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Pulp diagnosis. Pulse oximetry and electrical tests on healthy and restored permanent teeth.

Comparative analysis. Clinical study.

Bárbara Marques Amorim

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

Gandra, 9 de setembro de 2021

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Trabalho realizado sob a Orientação de Especialista Dr. António Ferraz

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Eu, **Bárbara Marques Amorim**, 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

Aos meus pais, por confiarem sempre em mim. Sem vocês não seria possível, devo-vos aquilo que tenho e o que sou. Este trabalho também é vosso.

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Resumo

Objetivo: O objetivo deste estudo foi avaliar e comparar o uso do oxímetro de pulso (PO) com o teste elétrico da polpa (EPT) para determinar a vitalidade da mesma em dentes permanentes hígidos e restaurados.

Materiais e métodos: 71 voluntários humanos foram testados para determinar a vitalidade dos seus dentes hígidos e restaurados. Leituras do ritmo cardíaco e de saturação de oxigénio foram também obtidas através do dedo indicador de cada paciente, para verificar a correta funcionalidade e assegurar que o paciente não apresentava alterações de perfusão sistémica. A vitalidade dos dentes foi investigada com uma sonda especificamente modificada (S906V veterinary sensor SpO2 sensor DB9 Probe cable) e um oxímetro de pulso (ARSTN 2.8 TFT LCD handled pulse oximeter H381V (certificate: CE/ISO13485)). O teste ao frio foi realizado com Roeko Endo Frost (Coltene, Alemanha) e para o teste elétrico foi utilizado o Dental Pulp Tester AZ310.

Resultados: Foram obtidos valores de saturação de oxigénio mais baixos em dentes restaurados quando comparados com dentes hígidos. Os caninos necessitam de um estímulo de corrente superior para provocar uma sensação idêntica àquela que é sentida nos restantes dentes avaliados. O método de avaliação através de um risk score apresenta valores de especificidade e sensibilidade suficientemente bons para ser usado em detrimento do teste ao frio.

Conclusão: Há uma maior SatO2 em dentes sem nenhuma superfície restaurada, comparativamente a dentes com pelo menos uma superfície restaurada. Para o teste elétrico nenhuma diferença estatisticamente significativa foi encontrada comparando dentes restaurados e não restaurados. O oxímetro de pulso é um método preciso, muito sensível e não invasivo que deve ser utilizado, caso tenhamos essa capacidade de investimento, como complemento do teste elétrico e do teste de sensibilidade ao frio.

Palavras-chave: *Teste elétrico da polpa (EPT), Oxímetro de pulso, Vitalidade da polpa, Teste da polpa, Endodontia, Diagnóstico, Oximetria, Trauma dentário.*

Abstract

Objective: The purpose of this study was to evaluate and compare pulse oximeter (PO) and electric pulp test method (EPT) to determine pulp vitality on healthy and restored permanent teeth.

Materials and Methods: 71 human volunteers were tested for the vitality of their healthy and restored teeth. Also, pulse rate and oxygen saturation readings were obtained from each subject's index finger, to verify proper function and to ensure the patient didn´t have systemic perfusion alterations. The teeth vitality was investigated with a specially modified probe (S906V Veterinary sensor SpO2 sensor DB9 Probe cable) and a pulse oximeter (ARSTN 2.8 TFT LCD handhled pulse oximeter H381V (certificate: CE/ISO13485)). The cold test was made using Roeko Endo Frost (Coltene, Germany) and the electric pulp test using the Dental Pulp Tester AZ310.

Results: Only a meaningful statistical difference was found related to PO test, restored vs healthy teeth. We obtained lower values of oxygen saturation in restored teeth when compared with healthy teeth. Canines required higher current to evoke a sensation compared to the other teeth. The risk score method has specificity and sensitivity values good enough to be able to rely over the cold test.

Conclusions: Higher $SatO_2$ for teeth without any surface restored was found when compared with teeth with at least one surface restored. For the electric test we found no statistical difference between restored and not restored teeth. Pulse oximeter is an objective, very sensitive and non-invasive method that should be used, if we have that investment capacity, as a complement of electric and cold sensibility tests as a routine method for assessing the pulp vitality.

Keywords: *Electric pulp tester (EPT), Pulse oximeter, Pulp vitality, Pulp test, Endodontics, Diagnosis, Oximetry, Dental trauma.*

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List of abbreviations and acronyms

EPT	Electric pulp tester
PO	Pulse oximetry
SpO2%	Oxygen saturation
CPT	Cold sensibility test
n	Frequencies
%	Percentages
SD	Standard deviations
Mdn	Medians
RS	Risk score

