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Pulp diagnosis. Comparative analysis of values obtained with pulse oximetry and electrical tests on restored permanent teeth. Clinical study.

Clique ou toque aqui para introduzir texto.

Giacomo De Boni

Trabalho de Projeto conducente ao Grau de Mestre em Medicina Dentária (Ciclo Integrado)

Gandra, 1 de setembro de 2021

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Trabalho realizado sob a Orientação de Especialista Dr. António Ferraz

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Declaração de Integridade

Eu, acima identificado, declaro ter atuado com absoluta integridade na elaboração deste trabalho, confirmo que em todo o trabalho conducente à sua elaboração não recorri a qualquer forma de falsificação de resultados ou à prática de plágio (ato pelo qual um indivíduo, mesmo por omissão, assume a autoria do trabalho intelectual pertencente a outrem, na sua totalidade ou em partes dele). Mais declaro que todas as frases que retirei de trabalhos anteriores pertencentes a outros autores foram referenciadas ou redigidas com novas palavras, tendo neste caso colocado a citação da fonte bibliográfica.

Agradecimentos

Chegando ao fim do que eles dizem ser os melhores anos da vida, devo primeiro agradecer à minha família por me apoiar e tornar cada momento destes cinco anos possível.

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Agradeço a Portugal, um país especial que me deu muito e para o qual deixo uma parte de mim.

"Oh, get born, keep warm
Short pants, romance
Learn to dance, get dressed, get blessed
Try to be a success
Please her, please him, buy gifts
Don't steal, don't lift
Twenty years of schoolin'
And they put you on the day shift."

Bob Dylan

Resumo

Introdução: os testes pulpares fornecem informações essenciais ao processo diagnóstico e são divididos em duas categorias: testes de sensibilidade (térmicos e elétricos) e testes de vitalidade (oximetria de pulso). Os primeiros são subjetivos, pois dependem da resposta do paciente, enquanto o último fornece informações objetivas sobre a vitalidade pulpar através da saturação de oxigênio.

Objetivos: estudar se as restaurações dentárias influenciam os resultados da oximetria de pulso e dos testes elétricos, e comparar qual o teste mais preciso.

Materiais e métodos: 57 dentes, com pelo menos uma superfície restaurada de 29 pacientes, foram avaliados com testes de frio, elétrico e oxímetro.

Resultados: não foram detetadas associações entre o número de superfícies restauradas e os resultados. Considerando o teste de frio como gold-standard, obtivemos 80,2% área sob a curva ROC para o oxímetro e 90,5% para o teste elétrico. O ponto de corte de 79,59% SpO2 foi o melhor valor para discriminar a vitalidade pulpar da necrose.

Discussão: os nossos resultados estão de acordo com a literatura ao confirmar que as restaurações podem obstacular os raios de luz do oxímetro, conferindo menor especificidade e sensibilidade.

Conclusão: A oximetria de pulso é bastante fiável em dentes restaurados, embora o teste elétrico seja mais preciso.

Palavras-chave: "Oximetria de pulso", "Teste elétrico", "Restauração dentária", "Diagnóstico pulpar", "Teste ao frio".

Abstract

Introduction: pulp tests provide essential information to the diagnostic process, and they are divided in two categories: sensibility tests (thermal and electric tests), and vitality tests (pulse oximetry). The first is subjective since they depend on patient's response, while the latter provides objective information about vitality of the pulp through oxygen saturation.

Objectives: to study whether dental restorations influence the outcome of pulse oximetry readings and electric tests results, and compare which test is more accurate.

Materials and methods: a total of 57 teeth, with at least one surface restored, from 29 patients were assessed with cold, electric and pulse oximetry tests.

Results: no associations were detected between the number of restored surfaces and test result. Considering the cold test as gold-standard, we obtained 80.2% as area under the curve for pulse oximeter, and 90.5% for the electric test. The cut-off point of 79.59% SpO2 was the best value to discriminate pulp vitality from necrosis.

Discussion: our results were consistent with literature in confirming that restorations may hinder light rays when using oximetry, giving lower specificity and sensitivity.

Conclusion: Pulse oximetry is quite reliable in restored teeth although electric pulp testing is more accurate.

Keywords: "Pulse oximetry", "Electric pulp test", "Dental restoration", "Pulp diagnosis", "Cold pulp test"

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Abbreviations

CPT: cold pulp test

EPT: electric pulp test

PO: pulse oximetry

SpO2%: percentage of oxygen saturation

Bpm: beats per minute

ROC: receiver operating characteristic curve

AUC: area under the curve

Introduction

A precise diagnosis of the state of the tooth is an essential procedure before any dental treatment. Anamnesis, oral and radiological examination, evaluation of pain to percussion and palpation, and pulp vitality tests, aid towards the accurate diagnosis and appropriate treatment planning (1,2).

Diseases affecting the dental pulp are inflammatory or infectious. In either case, the microcirculation within the healthy dental pulp initiates an inflammatory response as part of a defensive mechanism to maintain the integrity and health of the pulp. It is generally accepted that assessment of the blood supply within the dental pulp (pulp vitality) is the earliest and maybe the only true indicator of the state of pulpal health (1).

Since performing a histological study on the dental pulp without damaging it is unfeasible, non-invasive diagnostic procedures such as pulp vitality tests turn necessary (3).

The most used method for the diagnosis of pulp conditions is pulp sensibility testing such as cold pulp testing (CPT), and electric pulp testing (EPT). These tests assess the pulp condition through nerve stimulation and are categorized as sensitivity tests. The nervous tissue being highly resistant to inflammation may remain reactive long after the surrounding tissues have degenerated. In such conditions pulp sensibility shows a false positive response. False negative responses may be encountered in teeth that have undergone trauma (2,3).

The EPT is technique sensitive and has several limitations: the patient's perception of the stimulus, which may be affected by psychological and emotional factors, variations in the thickness of enamel, secondary dentin formation, cracks or restorations, and defects within the instrument. Tooth isolation and drying the enamel during EPT is essential as it can prevent the spread of electrical impulses to adjacent teeth or gingival tissue. Electric current can also be transferred between adjacent teeth through contacting metallic restorations and orthodontic bands. EPT is also contraindicated in full crown restorations (1,4–7).

To overcome the shortcomings of pulp sensibility testing, pulse oximetry (PO) has emerged as objective pulp vitality testing being able to detect pulpal blood flow (8).

PO is a non-invasive method that consists of a LED sensor with two diodes of different wavelengths that are absorbed by deoxygenated and oxygenated hemoglobin: red light (600 nm) and infrared light (940 nm). A photoreceptor captures the emissions and obtains the pulp oxygen saturation (SpO2%) and pulse data (bpm) (2).

