Restor Dent Endod. 2020 Nov;45(4):e48
https://doi.org/10.5395/rde.2020.45.e48
pISSN 2234-7658·eISSN 2234-7666

Restorative Dentistry & Endodontics RDE

Research Article

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Reference values for pulp oxygen saturation as a diagnostic tool in endodontics: a systematic review and meta-analysis

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Received: Jan 8, 2020
Revised: Apr 25, 2020
Accepted: Apr 27, 2020

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Funding
This study was financed in part by the Coordenação de Aperfeiçoamento de Pessoal de Nível Superior-Brasil (CAPES)-Finance Code 001.

Conflict of Interest
No potential conflict of interest relevant to this article was reported.

Trial Registration
International Prospective Register of Systematic Reviews Identifier: CRD42018085598

ABSTRACT

Objectives: This systematic review aimed to identify mean oxygen saturation values (SpO_2) using pulse oximetry in permanent maxillary anterior teeth.
Materials and Methods: The MEDLINE, Scientific Electronic Library Online, Cochrane Central Register of Controlled Trials, EMBASE, and Literatura Latino Americana em Ciências da Saúde electronic databases were searched. Combinations and variations of "oximetry" AND "dental pulp test" were used as search terms. Studies reporting means and standard deviations of SpO_2 values were included. Two reviewers independently extracted data following the Preferred Reporting Items for Systematic Reviews and Meta-Analyses checklist. Heterogeneity was assessed using the I^2 statistic, and all analyses were performed using R software. Study quality was assessed using the Quality Assessment of Diagnostic Accuracy Studies-2 tool and the Newcastle-Ottawa scale.
Results: Of the 251 studies identified, 19 met the eligibility criteria and were included (total sample, 4,541 teeth). In the meta-analysis, the mean SpO_2 values were 84.94% (95% confidence interval [CI], 84.85%–85.04%) for the central incisors, 89.29% (95% CI, 89.22%–89.35%) for the lateral incisors, and 89.20% (95% CI, 89.05%–89.34%) for the canines. The studies were predominantly low-quality due to the high risk of bias associated with the index test, unclear risk regarding patient selection, and concerns about outcome assessment.
Conclusions: Although most studies were low-quality, the oxygen saturation levels in normal pulp could be established (minimum saturation, 77.52%). Despite the risk of bias of the included studies, the reference values reported herein are clinically relevant for assessments of changes in pulp status.

Trial Registration: International Prospective Register of Systematic Reviews Identifier: CRD42018085598

Keywords: Dental pulp test; Diagnostic techniques and procedures; Endodontics; Oximetry; Systematic review

Author Contributions
Conceptualization: Lambert P, Miguens SAQ Jr, Barletta FB; Data curation: Lambert P; Formal analysis: Miguens SAQ Jr, Reichert LA; Investigation: Solda C, Lambert P, Sganzerla JT; Methodology: Miguens SAQ Jr, Lambert P; Project administration: Barletta FB; Software: Solda C; Supervision: Reichert LA; Validation: Estrela C; Writing - original draft: Lambert P, Miguens SAQ Jr; Writing - review & editing: Estrela C, Barletta FB.

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INTRODUCTION

Evaluating the status of the dental pulp is fundamental for determining appropriate endodontic therapy [1-3]. However, establishing the actual clinical status of the pulp is challenging. Numerous factors contribute to the difficulty in making a diagnosis, in particular the subjectivity of the tests used to determine pulp vitality and the characteristics of pulpal disease [4,5].

The status of the pulp is evaluated by taking a dental history, along with a clinical examination, imaging, and vitality tests. Thermal tests (specifically, the cold test and the heat test) and electric pulp tests are the methods most commonly used to assess vitality. However, these tests evaluate only the vasoconstriction and the stimulation of the nervous structures of the pulp and fail to provide information about blood flow [5,6]. The assessment of pulp vitality via thermal and electric pulp sensitivity testing is questionable because of its subjectivity, as in reality, the vitality of pulp tissue depends on blood supply rather than on nerve response. Therefore, the results of sensitivity tests for the determination of pulp vitality are limited, since these tests may yield false-negative or false-positive results [7,8].

The determining factor in establishing the vitality of pulp tissue is the supply of oxygenated blood. However, due to the positioning of the pulp between the rigid and inelastic dentin walls, it is extremely difficult to determine the actual pulp status with the tests routinely used in clinical dental practice [3].