1.Introduction

The vitality of pulp is a function of the vascular supply of the pulp within a tooth, and pulpal circulation is a true determinant of pulp vitality. The assessment of pulpal status is a diagnostic challenge in clinical practice. An accurate diagnosis is crucial to achieve a good treatment outcome. An important part of the diagnosis procedure is pulp tests, which can help the clinician to reproduce the patient`s symptoms and chief complaint to differentiate normal and abnormal responses. For this purpose, various methods have been proposed including sensitivity and vitality tests. However, all sensitivity tests including electric pulp tests and cold sensibility tests are subjective and cause some discomfort for the patient. These tests assess the nervous response of the pulp rather than the pulp vascularity. Nervous tissues show high resistance to inflammation so they may respond to irritants after the degeneration of neighboring tissues. (1,2)

Electric pulp tester (EPT) should not be used to determine pulp status. There is no correlation between positive and negative responses to the EPT and the histological status of the pulp. A positive response 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 loss of these fibers. (3,4)

Therefore, new, improved diagnostic methods are needed to assist in the diagnosis of teeth with pulpal pathosis and consequently to aid in their correct treatment. Pulse oximetry (PO) is a non-invasive method for assessing blood flow in microvascular systems, which has been recently introduced as a new method to diagnose pulp vitality in human teeth (5). It is generally accepted that the evaluation of the blood supply within the dental pulp may be the only true indicator of the state of pulpal health. Higher oxygen saturation (SpO2%) readings are found in healthy, non-Inflamed pulps, while lower in Inflamed or necrotic pulps.

1.1 The EPT measurement technique

The electric test is performed with an electric pulp tester (EPT). This monopolar device flows high-frequency electrical current from the probe tip past the tooth. While the current is flowing through the tooth, viable A-delta nociceptive fibers will be stimulated (resulting in tingling or "zinging" sensation to the patient).

1.2 The PO measurement technique

Pulse oximetry is a relatively recent advancement in non-invasive monitoring of the patient`s oxygen saturation (SpO2) of the blood and pulse rate (5). Although, according to literature dental restorations influence oxygen saturation levels. (6)

This method uses a probe containing 2 light-emitting diodes; 1 transmits red light, and the other transmits infrared light to measure the absorption of oxygenated and deoxygenated hemoglobin, respectively. Oxygenated and deoxygenated hemoglobin absorb different amounts of red and infrared light. This light is received by a photodetector diode connected to a microprocessor. The pulsatile change in the blood volume causes periodic changes in the amount of red and infrared light. The relationship between the pulsatile change in the absorption of red light and infrared light is evaluated by the oximeter to show the saturation of arterial blood. It uses this information along with known absorption curves for oxygenated and deoxygenated hemoglobin to determine the oxygen saturation levels.

However, a critical requirement of the application of pulse oximetry in endodontics is that the probe should conform to the selected teeth`s shape and anatomic contours.

This technique may have the ability to be used as a suitable clinical method for pulp vitality evaluation. (2)

2. Objective and Hypotheses

The purpose of this study was to evaluate and compare pulse oximeter and conventional pulp testing method (EPT) to determine pulp vitality on healthy and restored permanent teeth. It was hypothesized that restorations influence pulp´s response to electrical tests and pulse oximetry.

3. 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.

71 human volunteers were tested for the vitality of their healthy and restored teeth. Also, pulse rate and oxygen saturation readings were obtained from each subject's index finger, to verify proper function and to ensure the patient didn´t have systemic perfusion alterations. The teeth vitality was investigated with a specially modified probe (S906V Veterinary sensor SpO2 sensor DB9 Probe cable) and a pulse oximeter (ARSTN 2.8 TFT LCD handhled pulse oximeter H381V (certificate: CE/ISO13485)). The cold test was made using Roeko Endo Frost (Coltene, Germany) and the electric pulp test using the Dental Pulp Tester AZ310.

3.1 The PO apparatus

Even being the ones that best adapts the human tooth, the probes used for vet readings cannot accommodate perfectly (Figure 1a). So, a probe holder developed for the tooth testing was designed (Figure 1b) to consider the selected teeth curvature and thus prevent false readings from the beam`s distortion as it passed through a convex surface. Thus, it can be used for all widths of teeth while maintaining parallelism and provide accurate measurements. (7,8)

Figure 1. PO apparatus (a and b).

3.2 The PO measurement procedures

Initially, the patient`s oxygen saturation levels (%SpO2) were recorded on the index finger and then the same was done, but on the selected tooth (Figure 2a).

After selecting the tooth, the dental probe was required to be placed against the crown (Figure 2b) in such a manner that the light could travel from the labial surface to the lingual surface through the middle of the tooth`s crown (Figure 2c).

The selected tooth could not be exposed to light, to avoid errors when crossed by the red light.

Figure 2. Oxygen saturation (%SpO2) levels on the index finger (a), dental probe placed against the crown of the tooth (b) and light travelling from the labial surface to the lingual surface through the middle of the tooth`s crown (c).

3.3 The EPT measurement procedures

The tooth that was measured, was protected from saliva with cotton rolls, then the surface of the tooth was blown until it was dry to prevent the stimulation of electric current to conduct from the gum, or else it would appear a false stimulus current (Figure 3a).