Different studies show that SpO2% levels are inversely proportional to the severity of pulp disease. Higher percentage of oxygen is found in vital, healthy pulps, lower in inflamed or necrotic pulps, while zero in endodontically treated pulp-less teeth (9,10).

However, PO's use in dentistry has some limitations inherent to its technology. There are systemic (low peripheral perfusion, increased venous pulsations, hemoglobin disorders, vasoconstriction), local (calcification of the coronary chamber, extended or indirect

restorations, and increased acidity and metabolic rate arising from inflammation) and environmental factors (electrocautery near the sensor, ambient light interferences, probe and patient movement and scattering of emitted light rays) that can interfere with the readings of SpO2% (11–13).

A requirement for PO in dentistry is that its sensor conforms to the size, shape, and anatomy of the tooth and that the LED and photodetector should be parallel to each other so that all the light rays emitted by the sensor are received by the photodetector. If the sensor cannot adapt to the crown, reliable results may not be obtained. Finger probes cannot adapt to the external tooth surface. The absence of a standardized dental PO probe results in the creation of custom-made sensor holders (2,11,13).

Objectives

The objectives of this study were:

- Investigate correlations between SpO2% and EPT results and the number of restored faces of the tooth within groups of similar anterior teeth.
- Study if PO and EPT are reliable methods to diagnose dental pulp and compare their diagnostic accuracy when considering CPT as gold standard.

Materials and Methods

This study derives from the project “Effectiveness of pulse oximetry in measuring pulp condition. Comparison with commonly used tests“, (“Eficácia da oximetria de pulso na aferição da condição pulpar. Comparação com os testes habitualmente utilizados”), which was approved by the IUCS Ethics Committee – CESPU (ref. CE/IUCS/CESPU-15/21).

All human subjects who participated in the experimental investigation described in this article signed informed consent forms after the nature of the procedure and the possible discomforts and risks had been fully explained.

The study has taken place in CESPU university clinic (Gandra, Paredes, Porto) with the approval of the clinic director, and was taken by 5 undergraduate dental students coordinated by two professors.

We assessed a total of 57 teeth, with at least one surface restored, from 29 patients, 21 (72.4%) females and 8 (27.6%) males, aged from 22 to 72 years old, mean 39.45 years (SD=17.22).

Number of restored dental faces was registered from 1 to 4 (mesial, distal, vestibular, palatal).

The results of the tests in teeth were reported as follows:

- The number of seconds from the application of the stimulus until the participant felt the cold and raised a hand for the CPT. In case of non-response after 15 seconds from the start of the stimulus, the tooth was registered with a negative response (-);
- The number of seconds from the application of the stimulus until the participant raised a hand for the medium intensity EPT. In case of non-response after the 80 unit display in the EPT device, the tooth was registered with a negative response (-);
- SpO2% of the tooth was registered after 5s of stabilization of the reading by the oximeter;
- Number of bpm (beats per minute) was recorded at the same moment of stabilization SpO2%.

Teeth eligibility criteria

❖ **Inclusion criteria:**

- Permanent superior anterior teeth (upper canines, upper lateral and central incisors)
- Minimally/moderately/extensively restored
- Teeth with active carious lesions

❖ **Exclusion criteria:**

- Non-permanent teeth
- Full prosthetic dental crowns
- Endodontically treated teeth

PO measurement:

In this study a pulse oximeter (ARSTN 2.8 TFT LCD handheld pulse oximeter H381V (Certificate: CE/ISO13485) was used to assess the SpO2% in dental pulps of single rooted anterior superior human permanent teeth (Figure 1). Dental pulse oximeter sensor holder (Figure 2) was designed and custom made to ensure accurate placement and adaptation of the sensor on human permanent teeth. It consisted of a metal rod that allows the positioning of the LED sensor and the photoreceptor to the tooth, connected to a spring that allows vestibulo-palatal adjustment. This type of custom probe served well in superior later incisors and superior canines, given the curvature of the dental arch. A veterinary standard probe (S906V Veterinary sensor SpO2 sensor DB9 Probe cable) was also used in cases where the anatomy of the tooth hindered the measurement with our custom probe (Figure 3). Before the dental testing, each patient's index finger's SpO2 was assessed and registered in the results using a normal finger probe to ensure the patient did not have systemic perfusion alterations (Figure 4).

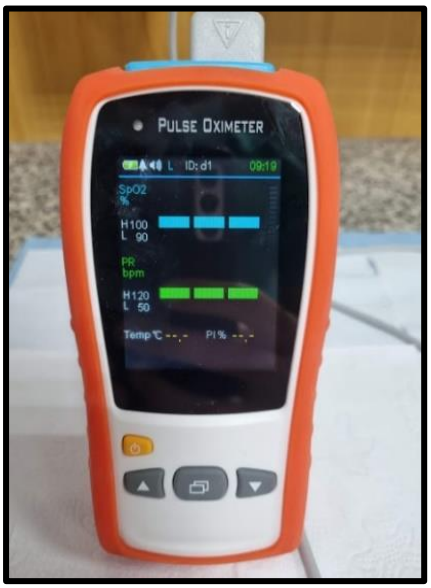

Figure 1: pulse oximeter (ARSTN 2.8 TFT LCD handheld pulse oximeter H381V)

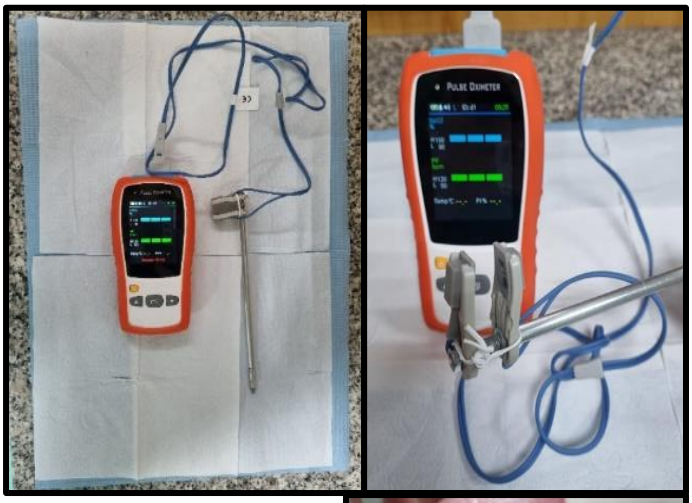

Figure 2: custom PO probe. Its form permitted parallel positioning of the emitter and the sensor, although its form did not always accommodate tooth's structure