Technological advances have benefited dentistry in recent years, improving the resources available for endodontic diagnosis. Innovative methods that assess the pulp vasculature, rather than the sensory response, have been studied and used. One such method is pulse oximetry, considered a promising tool in endodontics [7-10]. In addition to being more objective than pulp sensitivity tests (either thermal or electric), pulse oximetry has been shown to be a reliable diagnostic resource in the determination of pulp vitality [2,11,12].

For an accurate assessment of dental pulp vitality, in-depth knowledge of the diagnostic values of each pulp test is crucial. Therefore, the aim of this systematic review was to gather and summarize the data on pulse oximetry performed in permanent maxillary anterior teeth in order to establish mean values for oxygen saturation (SpO_2) for use as a diagnostic parameter.

MATERIALS AND METHODS

Search strategy and study selection

This systematic review was registered with the International Prospective Register of Systematic Reviews under registration number CRD42018085598 (available at www.crd.york.ac.uk/prospero) and was performed in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses statement [13].

The following electronic databases were searched from inception to April 2019: MEDLINE (via PubMed; www.ncbi.nlm.nih.gov/pubmed), the Scientific Electronic Library Online (SciELO; www.scielo.org), the Cochrane Central Register of Controlled Trials (CENTRAL; http://www.thecochranelibrary.com), and EMBASE (www.elsevier.com/solutions/embase-biomedical-research#GetStarted). A search strategy was developed for each database using

Table 1. Search strategy: MEDLINE, Literatura Latino Americana em Ciências da Saúde (LILACS), and EMBASE

Database	Search strategy
MEDLINE (MeSH terms)	(“Oximetry” [MeSH] OR (“Oximetries”) OR (“Oximetry, Pulse”) OR (“Oximetries, Pulse”) OR (“Pulse Oximetries”) OR (“Pulse Oximetry”)); AND (“Dental Pulp Test” [MeSH] OR (“Tests, Dental Pulp”) OR (“Pulp Tests, Dental”) OR (“Dental Pulp Tests”) OR (“Pulp Test, Dental”)); OR (“Dental Pulp” [MeSH] OR (“Pulp, Dental”) OR (“Pulps, Dental”) OR (“Dental Pulps”))
LILACS (DeCS terms)	“Oximetry” OR “Blood Gas Monitoring” And “Dental Pulp Test” “Oximetría” AND “Prueba de la Pulpa Dental” “Oximetría” AND “Teste da Polpa Dentária”
EMBASE (Emtree terms)	(‘oximetry’/exp OR ‘oximetry’ OR ‘oximetries’ OR ‘oximetry, pulse’/exp OR ‘oximetry, pulse’ OR ‘oximetries, pulse’ OR ‘pulse oximetries’ OR ‘pulse oximetry’/exp OR ‘pulse oximetry’) AND [embase]/lim (‘tooth pulp’/exp OR ‘tooth pulp’ OR ‘dental pulp’ OR ‘dental pulpa’ OR ‘pulp vitality’ OR ‘pulp, tooth’ OR ‘pulpa’ OR ‘pulpa dens vitality’ OR ‘pulpa dentis’ OR ‘pulpal tissue’ OR ‘tooth pulp vitality’ OR ‘tooth pulpa’ OR ‘tooth, pulp’ OR ‘dental pulp test’ OR ‘tests, dental pulp’ OR ‘pulp tests, dental’ OR ‘dental pulp tests’ OR ‘pulp test, dental’ OR ‘pulp, dental’ OR ‘pulps, dental’ OR ‘dental pulps’) AND [embase]/lim

MeSH, Medical Subject Headings; DeCS, Descritores em Ciências da Saúde.

controlled vocabulary descriptors (Medical Subject Headings and Emtree terms). No filters were applied. The CAPES, Literatura Latino Americana em Ciências da Saúde (LILACS), and American Endodontic Society databases and Google Scholar were also searched, with searches limited to the first 40 screens (400 citations). Different combinations and variations of the search terms “oximetry” AND “dental pulp test” were used (**Table 1**). The reference lists of the retrieved articles were hand-searched to identify other potentially eligible studies.

Two reviewers (PL and CS) independently screened the titles and abstracts identified in the initial search. Disagreements between the 2 reviewers were resolved by consulting a third reviewer *ad hoc* for arbitration. A reference manager (Endnote; www.endnote.com) was used to consolidate the data extracted from the databases.

Eligibility criteria

Human studies that involved the use of pulse oximetry to determine oxygen saturation in the dental pulp of permanent maxillary anterior teeth (central incisors, lateral incisors, and canines), that included experimental groups or control groups consisting of teeth with normal pulp vitality, and that reported the sample size and the mean SpO_2 values (with standard deviations) for each tooth group were eligible for inclusion. Case reports, case series, literature reviews, and letters to the editor were excluded.