We hanged the stainless hook on any side of the mouth, then selected stimulation frequency (we selected middle speed for all teeth studied, except for teeth that didn't respond after the 40s, in that case we switched to high speed).

Before positioning on the tooth, the electrode was coated with toothpaste containing zync oxide (Colgate™ Total) to ensure electric conduction. The power switch was pressed, and then we laid the test electrode on the selected tooth surface. The electrode should be placed along the cervical half of the tooth (9). Afterward, the unit was activated and simultaneously the scale kept rising on the screen (Figure 3b).

When the patient slightly feels toothache or anesthesia, we proceed to take the test electrode away from the tooth and observe the number on the screen to record it. This number is the tooth´s stimulation current reaction number.

Figure 3. EPT (a) and EPT measurement procedure (b).

3.3.1 The EPT results meaning

The peak of the stimulus current reaction numerical value is 80.

According to the manual book of Dental Pulp Tester AZ310:

When the numerical value goes between 0-40, the patient who feels ache and a feeling like anesthesia, we can be assume that the nerve is still alive, so the tooth is healthy.

Only when the numerical value goes up to 40-80, the patient has the above-mentioned reaction, the dentist can be certain that part of the tooth has some alteration or pathology.

When the numerical value has reached 80, but the tooth has no above-mentioned reaction, this shows that we probably have a necrotic tooth.

3.4 The cold sensibility test measurement procedures

CPT was performed under relative isolation with cotton rolls. The teeth were dried. A refrigerant spray (Figure 4a) 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 4b). The spray jet was directed to a cotton swab and then applied on the tooth surface (Figure 4c) 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.

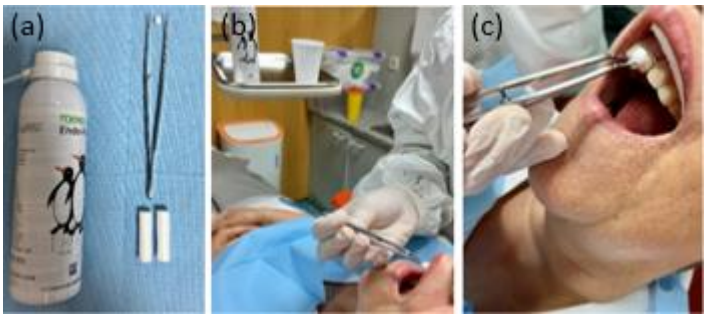


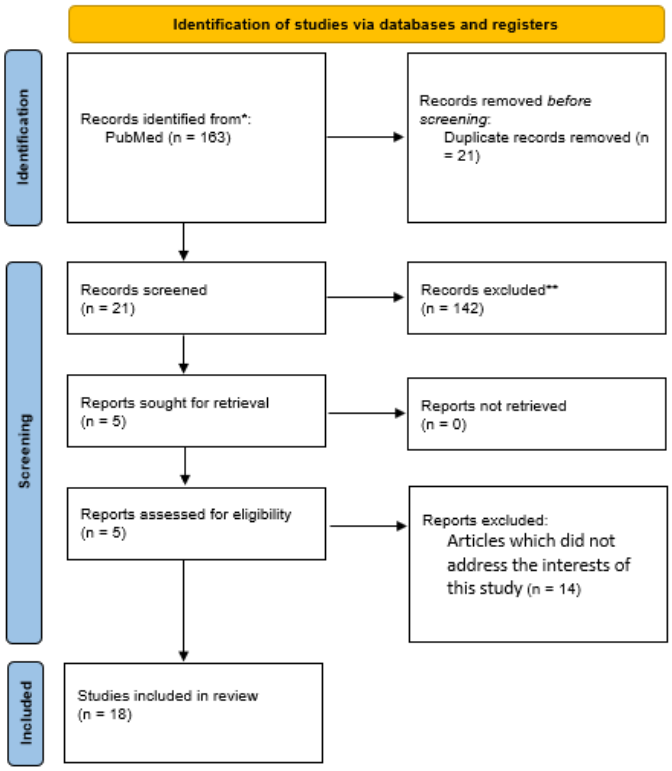
Figure 4. Cold sensibility test (a), cold sensibility test measurement procedure (b) and cotton ball freezed applied in the middle third of the tooth crown on the labial surface (c).

3.5 Information sources and search strategy

A bibliographic review was performed on PUBMED (via National Library of Medicine) considering such database includes the major articles in the field of endodontics. The following search terms were applied: “pulp vitality” OR “endodontic” AND “dental trauma” OR “dental diagnosis” AND “electric pulp test” OR “pulse oximeter” OR “pulp test”. Also, a hand-search was performed on the reference lists of all primary sources and eligible studies of this clinical study for additional relevant publications. The inclusion criteria encompassed articles published in the English language, from March 1969 up to January 2021, reporting pulse oximetry and electrical tests on healthy and restored permanent teeth. The eligibility inclusion criteria used for article searches also involved: *in vitro* studies; meta-analyses; randomized controlled trials; and prospective cohort studies. The exclusion criteria were the following: articles which did not address the interests of this study and articles which were not fully available online.