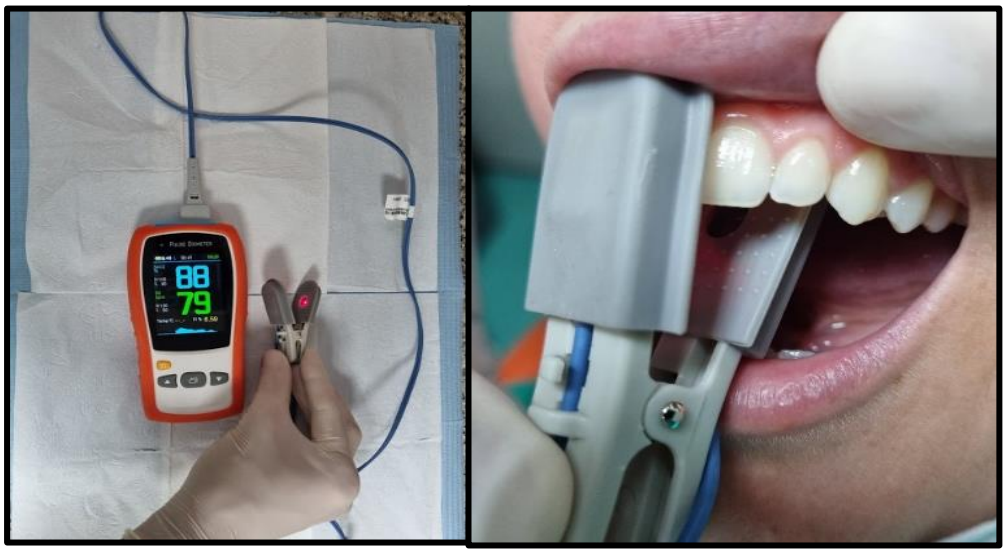

Figure 3: veterinary PO probe used when we could not obtain SpO2% readings with our custom probe.

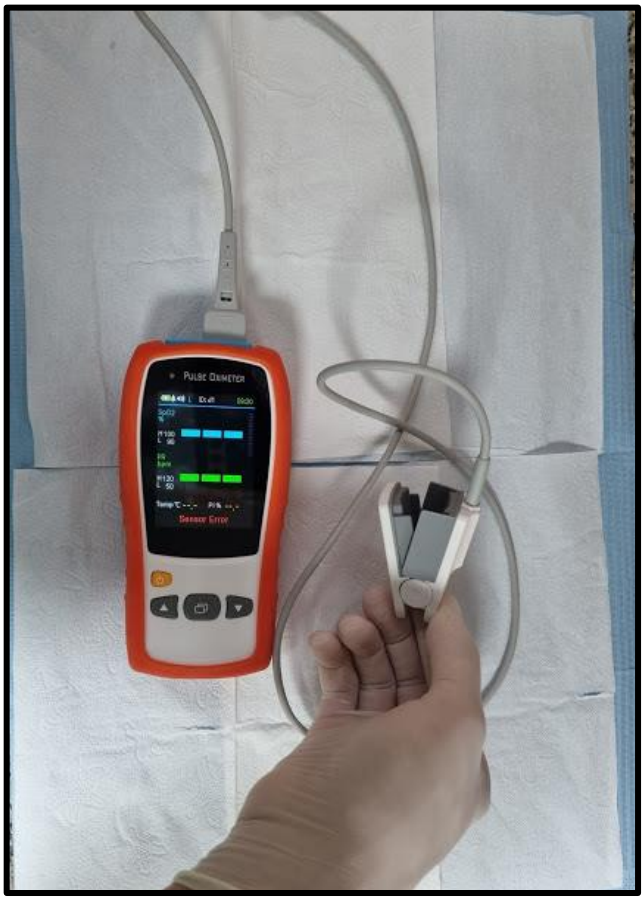

Figure 4: standard PO index finger probe

EPT testing:

The teeth were isolated using cotton rolls and dried with compressed air for 5 s, and threshold sensibility was recorded using a Dental Pulp Tester AZ310 (Figure 5) at medium intensity for all patients. A stainless lip clip connected with a test cable to the device was positioned in the patient's mouth. The electrode was positioned on the facio-cervical half of the tooth (Figure 6). The device generates an increasing voltage and corresponds to the values shown on the digital display on a scale of 0–80. The electrode was made of stainless steel. Before positioning on the tooth, the electrode was coated with toothpaste containing zync oxide (Colgate™ Total) to ensure electric conduction. Patients were instructed to raise their hand when they experienced sensibility in the tested teeth. Cases of non-responses after reaching 80 units were reported as negative responses.

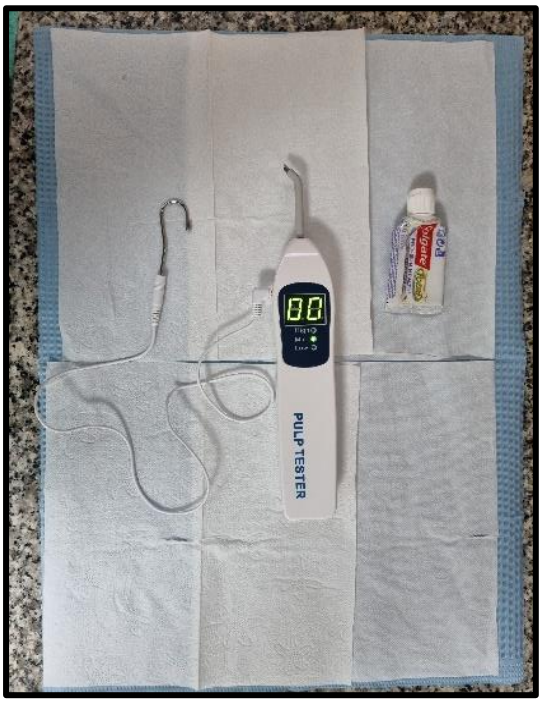

Figure 5: EPT device with electrode, lip clip and toothpaste

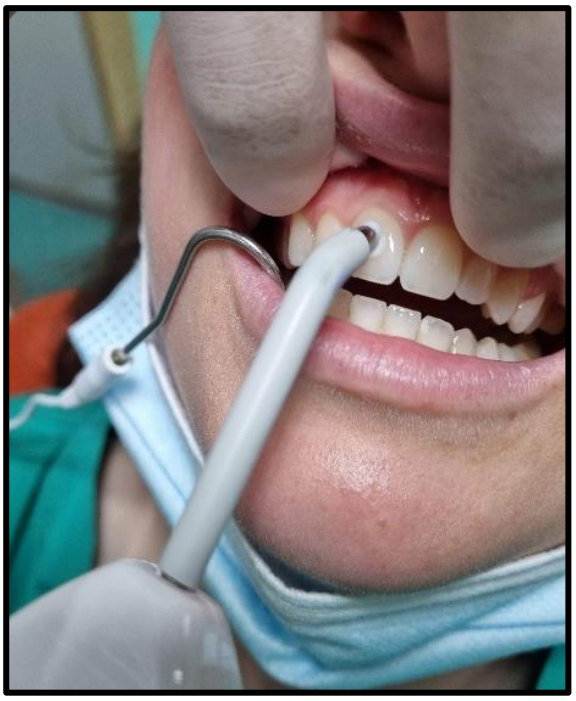

Figure 6: EPT testing methodology under relative isolation with cotton rolls. The tooth was carefully dried before measurement.