Data extraction and synthesis

Full-text versions were obtained for all articles that appeared to meet the eligibility criteria. The full-text articles were read by the 2 independent reviewers, and the following data were extracted from the selected studies using a standardized form: patient age, tooth group (central incisors, etc.), type of oximeter and probe used, number of specimens, SpO_2 levels (means and standard deviations), confirmation test used, and whether a control group was included. When data were missing and/or clarification was needed, the authors of the selected studies were contacted via e-mail in order to include the studies in the review. An analysis was performed for each tooth group (central incisors, lateral incisors, and canines) to identify the mean SpO_2 level in the dental pulp of each.

Heterogeneity among studies was assessed using the I^2 statistic, with I^2 values < 25%, 25%–75%, and > 75% indicating low, intermediate, and high heterogeneity, respectively. All meta-analyses were performed using R software version 3.5.0 (R Project for Statistical Computing, Vienna, Austria) (package, Meta; United States Environmental Protection Agency, Corvallis, OR, USA).

https://doi.org/10.5395/rde.2020.45.e48

Assessment of study quality

The quality of each included study was assessed with the Quality Assessment of Diagnostic Accuracy Studies-2 (QUADAS-2) tool [14] or the Newcastle-Ottawa scale (NOS) adapted for cross-sectional studies [15] according to the characteristics and design of the study. If the study presented comparison groups, such as a negative control group or a comparison with other assessments of pulp vitality, it was evaluated using the QUADAS-2 tool. Studies that lacked a comparison group were assessed using the adapted NOS. The study quality was rated as high, moderate, or low. On the adapted NOS, 0 to 4 points indicated a low-quality study, 5 to 8 points a moderate-quality study, and 9 to 10 points a high-quality study.

RESULTS

Of 407 studies identified through the search strategy, 27 were selected for full-text reading. Of these, 13 were included in this review. Six additional studies were found by hand-searching reference lists ($n = 2$) and contacting study authors ($n = 4$), resulting in a total of 19 studies included in the present systematic review (**Figure 1**).

Most included studies were conducted in Brazil (38.4%) and had participants of both sexes, with a minimum age of 7 years and a maximum age of 65 years. The most commonly used oximeter models (by brand name) were the BCI 3301 handheld pediatric pulse oximeter (Smiths Medical PM Inc., Waukesha, WI, USA) and the Contec CMS60D handheld pulse oximeter (Contec Medical Systems Co., Ltd, Qinhuangdao, China). The most commonly used probes were custom-made (specially modified probe). A total of 4,541 teeth were included in the sample to be analyzed. The range of SpO_2 levels by tooth group were 77.5%–95.81%