A total of 163 articles were identified, and 18 studies were included for the final review as shown in Table 1.

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



3.6 Study selection and data collection process

Studies were primarily scanned for relevance by title, and the abstracts of those that were not excluded at this stage were assessed. The total of articles was compiled for each combination of key terms and therefore the duplicates were removed using Zotero citation manager. The second step comprised the evaluation of the abstracts and non-excluded articles, according to the eligibility criteria on the abstract review. Selected articles were individually read and analyzed concerning the purpose of this study. At last, the eligible articles received a study nomenclature label, combining first author names and year of publication. The following variables were collected for this review: authors' names, journal, publication year, purpose, oxygen saturation (%SpO2), tooth´s stimulation current, tooth`s reaction time, electric pulp test, cold sensibility test, pulse oximetry test, main outcomes. PICO question was used with "P" related to the patients and "I" referred to the exposure, where we observed the patient´s teeth and collect the relevant information. Data of the reports were harvested directly into a specific data-collection form to avoid multiple data recording regarding multiple reports within the

same study (e.g., reports with different set-ups). This evaluation was individually carried out by two researchers, followed by a joint discussion to select the relevant studies.

3.7 Statistical analysis

Statistical analysis was executed in SPSS environment, 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. Oxygen saturation and teeth bpm had 15 missing values that we imputed by using a simple strategy of mean replacement considering teeth groups stratification. The same was done for two values of teeth bpm (bpm=206 e bpm=170) considered as faulty results. Hence, we replaced missing values for oxygen saturation and teeth bpm, respectively with 84, 76 (centrals), 86, 77 (laterals) and 82, 77 (canines). Missing imputation assumed missing's completely at random (MCAR), what does not alter oxygen saturation and teeth bpm global and stratified estimations.

Bifactorial ANOVAs were performed to assess the association of restored vs non restored teeth and teeth groups with the electric test, oxygen saturation and teeth bpm. Residual's normality was assessed with Komogorov-Smirnov test (n>50). Histogram was also observed. Variance's homoscedasticity was assessed with Levene test. Effect size was assessed with eta^2 (η^2), considering the following thresholds, as established by Cohen (1988): 0.01 (low), 0.06 (moderate) and 0.14 (high).

Binary logistic regression was used to create a risk score for detection pulp vitality, considering the cold test as dependent variable and oxygen saturation as predictor, when adjusted for other variables namely surfaces restored, electric test categories and teeth bpm. The novel risk score was then assessed via ROC curve. Sensitivity, specificity, and area under the curve were calculated and a cut-off was proposed.

The decision of significance was maintained at 5%. We also checked tendency for significance considering p<.10.

4. Results

We assessed a total of 354 teeth, 297 (83.9%) healthy and 57 (16.1%) with at least one surface restored from 71 patients, 47 (66.2%) females and 24 (33.8%) males, aged from 22 to 73 years old, mean 30.62 years (SD=13.33) (Table 2).

Table 2. Teeth features

Type of tooth	*n*	*%*
Centrals	**139**	**39.3%**
11	70	19.8%
21	69	19.5%
Laterals	**109**	**30.8%**
12	53	15.0%
22	56	15.8%
Canines	**106**	**29.9%**
13	54	15.2%
23	52	14.7%
Number of surfaces restored	*n*	*%*
0	297	83.9%
1	14	4.0%
2	16	4.5%
3	16	4.5%
4	11	3.1%

A total of 331 (93.5%) teeth had a positive result in the cold test. For those teeth, the median of the elapsed time was 1 second, (P25=1.0, P75=2.0), varying from 1 to 20 seconds. Results for the electric test were normal for 302 (85.3%) teeth; 29 (8.2%) had some pathology and 23 (6.5%) were necrotic. The electric test had a median of 6.0 (P25=2.0, P75=17.3), with a minimum of 1 and maximum of 80. Mean of oxygen saturation (% SpO_2) was 84.01 (SD=13.36), ranging from 2% to 99%. Oxygen saturation categories were pulp vitality (53.4%), reversible pulpitis (19.2%), irreversible pulpitis (18.6%) and pulp necrosis (8.8%). Mean teeth bpm was 75.97 (SD=8.95), varying from 60 to 93 (Table 3).