CPT testing:

CPT was performed under relative isolation with cotton rolls. The teeth were dried. A refrigerant spray (figure 7) based on propane-butane mixture at -50C° (Endo-Frost - Roeko, Langenau, Germany) was applied on the middle third of the buccal face of each tooth (figure 8). The spray jet was directed to a cotton swab and then applied on the tooth surface until the pulp emits a pain response. To assess pulp response time, in seconds, the patients received instructions to raise their right hand immediately after they feel sensibility to the cold stimulus. If there was no response to the test after 15 s, the test was considered negative.

Figure 7: propane-butane spray and cotton swab

Figure 8: cotton swab applied on the buccal face of tooth 11

Search strategy:

We used the PRISMA 2020 statement as the methodology for addressing existing knowledge on the subject and writing the introduction and discussion of this study.
The primary null hypothesis of this study was: "the number of restored surfaces in teeth does not influence EPT and PO diagnostic results".
MEDLINE database was researched through PubMed search engine.

Inclusion criteria were:

- Systematic review or clinical trial
- Articles written in English language

Exclusion criteria were:

- Articles that did not address the interests of this study
- Articles that were not fully available online

1) The first research on EPT tests had the following query box and gave a total of 92 articles ranging from January 1976 to July 2021. 10 articles were included after the application of inclusion and exclusion criteria.

((Pulp diagnosis) OR (pulpal test) OR (diagnostic test) OR (pulp vitality) OR (pulp sensibility) OR (dental pulp test) OR (vitality test)) AND (teeth) AND ((electric test) OR (electric pulp)) AND ((restoration) OR (restored))

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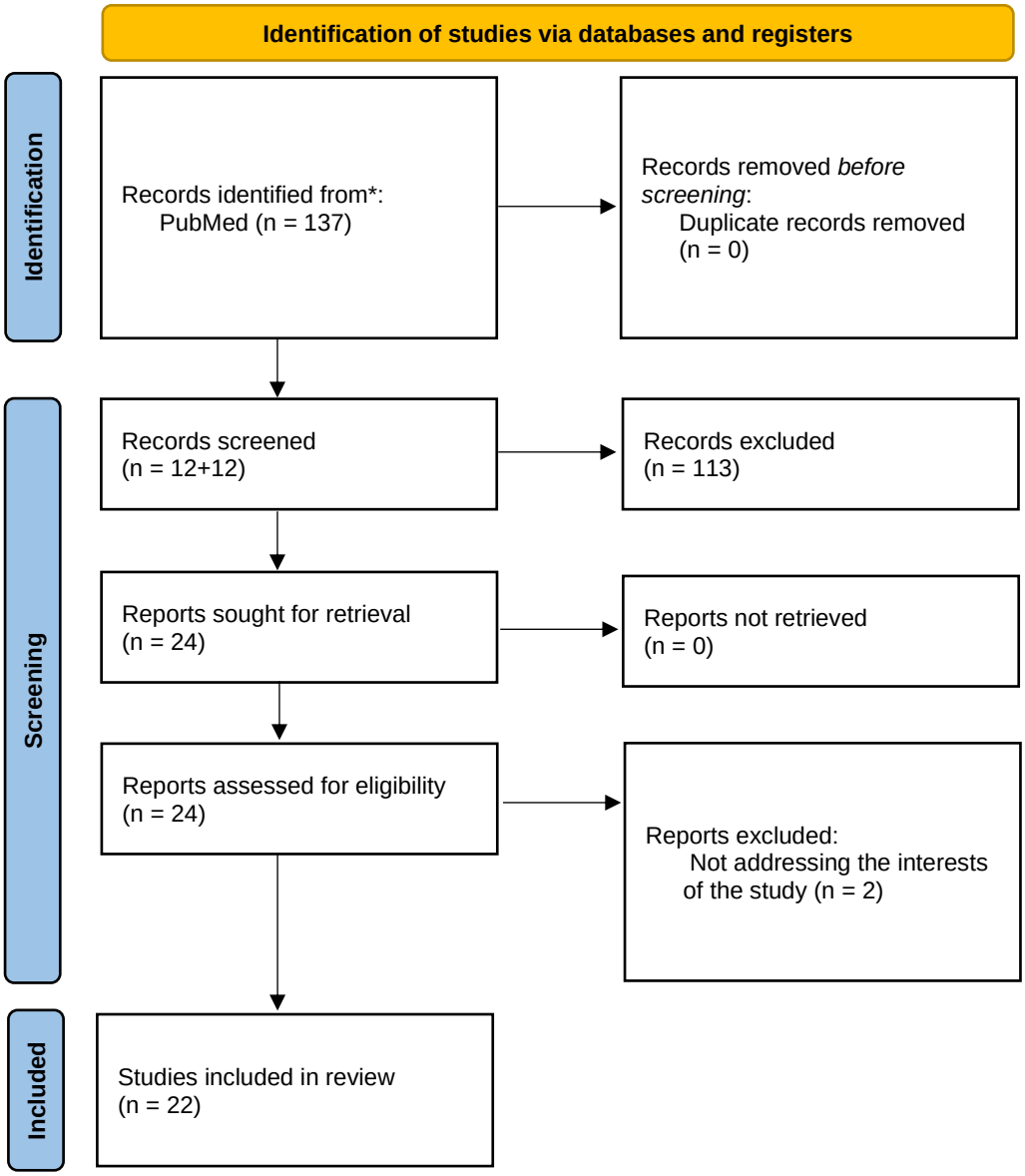
2) The second research on PO tests gave a total of 45 articles ranging from January 1991 to July 2021. 12 articles were included after the application of inclusion and exclusion criteria.

(Pulse oximetry) AND ((pulp diagnosis) OR (dental pulp)) NOT ((traumatized) OR (flowmetry))

A total of 137 articles were identified, and 22 studies were included for the final review as shown in Table 1.

A total of 2 studies were used to interpret the results from the statistic study and were included in the bibliography.

Table 1: PRISMA flow diagram (http://prisma-statement.org/PRISMAStatement/FlowDiagram)



Results

Statistical analysis:

Statistical analysis was performed with SPSS, version 24. Descriptive statistics were presented as frequencies (n) and percentages (%) for categorical variables, means (M) and standard deviations (SD) for symmetrical continuous variables and medians (Mdn) and percentiles P25 and P75 for asymmetrical continuous variables.