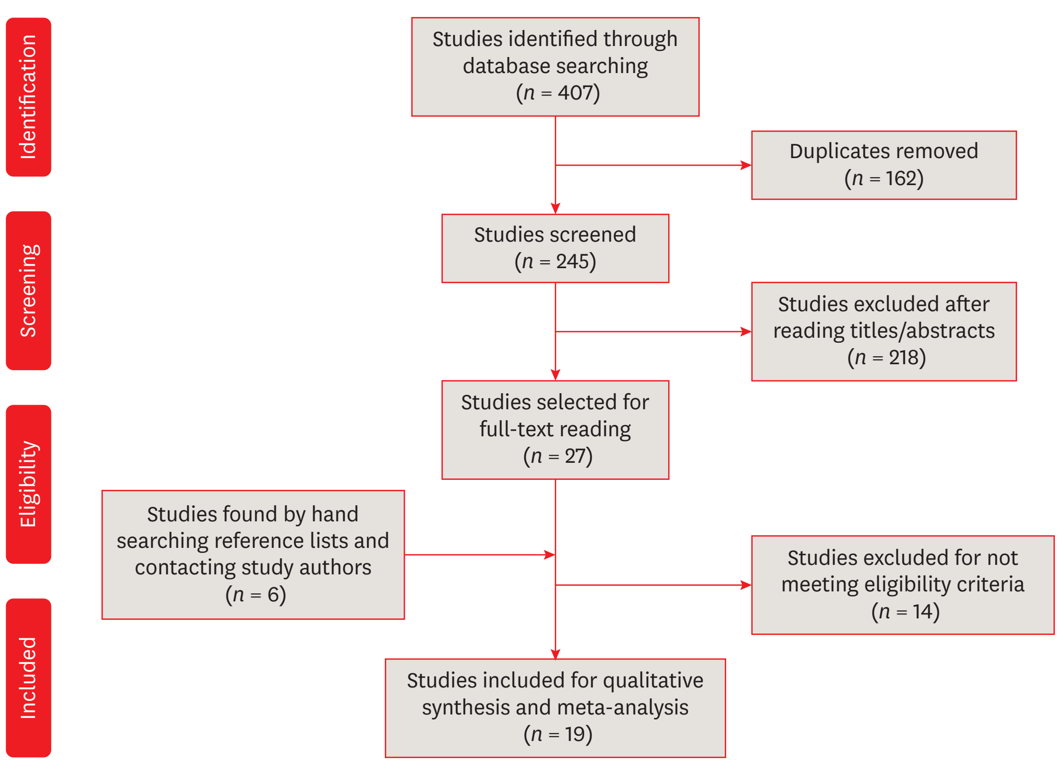

Figure 1. Flow diagram of study identification, selection, and inclusion [14].

Table 2. Characteristics of studies included in the systematic review and the oxygen saturation values by tooth group, index finger oxygen saturation, and method of diagnostic confirmation

Variable					Pulse oximetry evaluation of maxillary teeth									Index finger saturation		Confirmation method
Study	Country	Age (yr)	Type of oximeter	Type of probe	Central incisor			Lateral incisor			Canine					
					No.	Mean (%)	SD	No.	Mean (%)	SD	No.	Mean (%)	SD	Mean (%)	SD	
Schnettler and Wallace [16]	USA	18–55	Novametrix	-	44	94.0	-	NA	-	-	NA	-	-	97	-	TT
Radhakrishnan *et al.* [9]	India	-	Simed 100e	SMP	200	81.0	1.5	200	80.6	1.7	NA	-	-	98	0.7	EPT
Gopi Krishna *et al.* [17]	India	15–40	Nellcor OxiMax N-550	Dura Y D-YS	40	79.3	3.1	30	79.6	2.7	30	79.9	2.09	98	0.6	No
Calil *et al.* [18]	Brazil	26–38	Oxygraph	SMP	28	91.3	2.6	NA	-	-	32	90.7	2.71	95	2.6	TT
Karayilmaz and Kirzioğlu [4]	Turkey	12–18	Life Scope I	SMP	38	86.3	3.3	21	87.5	3.1	NA	-	-	-	-	LDF
Pozzobon *et al.* [19]	Brazil	4–13	BCI 3301	SMP	25	87.8	6.6	NA	-	-	28	83.4	8.57	93	3.5	No
Siddheswaran *et al.* [11]	India	> 18	Datex Ohmeda	OxyTip+®	100	87.8	1.8	NA	-	-	NA	-	-	98	0.4	TT
		7–12			100	87.1	2.8	-	-	-	NA	-	-	97	1.1	TT
Ciobanu *et al.* [20]	Romania	20–40	Portable NT 1	SMP	40	83.3	-	40	78.5	-	40	84.5	-	97	-	No
Sadique *et al.* [3]	India	15–40	Criticare 504	Finger probe	120	85.1	2.1	120	80.2	2.0	120	89.6	1.09	96	0.7	No
Stella *et al.* [21]	Brazil	22–36	BCI 3301	3025 sensor	56	77.9	1.4	NA	-	-	NA	-	-	96	2.9	No
		7–13			54	84.4	1.4	NA	-	-	NA	-	-	96	2.9	
Kosturkov *et al.* [22]	Bulgaria	18–25	Contec CMS 60D	SMP	174	84.4	8.0	175	83.3	8.4	175	83.4	8.02	98	-	EPT
Kataoka *et al.* [23]	Brazil	35–65	Oxygraph	Y-type sensors	235	93.5	1.7	235	90.0–98.0	1.6	115	92.0	1.67	-	-	TT
Khademi *et al.* [24]	Iran	13–24	Criticare 504	Ear probes	NA	-	-	NA	-	-	20	87.8	4.01	-	-	EPT
Kosturkov *et al.* [25]	Bulgaria	22–29	Contec CMS 60D	SMP	395	84.0	8.5	392	83.5	7.9	398	83.8	6.99	-	-	EPT
Kosturkov and Uzunov [26]	Bulgaria	-	Contec CMS 60D	SMP	3	92.0	1.7	3	90.0	0.0	7	90.4	1.61	-	-	EPT
Souza *et al.* [27]	Brazil	17–39	MD300A	SMP	102	89.0	2.3	132	87.0	2.3	174	86.0	5.00	87	-	TT
Kosturkov *et al.* [28]	Bulgaria	22–29	Contec CMS 60D	SMP	44	83.0	1.0	NA	-	-	NA	-	-	-	-	No
Solda *et al.* [29]	Brazil	19–36	BCI 3301	3026 sensor	136	85.1	1.9	NA	-	-	NA	-	-	97	1.5	TT
Lima *et al.* [30]	Brazil	18–27	BCI 3301	SYS 103	120	84.8	-	NA	-	-	NA	-	-	97	-	TT