Table 3. Teeth assessments

Cold test	
Negative	23 (6.5%)
Positive	331 (93.5%)
Time (a)	1.0 (1.0 – 2.0) [1-20]
Electric test	6.0 (2.0 – 17.3) [1-80]
Normal (<40)	302 (85.3%)
Some patology (40-79)	29 (8.2%)
Necrotic (≥ 80)	23 (6.5%)
Oxygen saturation (% SpO_2)	84.01 (13.36) [2-99]
Pulp vitality (95-86)	189 (53.4%)
Reversible pulpitis (85-82)	68 (19.2%)
Irreversible pulpitis (81-71)	66 (18.6%)
Pulp necrosis (<71)	31 (8.8%)
Teeth bpm	75.97 (8.95) [60-117]

(a) Calculated for positive cold tests; 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

Table 4 show descriptive results for electric test, oxygen saturation and teeth bpm along with bifactorial ANOVAs considering the association of restored surface and teeth group. For the electric test no associations were found with restored surface (p=.072), teeth group (p=.080) and restored surface x teeth group (p=.207). Considering the oxygen saturation, significant differences were found for the restored surface, $F_{(348,1)}$=12.02 (p=.001), η^2=0.33, with high effect size, suggesting higher $SatO_2$ for teeth without any surface restored (M=85.08, SD=12.17), compared with teeth with at least one surface restored (M=78.40, DP=17.42). No other significant differences were found for oxygen saturation, considering teeth group (p=.116) and restored surface x teeth group (p=.840). For teeth bpm, no significant differences were found when comparing for restored surface (p=.096), teeth group (p=.526) and restored surface x teeth group (p=.207). Residuals normality and variances homoscedasticity were verified and confirmed.

Mean results can be also observed in Figures 5, 6 and 7. Despite the absence of significant results, canines seem the have higher result for the electric test (Figure 6), partially corroborated by a marginal significant result (p=.080); also teeth with at least

one surface restored showed higher mean result of the electric test, marginally significant at p=.072 (Table 4). A marginal significant result was also found for teeth bpm when comparing teeth with and without any restored surface, higher in the last (p=.096).

Table 4. Bifactorial ANOVAs

	Teeth group	***Electric test***	***Oxygen saturation***	***Teeth bpm***
Restored surface				
No	Centrals (n=107)	6.93 (13.31)	86.20 (9.11)	74.80 (8.44)
	Laterals (n=90)	10.59 (18.66)	87.07 (7.61)	75.97 (8.11)
	Canines (n=100)	26.81 (25.90)	82.10 (16.97)	77.89 (9.97)
	Total (n=297)	14.73 (21.66)	85.08 (12.17)	76.19 (8.96)
Yes	Centrals (n=32)	20.81 (28.16)	78.06 (16.23)	74.97 (9.37)
	Laterals (n=19)	20.58 (24.40)	80.84 (20.41)	76.16 (8.19)
	Canines (n=6)	23.17 (30.62)	72.50 (14.21)	69.67 (8.04)
	Total (n=57)	20.98 (26.73)	78.40 (17.42)	74.81 (8.91)
Total	Centrals (n=139)	10.12 (18.67)	84.32 (11.61)	74.84 (8.63)
	Laterals (n=109)	12.33 (20.02)	85.98 (11.08)	76.00 (8.09)
	Canines (n=106)	26.60 (26.04)	81.56 (16.91)	77.42 (10.03)
F tests				
Restored surface		$F_{(348,1)}$=3.25 (p=.072) η^2=0.01	**$F_{(348,1)}$=12.02 (p=.001) η^2=0.33**	$F_{(348,1)}$=2.79 (p=.096) η^2=0.01
Teeth group		$F_{(348,1)}$=2.54 (p=.080) η^2=0.01	$F_{(348,1)}$=2.17 (p=.116) η^2=0.01	$F_{(348,1)}$=0.64 (p=.526) $\eta^2\approx$0.00
Restored surface x teeth group		$F_{(348,1)}$=1.58 (p=.207) η^2=0.01	$F_{(348,1)}$=0.17 (p=.840) $\eta^2\approx$0.00	$F_{(348,1)}$=1.58 (p=.207) η^2=0.01

Results presented as M (SD)