Symmetry was assessed with symmetry coefficient [-2, 2] and by observing histograms. Associations of categorical variables were assessed with chi-square tests or the alternative Fisher exact test. Associations of continuous variables with teeth groups were performed with Kruskall-Wallis for non-normal distributed variables and ANOVAs for normal-distributed variables. Finally, the association of the number of restored faces with the tests results was measured with Spearman-rank correlation coefficient. Normality was assessed with Shapiro-Wilk test (n<50).

ROC curve was used to assess oxygen saturation as a test of pulp vitality for the restored teeth considering the cold test as a gold standard. Sensitivity, specificity, and area under the curve were calculated. Significance level was generally p<.05, but we considered a higher threshold (p<.10) when including canines (n=6) in the comparisons.

Descriptive statistics

We assessed a total of 57 teeth, with at least one surface restored, from 29 patients, 21 (72.4%) females and 8 (27.6%) males, aged from 22 to 72 years old, mean 39.45 years (SD=17.22) (Table 2).

Table 2. Teeth features

Type of tooth	***n***	***%***
Centrals	32	56.1%
11	19	33.3%
21	13	22.8%
Laterals	19	33.3%
12	9	15.8%
22	10	17.5%
Canines	6	10.6%
13	1	1.8%
23	5	8.8%

Number of surfaces restored	*n*	*%*
1	14	24.6%
2	16	28.1%
3	16	28.1%
4	11	19.3%

A total of 45 (78.9%) teeth had a positive result in the cold test. For those teeth, the median of the elapsed time was 2 seconds, (P25=1.0, P75=3.5), varying from 1 to 14 seconds. Results for the electric test were normal for 44 (77.2%) teeth; 6 (10.5%) had some pathology and 7 (12.3%) were necrotic. The electric test had a median of 6.0 (P25=3.0, P75=29.0), with a minimum of 1 and maximum of 80. Mean of oxygen saturation (% SpO_2) was 78.40 (SD=17.42), ranging from 2% to 98%. SpO2% categories (using cut-off values from Anusha's study (9)), were pulp vitality (36.8%), reversible pulpitis (19.3%), irreversible pulpitis (24.6%) and pulp necrosis (19.3%). Mean teeth bpm was 74.81 (SD=8.91), varying from 60 to 93 (Table 3). Sample size was too little to find statistical correlations between categories of different tests.

Table 3. Teeth assessments

Cold test	
Negative	12 (21.1%)
Positive	45 (78.9%)
Time (a)	2.0 (1.0 – 3.5) [1-14]
Electric test	6.0 (3.0 – 29.0) [1-80]
Normal (<40)	44 (77.2%)
Some pathology (40-79)	6 (10.5%)
Necrotic (≥ 80)	7 (12.3%)
Oxygen saturation (% SpO_2)	78.40 (17.42) [2-98]
Pulp vitality (95-86)	21 (36.8%)
Reversible pulpitis (85-82)	11 (19.3%)

Irreversible pulpitis (81-71)	14 (24.6%)
Pulp necrosis (<71)	11 (19.3%)
Teeth bpm	74.81 (8.91) [60-93]

(a) Calculated for positive CPT; results presented as n (%) for categorical variables, M(SD) [min-max] for symmetrical continuous variables and Mdn (P25-P75) [min-max] for asymmetrical continuous variables.

Statistical associations

The CPT results were not associated with the different teeth groups (p=.713), but the time of the test was marginally associated (p=.098), with higher time for canines (Mdn=13.0) when compared with centrals (Mdn=2.0) or laterals (Mdn=1.0). No associations with teeth groups were found for the electric test (p=.483), oxygen saturation (p=.593), oxygen saturation (healthy vs non-healthy) (p=.109) and teeth bpm (p=.300) (Table 4).

Table 4. Teeth assessments compared by groups

	Centrals (n=32)	**Laterals (n=19)**	**Canines (n=6)**	**Statistics**
Cold test				
Negative	6 (18.8%)	4 (21.1%)	2 (33.3%)	p=.713 (a)
Positive	26 (81.3%)	15 (78.9%)	4 (66.7%)	
Time (for positive cold test)	2.0 (1.0 – 3.0)	1.0 (1.0 – 5.0)	13.0 (7.0 - 13.5)	p=.098 (b)
Electric test	5.0 (3.0 – 37.0)	11.0 (5.0 – 25.0)	12.0 (1.0 – 33.0)	p=.483 (b)
Oxygen saturation (% SpO_2)	78.06 (16.23)	80.84 (20.41)	72.50 (14.21)	p=.593 (c)
Healthy (95-82)	18 (56.3%)	13 (68.4%)	1 (16.7%)	p=.109 (a)
Non-healthy (<82)	14 (43.8%)	6 (31.6%)	5 (83.3%)	
Teeth bpm	74.97 (9.37)	76.16 (8.19)	69.67 (8.04)	p=.300 (c)

Results presented as n (%) for categorical variables, M(SD) for symmetrical continuous variables and Mdn (P25-P75) for asymmetrical continuous variables; (a) Fisher exact test; (b) Kruskall-Wallis test; (c) ANOVA test.

No associations were detected between the number of restored surfaces and the teeth test results, considering the total number of teeth, or stratified by teeth groups (Table 5).

Table 5. Associations of the number of restored surfaces with teeth test results

	Total (n=57)	**Centrals (n=32)**	**Laterals (n=19)**	**Canines (n=6)**
Electric test	r_s=0.06 (p=.633)	r_s=0.23 (p=.215)	r_s=-0.34 (p=.157)	r_s=0.15 (p=.771)
Oxygen saturation % SpO_2	r_s=0.05 (p=.726)	r_s=-0.02 (p=.927)	r_s=0.19 (p=.444)	r_s=-0.09 (p=.864)
Teeth bpm	r_s=-0.01 (p=.916)	r_s=0.08 (p=.685)	r_s=-0.23 (p=.350)	r_s=0.40 (p=.439)

Receiver operating characteristic curve (ROC)

Considering the cold test as gold-standard for establishing vitality we assessed the sensitivity and specificity of the oxygen saturation in restored teeth as shown in the receiver operating characteristic curve (ROC) in Figure 9. We obtained 80.2% as area under the curve (AUC), as measure of precision. The cut-off point of 79.59% SpO2 in the PO obtained a sensitivity of 77.8% and specificity of 83.3%. The electric test threshold of 24.5 units had a sensitivity of 91.7% and specificity of 91.1% for detecting positive results, considering the cold test. AUC was 90.5% (Figure 10).

