. *Quality Assessment*

Article Title	**Type of Study**	**Clear Definition of Criteria (CS)**	**Sample Selection and Setting Described (CS)**	**2 Groups from Same Population**	**Exposures to both Exposed and Unexposed Groups**	**Validity of Exposures**	**Standard Criteria Used for Measurement (CS)**	**Groups and Participants are Free of Outcome from the Start**	**Follow-Up Time was Sufficient and Reported**	**Strategies to Address Incomplete Follow-up**	**Confounders *****	**Strategies for Confounders *****	**Validity of Outcomes *****	**Appropriate Statistical Analysis Used *****
Steinmeir et al	CS	N	N	N/A	N/A	Y	Y	N/A	N/A	N/A	Y	N	N	Y
Kale et al	CO	N/A	N/A	Y	Y	Y	N/A	Y	Y	N	Y	Y	Y	Y
Park et al	CO	N/A	N/A	Y	Y	Y	N/A	Y	N	N	Y	Y	Y	Y
Alshaya et al	CS	Y	Y	Y	N/A	Y	Y	N/A	N/A	N/A	Y	Y	Y	Y
Kohara et al	CO	N/A	N/A	Y	Y	Y	N/A	N	N	N	Y	Y	Y	Y
Estai et al 2017	CS	N	N	N/A	N/A	Y	Y	N/A	N/A	N/A	Y	Y	Y	Y
Pentapati et al	CO	N/A	N/A	Y	Y	Y	N/A	Y	N	N	N	N	N	Y
Purohit et al	CS	Y	Y	N/A	N/A	Y	Y	N/A	N/A	N/A	Y	Y	Y	Y
Estai et al 2016	CO	N/A	N/A	Y	Y	Y	N/A	Y	N	N	Y	Y	Y	Y

Table 7. *Quality Assessment* (Continued)

Estai et al 2016	CS	Y	Y	N/A	N/A	Y	Y	N/A	N/A	N/A	Y	Y	Y	Y
Morosini et al	CS	Y	Y	N/A	N/A	Y	Y	N/A	N/A	N/A	Y	Y	Y	Y
Article Title	**Type of Study**	**Randomization**	**Allocation**	**Similar Treatment Groups**	**Blindness Participants**	**Equal**	**Follow -Up**	**Intention -to-Treat (ITT)**	**Were the outcomes measured the same for each treatment group?**	**Outcome Reliability**	**Appropriate Statistical Analysis**	**Was the trial design appropriate for the topic?**	**Delivering Treatment Blindness**	**Outcome Assessors Blindness**
Van Hilsen et al	RCT	Y	Y	Y	Y	Y	N	Y	Y	Y	Y	Y	Y	N

*Y is Yes
*N is No
*CO is cohort
*CS is cross-sectional
*RCT is randomized control trial
*N/A is not- applicable