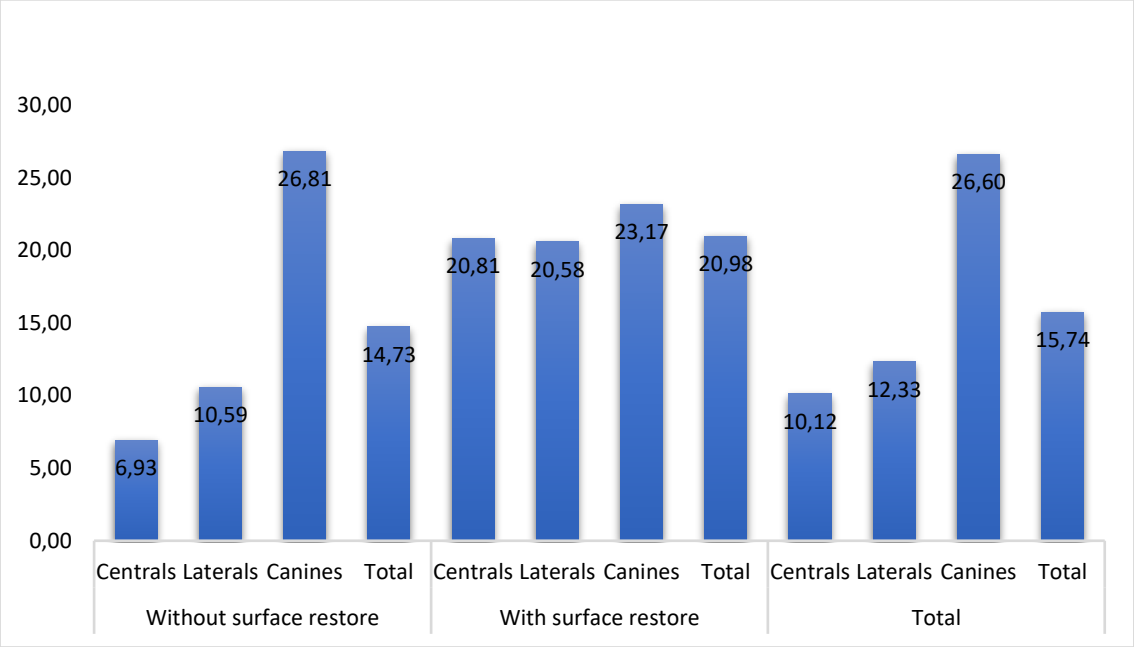


Figure 5. Electric test distribution according to restore and teeth group

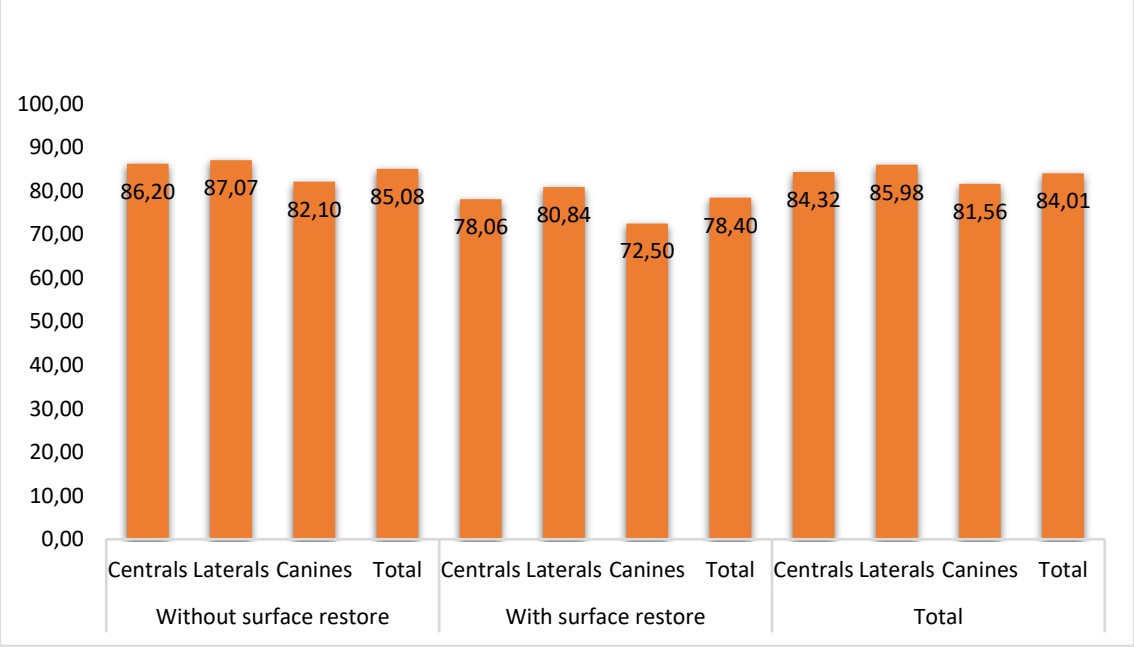


Figure 6. Oxygen saturation distribution according to restore and teeth group

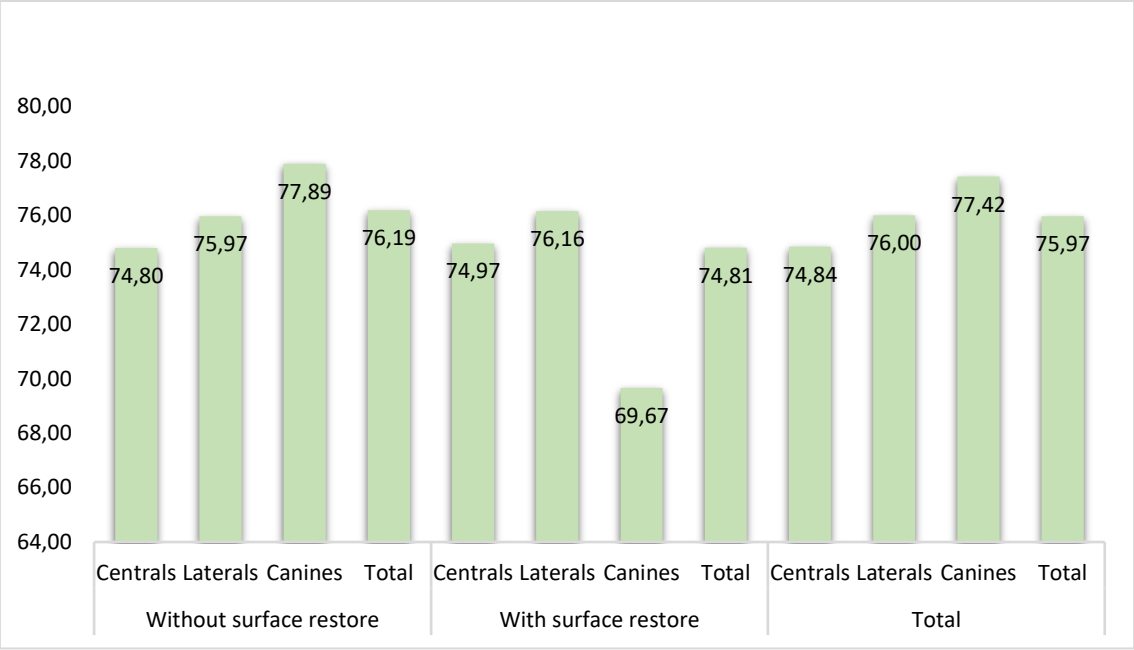


Figure 7. Teeth bpm distribution according to restore and teeth group

Next, logistic regression was implemented to assess the chance of negative cold test based on oxygen saturation, and then adjusted for the number of surfaces restored, electric test and teeth bpm.

Univariate logistic regression showed significant associations with oxygen saturation, namely irreversible pulpitis (81-71), with 3 times more chance of negative cold test (OR=3.09, p=.042) when compared with normal pulp. Pulp necrosis (<71) showed 5 times more chance of negative cold test (OR=5.00, p=.010), when compared with normal pulp. However, when adjusted for the other variables, oxygen saturation lost its statistical significance. The number of surfaces restored was associated with a negative result on the cold test, namely for 3 restored surfaces compared to none (OR=31.63, p=.001). The electric test was the most associated with the cold test with about 27 times more chance of a negative result for some pathology (OR=27.05, p<.001) and 423 more chance of a negative result for a classification of necrotic teeth (OR=423.43, p<.001).