SD, standard deviation; SMP, specially modified probe; NA, not applied; TT, thermal test; EPT, electric pulp test; LDF, laser Doppler flowmetry.

for the central incisors, 77.48%–94.29% for the lateral incisors, and 79.1%–92.3% for the canines. Index-finger SpO_2 measurements and thermal testing for the confirmation of pulp vitality were the most commonly used evaluation methods (**Table 2**).

In the meta-analysis by tooth group, 18 studies [3,4,9,11,16-23,25-30] were included in the central incisor group, for a total of 2,054 teeth. The mean fixed-effect measure of SpO_2 in the dental pulp of these teeth was 84.94% (95% confidence interval [CI], 84.85%–85.04%). The individual results of the studies selected for this analysis are shown in **Figure 2**.

For the lateral incisor group, 10 studies [3,4,9,17,20,22,23,25-27] were included in the meta-analysis, for a total of 1,348 teeth. The mean SpO_2 in the dental pulp of these teeth was 89.29% (95% CI, 89.22%–89.35%), and the individual results of these studies are shown in **Figure 3**. For the canine group, 11 studies [3,17-20,22-27] were included in the meta-analysis, for a total of 1,139 teeth. The mean combined effect measure of SpO_2 in the dental pulp of these teeth was 89.20% (95% CI, 89.05%–89.34%), and the individual results of these studies are shown in **Figure 4**.

Study or subgroup	TE	seTE	95% CI	Weight (fixed)	Weight (random)
Schnettler and Wallace [16]	94.00	0.4568	94.00 (93.10–94.90)	1.2%	5.0%
Radhakrishnan *et al.* [9]	81.00	0.1068	81.00 (80.79–81.21)	21.7%	5.0%
Gopi Krishna *et al.* [17]	79.31	0.4854	79.31 (78.36–80.26)	1.0%	5.0%
Calil *et al.* [18]	91.29	0.4932	91.29 (90.32–92.26)	1.0%	5.0%
Karayilmaz and Kirzioğlu [4]	86.32	0.5402	86.32 (85.26–87.38)	0.8%	5.0%
Pozzobon *et al.* [19]	87.76	1.3200	87.76 (85.17–90.35)	0.1%	4.7%
Siddheswaran *et al.* [11] - Adults	87.80	0.1800	87.80 (87.45–88.15)	7.6%	5.0%
Siddheswaran *et al.* [11] - Children	87.10	0.2800	87.10 (86.55–87.65)	3.2%	5.0%
Ciobanu *et al.* [20]	83.30	0.4791	83.30 (82.36–84.24)	1.1%	5.0%
Sadique *et al.* [3]	85.11	0.1890	85.11 (84.74–85.48)	6.9%	5.0%
Stella *et al.* [21] - Adults	77.88	0.1817	77.88 (77.52–78.24)	7.5%	5.0%
Stella *et al.* [21] - Children	84.35	0.1864	84.35 (83.98–84.72)	7.1%	5.0%
Kosturkov *et al.* [22]	84.43	0.6065	84.43 (83.24–85.62)	0.7%	5.0%
Kataoka *et al.* [23]	95.50	0.1602	95.50 (95.19–95.81)	9.6%	5.0%
Kosturkov *et al.* [25]	84.00	0.4272	84.00 (83.16–84.84)	1.4%	5.0%
Kosturkov and Uzunov [26]	92.00	0.9988	92.00 (90.04–93.96)	0.2%	4.8%
Souza *et al.* [27]	89.00	0.2228	89.00 (88.56–89.44)	5.0%	5.0%
Kosturkov *et al.* [28]	83.00	0.1508	83.00 (82.70–83.30)	10.9%	5.0%
Solda *et al.* [29]	85.10	0.1595	85.10 (84.79–85.41)	9.7%	5.0%
Lima *et al.* [30]	84.76	0.2766	84.76 (84.22–85.30)	3.2%	5.0%
Fixed effect model			**84.94 (84.85–85.04)**	**100.0%**	
Random effects model			**86.13 (83.97–88.30)**		**100.0%**