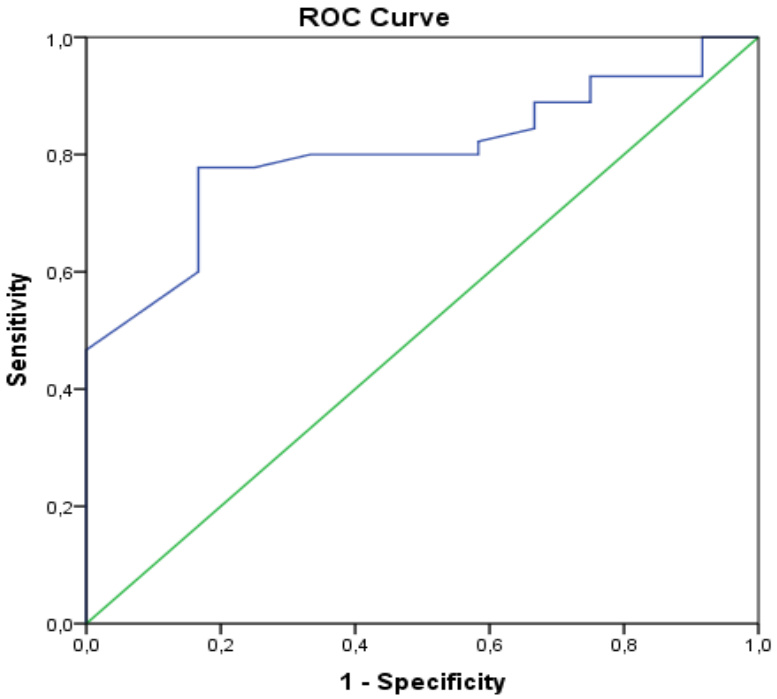


Figure 9: ROC curve for oxygen saturation

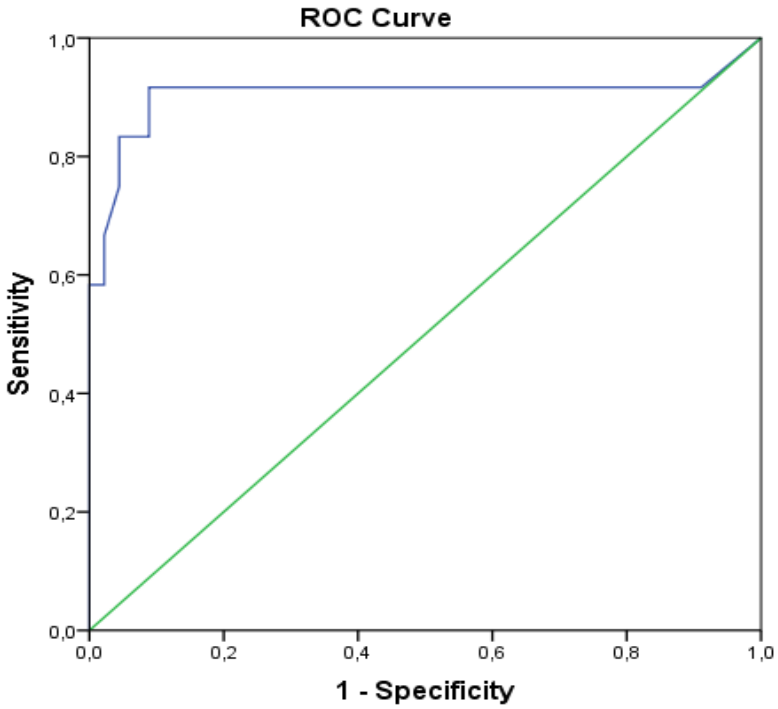


Figure 10: ROC curve for EPT testing

Discussion

In every day's practice, the clinician frequently must assess the state of the pulp of moderately or extensively restored teeth.

In literature, it has been generally reported that PO reading is not precise in teeth with indirect or extensive restorations and patients with periodontal disorders (11–13).

To our knowledge, this is the first study that correlates SpO2% findings to EPT sensitivity and the restorative condition of the tooth.

Most of the studies carried up this day directly excluded extensively restored teeth in the eligibility criteria (10,13–15), or did not directly correlate their SpO2% to restorative status (4,9).

Variables in SpO2% readings in permanent teeth

Oxygen saturation is related to the oxygen-carrying capacity of hemoglobins: each hemoglobin molecule can carry up to 4 oxygen molecules. When the 4 oxygen binding sites are occupied by oxygen, saturation is 100%. A healthy individual presents arterial oxygen saturation ranging from 95%–100% (16).

However, in teeth, oxygen saturation is generally lower: this fact may be explained by certain factors.

1. The location of the pulp, surrounded by hard tissue (enamel and dentine), creates an obstacle for vascularization detection;
2. The diffraction of infrared light through enamel prisms and dentinal tubules may lead to erroneously lower readings of oxygen saturation;
3. Pulse oximetry readings are more difficult to obtain in teeth with increased dentin thickness (17);
4. Age plays an important role because of secondary dentine deposition. Stella et al. (18), and Estela et al. (19), studied SpO2 levels among different age groups, concluding that younger participants had higher levels of saturation than older ones.

Correlation between SpO2% and pulp vitality

In literature, we found two studies (9,10) that associated levels of SpO2% to different inflammatory conditions.

A significant difference in the oxygen saturation levels between different pulpal inflamed posterior teeth was found in Setzer's study (10). The results were consistent with those found in anterior teeth in Anusha's study (9) showing that SpO2% levels were inversely proportional to the severity of the disease.

A systematic review (17) showed the median SpO2% in normal dental pulps of permanent teeth was higher than 87%. This could be used as a benchmark for permanent teeth to diagnose pulp vitality, although this result included both restored and not restored teeth.

In the present study, we used the mean oxygen saturation levels found in Anusha's study to assess the state of the pulps in restored teeth and then compare them to EPT and CPT results (Table 3). SpO2% categories of the teeth in our study were determined as vital (36.8%), reversible pulpitis (19.3%), irreversible pulpitis (24.6%), and pulp necrosis (19.3%). No anamnesis, history of pain, radiographic or histologic findings were taken into consideration during this study to confirm these diagnoses.

Correlation between EPT and pulp sensibility

Differently from PO, it is impossible to assess pulp status with EPT. Studies have shown no correlation between positive responses to the EPT and the histological status of the pulp. A positive response simply indicates that there are sensory fibers present within the pulp that can respond to the electrical stimulus, while a lack of response to the EPT suggests the lack of responding nerve fibers, and this usually means that there is likely to be necrosis of the pulp (7).