Table 5. Multivariate logistic regression

	Coef.	***OR***	***95% CI***	***p-value***
Oxygen saturation (% SpO_2)				
Pulp vitality (95-86)		1	1	1
Reversible pulpitis (85-82)	0.31	1.36	0.24 – 7.87	p=.731
Irreversible pulpitis (81-71)	-0.21	0.81	0.12 – 5.59	p=.833

Pulp necrosis (<71)	-0.97	0.38	0.04 – 3.60	p=.399
Number of surfaces restored				
0		1	1	1
1	2.36	10.57	0.79 – 141.80	p=.075
2	2.58	13.23	0.90 – 193.81	p=.059
3	3.45	31.63	3.79 – 263.83	p=.001
4	1.92	6.80	0.20 – 159.35	p=.234
Electric test				
Normal (<40)		1	1	1
Some pathology (40-79)	3.30	27.05	4.22 – 173.41	p=.001
Necrotic (≥ 80)	6.05	423.43	61.75 – 2903.40	p<.001
Teeth bpm	-0.07	0.93	0.85 – 1.02	p=.138

A risk score was then created by adding the coefficients of each category when existent in the patient. All variables contributed with their coefficients, regardless of their statistical significance. Risk score distribution was used as test variable for the ROC curve for determining cut-off values considering the cold test as state variable for diagnostic of pulp vitality. Figure 8 shows the risk score distribution.