Heterogeneity: I^2 = 100%, τ^2 = 24.2551, p = 0

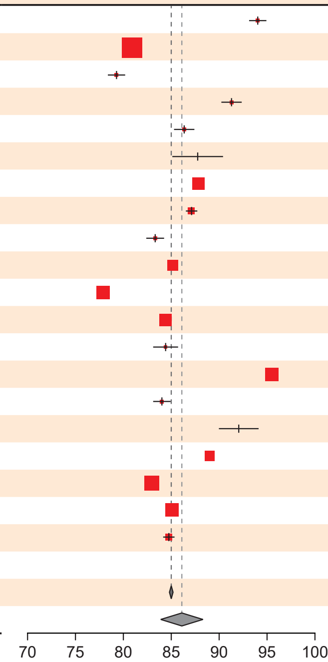

Figure 2. Results of the meta-analysis of individual and combined effect measures of mean oxygen saturation levels in the dental pulp of the maxillary central incisors in the included studies.
TE, treatment effect (mean oxygen saturation); seTE, standard error of the treatment effect (mean oxygen saturation); CI, confidence interval.

Study or subgroup	TE	seTE	95% CI	Weight (fixed)	Weight (random)
Radhakrishnan *et al.* [9]	80.63	0.1188	80.63 (80.40–80.86)	5.1%	10.0%
Gopi Krishna *et al.* [17]	79.61	0.4984	79.61 (78.63–80.59)	0.3%	10.0%
Karayilmaz and Kirzioğlu [4]	87.47	0.6677	87.47 (86.16–88.78)	0.2%	9.9%
Ciobanu *et al.* [20]	78.50	0.5218	78.50 (77.48–79.52)	0.3%	10.0%
Sadique *et al.* [3]	80.21	0.1853	80.21 (79.85–80.57)	2.1%	10.0%
Kosturkov *et al.* [22]	83.29	0.6312	83.29 (82.05–84.53)	0.2%	9.9%
Kataoka *et al.* [23]	94.00	0.1442	94.00 (93.72–94.28)	3.5%	10.0%
Kosturkov *et al.* [25]	83.51	0.4000	83.51 (82.73–84.29)	0.4%	10.0%
Kosturkov and Uzunov [26]	90.00	0.0289	90.00 (89.94–90.06)	86.2%	10.1%
Souza *et al.* [27]	87.00	0.1958	87.00 (86.62–87.38)	1.9%	10.0%
Fixed effect model			**89.29 (89.24–89.35)**	**100.0%**	
Random effects model			**84.43 (81.02–87.84)**		**100.0%**

Heterogeneity: I^2 = 100%, τ^2 = 30.1395, p = 0

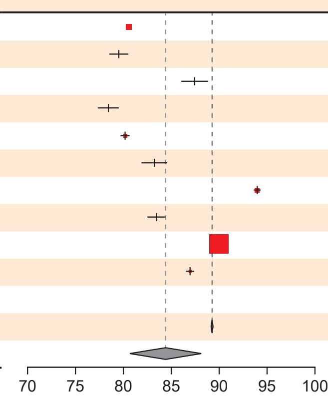

Figure 3. Results of meta-analysis of individual and combined effect measures of mean oxygen saturation levels in the dental pulp of the maxillary lateral incisors in the included studies.
TE, mean treatment effect (oxygen saturation); seTE, standard error of the mean treatment effect (oxygen saturation); CI, confidence interval.

The quality of 13 studies [4,9,11,16,18,22-27,29,30] was assessed using the QUADAS-2 (**Table 3**), while that of the remaining studies [3,17,19-21,28] was evaluated using the adapted NOS (**Table 4**). The studies were predominantly of low quality due to the high risk of bias related to the applicability and interpretation of the index test, unclear risk regarding patient selection, and concerns about overall applicability (**Table 3**). The quality of the cross-sectional studies [3,17,19-21,28] was rated as low (maximum 4 points) due to the high risk of bias related to