Although theoretically incorrect, following the developer's instruction manual, we assessed as "vital" a tooth that responded between 0-40 units; "with some pathology" when it responded from 40-80; "necrotic" when it did not respond after 80 units.

Results for the electric test were positive for 44 (77.2%) teeth; 6 (10.5%) were considered to have some pathology and 7 (12.3%) were necrotic.

Correlation between SpO2% and EPT result with restored surfaces

In literature is generally assessed that the presence of restorative materials (i.e., composite resin, glass ionomer) and pulp cappers (i.e., calcium silicate cement) may hinder the measurement since they can act as an obstacle for the light source. As a result, SpO2% levels may be lower (2).

It has been reported that erroneous responses may be obtained when EPT is used on teeth that have full-crown restorations, porcelain restorations, metallic restorations, or pulpotomy because the dental materials used may prevent the current from reaching the pulp (1,4–7).

In this study, we measured SpO2% and EPT sensibility in a total of 57 restored teeth.

The null hypothesis of this study was "there is no correlation between the number of restored surface and EPT or PO result of the tooth".

Statistical analysis did not find any correlation between the number of restored faces with SpO2% value and EPT sensibility, thus the null hypothesis was not rejected. No

correlation was found even when matching results in similar groups of teeth (Table 5).

For EPT results our study was consistent with the findings of Jespersen et al. (20), who reported that there was no significant correlation noted with gender, tooth type or location, and the number of restored surfaces on EPT sensibility.

A potential error in this result must be assessed: our study registered the number of restored faces, not which face was restored nor its extension. A little class IV restoration (that we registered as having 2 or 3 restored surfaces) would probably affect SpO2% reading less than a larger vestibular or cervical restoration since the composite resin in these cases is closer to the light. More studies should be carried out comparing these variables to corroborate our results.

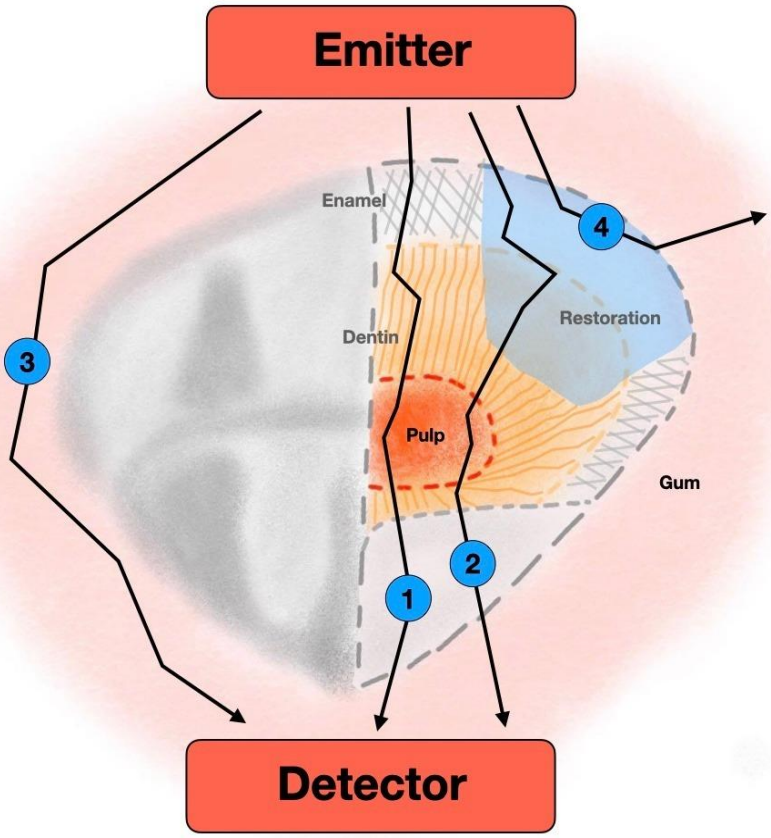


Figure11: Scattering light rays: Ray 1 passes through the pulp. It carries useful information about pulse amplitude or oxygenation. Ray 2 passes through the restoration and pulp. It may give lower SpO2% readings. Ray 3 passes through the gingiva. It may provide higher and misleading readings. Ray 4 does not reach the detector.

It's also important to note the possibility of scattering light rays. Fein et al. (21) investigated several subjects with different custom PO probes and non-invasive methods to isolate the tooth from highly perfused gingival tissue. They concluded that optical signals detected from teeth were contaminated by strong signals from the gingiva. Soon after entering the tooth, rays are traveling in completely random

directions, meaning that light rays may pass through the restoration (thus giving lower reading) as well as through the gingiva (giving higher readings) as shown in figure 11.

Within the limitations of this study, we concluded that it is possible to obtain SpO2% readings in restored teeth and that the number of dental faces of the restoration did not influence SpO2% reading and EPT sensibility.

ROC Curve of PO and EPT in restored teeth

"Sensitivity" is the ability of a test to correctly identify patients with a disease, measuring true-positive ratings. It describes the proportion of vital teeth that are accurately identified as vital by the sensibility test; while "specificity" is the ability of a test to correctly identify people without the disease, describing the proportion of necrotic teeth that are correctly identified as necrotic (22).

The ROC curve is produced by plotting sensitivity (true positive rate) on the y-axis against specificity (false positive rate) on the x-axis for the various values tabulated. The area under the ROC curve (AUC) is a global measure of the accuracy of a given diagnostic test representing its ability to discriminate whether a specific condition is present or not present. An AUC of 50% represents a test with no discriminating ability, while an AUC of 100% represents a test with perfect discrimination. This method is also used to compare two different diagnostic tests (23).

In our study, considering as gold-standard the CPT test, we obtained an AUC curve of 80.2% for the PO test and 90.5% for EPT. The thresholds cut-off points were 79,59% for SpO2% and 24,5 units for the EPT. This means that results above or below these threshold values have a sensitivity of 77.8% and specificity of 83.3% for PO; and respectively 91.7% and 91.1% for EPT.

Hence, we conclude that PO is a reliable test for restored teeth although EPT is more accurate and that the SpO2% above or below 79.59% is a reasonable measure for detecting pulp vitality in restored teeth. This result is generally lower than the ones found by most PO studies (9,10,14,17,24) but concordant with Gopikrishna study (4).

These results were consistent with the literature in confirming that composite resin restoration may give lower readings thus a lower specificity and sensitivity in PO testing (11,13).

We also confirmed the findings of Jespersen et al. (20), who reported that restorative status and tooth type or location resulted in no significant differences concerning pulpal sensibility.

Study limitations and potential errors

Many variables were not addressed by this study. These could include more thorough anamneses, presence or absence of pain, correlation with periapical percussion test results, recording the number of seconds from removing the stimulus until the absence of the sensation, and correlation of the results with radiographic and histologic findings.