Study or subgroup	TE	seTE	95% CI	Weight (fixed)	Weight (random)
Gopi Krishna *et al*. [17]	79.85	0.3816	79.85 (79.10–80.60)	3.9%	9.3%
Calil *et al*. [18]	90.69	0.4791	90.69 (89.75–91.63)	2.4%	9.2%
Pozzobon *et al*. [19]	83.43	1.6200	83.43 (80.25–86.61)	0.2%	7.8%
Ciobanu *et al*. [20]	84.50	0.6593	84.50 (83.21–85.79)	1.3%	9.1%
Sadique *et al*. [3]	89.55	0.0995	89.55 (89.35–89.75)	56.8%	9.4%
Kosturkov *et al*. [22]	83.44	0.6063	83.44 (82.25–84.63)	1.5%	9.1%
Kataoka *et al*. [23]	92.00	0.1557	92.00 (91.69–92.31)	23.2%	9.4%
Khademi et al. [24]	87.78	0.8967	87.78 (86.02–89.54)	0.7%	8.9%
Kosturkov *et al*. [25]	83.76	0.3504	83.76 (83.07–84.45)	4.6%	9.3%
Kosturkov and Uzunov [26]	90.42	0.6085	90.42 (89.23–91.61)	1.5%	9.1%
Souza *et al*. [27]	86.00	0.3790	86.00 (85.26–86.74)	3.9%	9.3%
Fixed effect model			**89.20 (89.05–89.34)**	**100.0%**	
Random effects model			**86.54 (84.39–88.69)**		**100.0%**

Heterogeneity: $I^2 = 99\%$, $\tau^2 = 12.8174$, $p < 0.01$

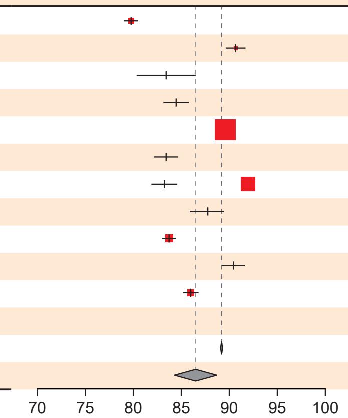

Figure 4. Results of meta-analysis of individual and combined effect measures of mean oxygen saturation levels in the dental pulp of the maxillary canines in the included studies.
TE, mean treatment effect (oxygen saturation); seTE, standard error of the mean treatment effect (oxygen saturation); CI, confidence interval.

Table 3. Quality assessment of studies using the Quality Assessment of Diagnostic Accuracy Studies-2 (*n* = 13)

Study	Risk of bias				Applicability concerns			Study quality
	Patient selection	Index test	Reference standard	Flow and timing	Patient selection	Index test	Reference standard	
Schnettler and Wallace [16]	Unclear	High	Unclear	Low	High	Low	High	Low
Radhakrishnan *et al*. [9]	Unclear	High	Unclear	Low	High	Low	High	Low
Calil *et al*. [18]	Unclear	High	Unclear	High	High	Low	High	Low
Karayilmaz and Kirzioglu [4]	Unclear	High	Unclear	Low	High	Low	High	Low
Siddheswaran *et al*. [11]	Unclear	High	Unclear	Low	High	Low	High	Low
Kosturkov *et al*. [22]	Unclear	High	Unclear	Low	High	Low	High	Low
Kataoka *et al*. [23]	Unclear	High	Unclear	Low	High	Low	High	Low
Khademi *et al*. [24]	High	High	Low	Low	High	Low	High	Low
Kosturkov *et al*. [25]	Unclear	High	Unclear	Low	High	Low	High	Low
Kosturkov and Uzunov [26]	Unclear	High	Unclear	Low	High	Low	High	Low
Souza *et al*. [27]	Unclear	Unclear	Unclear	Low	High	Low	High	Low
Solda *et al*. [29]	Unclear	High	Unclear	Low	High	Low	High	Low
Lima *et al*. [30]	Unclear	High	Low	Low	High	Low	High	Moderate

Table 4. Quality assessment of studies using the Newcastle-Ottawa scale adapted for cross-sectional studies (*n* = 6)

Study	Selection				Comparability	Outcome		Study quality
	Representation of the sample	Sample size	Non-respondents	Assessment of the exposure	Control of confounding factors	Assessment of the outcome	Statistical test	
Gopi Krishna *et al*. [17]	*	*	*	‡	†	*	†	Low
Pozzobon *et al*. [19]	*	*	*	‡	†	*	†	Low
Ciobanu *et al*. [20]	*	*	*	‡	†	*	†	Low
Sadique *et al*. [3]	*	*	*	‡	†	*	†	Low
Stella *et al*. [21]	*	*	*	†	†	*	†	Low
Kosturkov *et al*. [28]	*	*	*	†	†	*	*	Low

*No description/not justified/incomplete; †Poor quality; ‡Good quality.

the representativeness of the sample, the lack of description of the inclusion of subjects and of the sampling strategy, the lack of justification of the sample size, concerns regarding the assessment of the outcome, and the lack of description of the laboratory methods used or the use of non-standard methods (**Table 4**).