Potential sources of errors in the methodology of this study include possibly unreliable results given by the shapes of our custom and veterinary PO probes, the absence of rubber dam isolation during EPT and PO testing and scattering of light rays that passing through the gingiva giving misleading results.

Conclusion

Within the limitations of this study, we did not reject the null hypothesis: we found no correlation between the number of restored faces and SpO2%, teeth bpm, and EPT results.

We suggest PO may be a reliable method to diagnose pulp vitality in restored teeth, although EPT seems to be more accurate when considering the CPT as gold standard.

When diagnosing restored teeth with PO, we found SpO2 = 79,59% as the best value to discriminate pulp vitality from pulp necrosis.

The findings of the study must be correlated with more studies of a larger sample size and stricter methodology to interpolate data to the clinical scenario.

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Annexes:

1. Approval report

CESPU
INSTITUTO UNIVERSITÁRIO
DE CIÊNCIAS DA SAÚDE

Comissão de Ética

Exmo. Senhor Investigador
Paulo Manuel Cruz Miller

N/Ref.ª: CE/IUCS/CESPU-15/21 **Data:** 2021/junho/21

Assunto: - Parecer relativo ao Projeto de Investigação: 15/CE-IUCS/2021
- **Título do Projeto:** *"Eficácia da Oximetria de pulso na aferição da condição pulpar. Comparação com os testes habitualmente utilizados."*
- **Investigador responsável:** Paulo Manuel Cruz Miller

Exmo. Senhor,

Informo V. Exa. que o projeto supracitado foi analisado na reunião da Comissão de Ética do IUCS, da CESPU, Crl, no dia 17/06/2021.

A Comissão de Ética emitiu um parecer **favorável** à realização do projeto tal como apresentado.

Com os melhores cumprimentos.

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Prof. Doutor José Carlos Márcia Andrade
Presidente da Comissão de Ética do IUCS

2. Informed consent

CARTA EXPLICATIVA DO ESTUDO AOS PARTICIPANTES

O meu nome é _____, sou estudante do Mestrado integrado em Medicina Dentária no Instituto Universitário de Ciências da Saúde na CESPU. Gostaria de convidá-lo(a) a participar num estudo que estamos a desenvolver, para o trabalho de dissertação de Mestrado, integrado num Grupo de Investigação sobre diagnóstico pulpar, que tem como principal objetivo determinar a eficácia e comparar testes de diagnóstico da condição da saúde da polpa dentária.

Recoberta pela dentina, a polpa é composta por nervos, vasos sanguíneos e outras células. A polpa dentária é a responsável pela vitalidade dos dentes.

Os testes pulpares (testes de vitalidade e de sensibilidade) são utilizados como recurso complementar do exame clínico, para auxiliar no diagnóstico da normalidade ou da doença pulpar. Os testes de sensibilidade térmicos e elétricos são executados rotineiramente na prática clínica.

O teste de vitalidade por oximetria de pulso é uma técnica não invasiva e completamente indolor, não causando qualquer incómodo ou risco, sendo similar à medição da saturação de oxigénio no dedo.

A informação recolhida neste estudo poderá, no futuro, possibilitar a obtenção dum diagnóstico mais exato f da condição da polpa dentária, fator que influencia a decisão clínica.

A escolha de participar, ou não, no estudo é voluntária.

É recolhida a seguinte informação: Data de recolha dos dados, Iniciais do Nome, nº do processo Cespu, idade, género, dente(s) avaliado(s), Restauração nº de faces, teste frio (tempo resposta em segundos), Teste eléctrico (valor absoluto), Oximetria dedo (saturação e bpm), Oximetria dente (saturação e bpm).

O presente estudo não acarreta qualquer risco, não trazendo também qualquer vantagem direta para os que nele participam e não irá interferir no plano de tratamento. Serão aproveitadas as consultas normalmente programadas para a recolha de dados, evitando deslocação extra aos serviços. Se decidir participar no estudo, poderá abandonar o mesmo em qualquer momento sem ter que fornecer qualquer tipo de explicação. Todo o material recolhido será codificado e tratado de forma anónima e confidencial, sendo conservado à responsabilidade do Prof. Doutor Paulo Manuel Cruz Miller, Professor Auxiliar nesta instituição e responsável pelo estudo.

A decisão de participar implica a autorização para utilização de recolha dos dados sócio-demográficos e clínicos, acima descritos. Os dados recolhidos irão avaliar a resposta aos testes de sensibilidade e vitalidade pulpar. O responsável pelo seu tratamento irá recolher esta informação durante o seu período normal de tratamento. Os resultados do estudo serão apresentados no âmbito do Trabalho de Dissertação do Mestrado Integrado em Medicina Dentária, nunca sendo os participantes identificados de forma individual. Uma vez apresentados os resultados, os dados originais serão coligidos e aproveitados para investigações futuras.

Caso surja alguma dúvida, ou necessite de informação adicional, por favor contacte através do email paulo.miller@iucs.cespu.pt.

ESTE DOCUMENTO É COMPOSTO DE 2 PÁGINAS E FEITO EM DUPLICADO: UMA VIA PARA AGREGAR À NOSSA DOCUMENTAÇÃO E OUTRA PARA A PESSOA QUE CONSENTE

DECLARAÇÃO DE CONSENTIMENTO INFORMADO

Reconheço que os procedimentos de investigação descritos na carta anexa me foram explicados e que todas as minhas questões foram esclarecidas de forma satisfatória.

Compreendo igualmente que a participação no estudo não acarreta qualquer tipo de vantagens e/ou desvantagens potenciais.

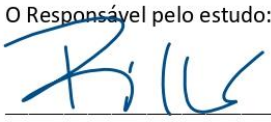
Fui informado(a) que tenho o direito a recusar participar e que a minha recusa em fazê-lo não terá consequências para mim.

Compreendo que tenho o direito de colocar agora e durante o desenvolvimento do estudo, qualquer questão relacionada com o mesmo.

Compreendo que sou livre de, a qualquer momento, abandonar o estudo sem ter de fornecer qualquer explicação.

Assim, declaro que aceito participar nesta investigação, com a salvaguarda da confidencialidade e anonimato e sem prejuízo pessoal de cariz ético ou moral.

O Responsável pelo estudo:



_____

(Paulo Manuel Cruz Miller)

Responsável pela recolha dos dados

_____

O Participante ou Representante:

_____

Gandra, ____ de _____ de 2021

ESTE DOCUMENTO É COMPOSTO DE 2 PÁGINAS E FEITO EM DUPLICADO: UMA VIA PARA AGREGAR À NOSSA DOCUMENTAÇÃO E OUTRA PARA A PESSOA QUE CONSENTE