DISCUSSION

Difficulties in establishing the pulp status by means of thermal tests in different clinical situations, such as dental trauma, bruxism, and radiotherapy, may lead to uncertainty, highlighting the complexity of the potential responses [1,28]. Since the 1990s, a growing number of studies have been focused on the use of flowmetry to assess pulpal microcirculation, and pulp oximetry is one of the tests that has been most extensively studied [31]. However, studies aimed to establish reference values for pulp oxygen saturation are scarce. The mean SpO_2 values found in the present study were 84.94% for the maxillary central incisors, 89.29% for the maxillary lateral incisors, and 89.20% for the maxillary canines. These values may serve as reference parameters for the normal pulp status in these tooth groups.

Oxygen saturation levels are related to the oxygen-carrying capacity of hemoglobin [26], and the level of oxygen saturation is often lower in the teeth than in the rest of the body due to the location of the pulp. The pulp is surrounded by hard tissue, which creates an obstacle for the detection of vascularization [25]. In addition, the diffraction of infrared light through enamel prisms may result in lower readings for oxygen saturation levels [21].

The mean values established in the present study are different from those reported in a previous review for the same tooth groups [8]. This difference may be explained by the smaller number of studies ($n = 6$) included in that review. In this respect, it is worth noting the increasing number of published studies on the use of pulse oximetry, especially in the last 4 years, making it possible to include a larger number of studies in the present systematic review. Even when considering the possible confounding factors and risks of bias of the included studies, the values reported in the present study are of clinical relevance for both specialists and clinicians, as they can be used as reference parameters for assessments of changes in the pulp status [2,3,6,9].

The high heterogeneity ($I^2 = 100\%$) of the included studies may directly relate to the study design, as the majority were diagnostic studies. Thus, differences in values observed between the included studies cannot be explained exclusively by sampling error, but rather by a set of factors (systematic errors) related to the differences between samples (participants), ages, oximeter models and brands, measurement methods, and outcome analyses. This aligns with the quality of studies as assessed by the aforementioned instruments (**Tables 2** and **3**). The assessment of a study depends on the quality of the reporting. However, it is important to acknowledge that no study is perfect, especially diagnostic studies, which are subject to several sources of bias, such as diagnostic review. It should also be noted that observational studies are inherently heterogeneous [32].

Although it was not possible to establish a summary value for the different tooth groups, minimum reference values for normal pulp status (vitality) could be established for the tooth groups evaluated. The minimum and maximum limits for each tooth group were combined with the weighted mean of the fixed effect measure, allowing us to state with certainty that pulse oximetry can be used to diagnose dental pulp vitality and to detect pulp abnormalities in different clinical situations [8]. We can also infer that this condition may be related to the accuracy of the test, which showed high sensitivity and specificity (1.00 and 0.95, respectively) [7]. In clinical practice, this represents an effective and objective method for assessing the vitality of pulp tissue in permanent teeth.

https://doi.org/10.5395/rde.2020.45.e48

Another factor to consider is the type of oximeter and probe used. Most of the included studies underscored that oximeter probes are suitable for measuring oxygen saturation on fingers, but not on teeth [2,5-12]. The values quantified in the present review are supported by a study conducted by Gopikrishna *et al.* [33], who established the efficacy of a custom-made probe for oxygen saturation readings in permanent anterior teeth as ranging from 75% to 85%. To obtain reliable readings, a probe adapted to the size, shape, and contour of each tooth should be used, allowing the light-emitting diodes to remain parallel to each other to ensure the transmission of light through the dental crown [8,27].

The clinical impact of this study is that it provides data for the definition of clinical protocols that can contribute to confirm the potential of pulse oximetry as a diagnostic test capable of establishing pulp vitality in permanent teeth. However, given the heterogeneity of the included studies, most of which were observational in design and were low-quality due to the high risk of bias, it is important to develop studies with a design that can promote a higher level of evidence and control bias, especially for diagnostic accuracy studies. Additionally, improvements in the technology of pulse oximeters are needed with regard to the development of specific devices for measurements of teeth [12], thus facilitating the routine use of these oximeters in clinical practice.

CONCLUSIONS

Even when considering the possible confounding factors and risks of bias of the included studies, the values reported in the present study are of clinical relevance for both specialists and clinicians, as they can be used as reference parameters for assessments of changes in the pulp status. Specifically, the results of this review suggest that the oxygen saturation levels in the normal pulp of permanent maxillary anterior teeth have a minimum value of 77.52%, which may contribute to providing a reference parameter in clinical practice.

ACKNOWLEDGEMENTS

André Ferreira Azeredo Da Silva, a researcher at the Institute of Health Technology Assessment, contributed to the statistical analysis conducted as part of this study.

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