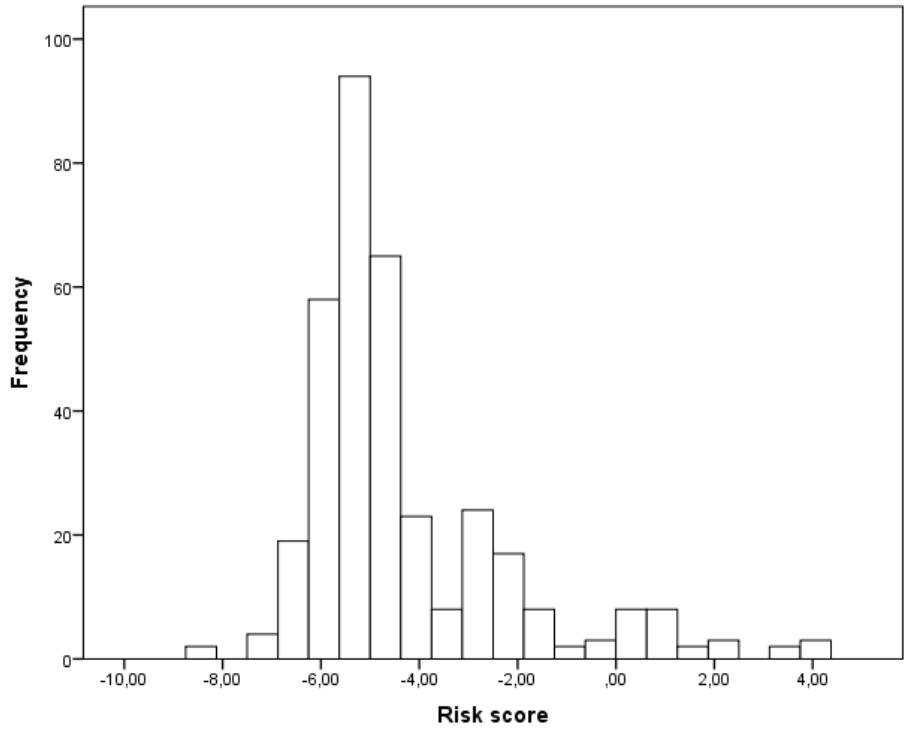


Figure 8. Risk score distribution

Finally, sensitivity and specificity of the risk score (RS) was assessed. With an area under the curve of 95.3%, suggesting excellent precision, we propose RS > -2.12 for detecting a negative cold test with sensitivity of 95.7% and specificity of 92.4%.

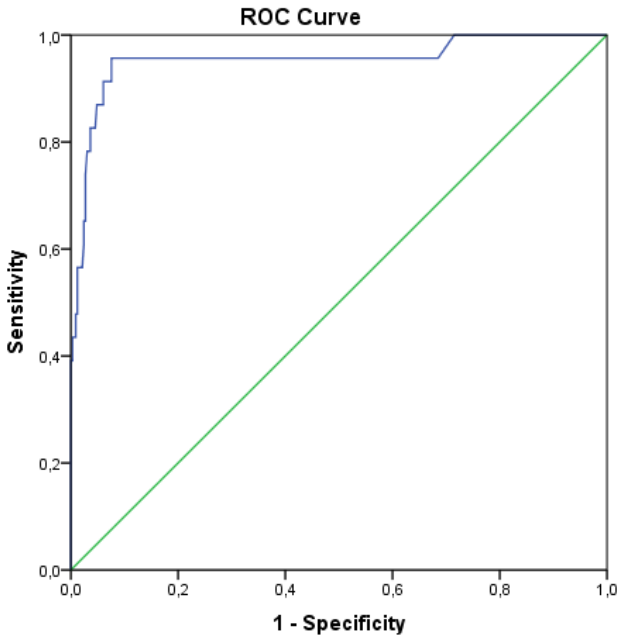


Figure 9. ROC curve for the risk score

Cohen, J (1988). *Statistical power analysis for the behavioral sciences* (2nd ed.). Hillsdale, NJ: Erlbaum.

5. Discussion

The assessment of pulpal status accurately is important to achieve a good treatment outcome. All conventional vitality tests determined functioning of the nerves. The nerve response to stimulus may not be the true determinant of the pulp vitality as the life of the pulp tissue is dependent on the blood supply and not on nerve functioning, thus are not indicative of the vitality of a pulp. (1)

The results of the present study support the hypothesis that restorations influence pulp´s response to electrical tests and pulse oximetry.

First of all, different values for healthy teeth and restored teeth ensured an important correlation. Between the pulp and oxygen saturation readings, as well as a 100%

correlation between the histological and clinical diagnosis of the pulp vitality, as stated by Wallace and Schnettler. (10)

Anterior teeth were selected because the greater frequency of traumatic injuries to these teeth results in a frequent need for methods to diagnose their pulp status. Using pulse oximetry to assess the degree of oxygen saturation of a central incisor after a traumatic dental injury offers more accurate diagnosis of the actual conditions of vascular pulp tissue. Moreover, it is easier to interpret the results of readings when dealing with teeth with flat surfaces and greater cervical-incisal length.

Considering the association of restored surface and teeth group, we only found a meaningful statistical difference related to PO test, restored vs healthy teeth. We obtained lower values of oxygen saturation in restored teeth when compared with healthy teeth. The reasons for this could be the scattering of the light (transmitted from PO) from the composite restorations to the adjacent tissues (gingiva, etc.) and the physical limitations of PO. (5,6)

The findings of this study have shown that the oxygen saturation levels were inversely proportional to the severity of the disease, teeth with pulp necrosis, irreversible pulpitis, reversible pulpitis and normal pulp vitality show increasing values, respectively.

There was no significant statistical correlation between the values obtained for blood oxygen saturation between the tooth and those obtained for the index finger of the patient. (11)

In our study, the oxygen saturation levels of the index finger were higher than in the tested teeth. These findings are in accordance with previous studies (12,13). The explanation of the higher oxygen saturation in the index finger compared to the teeth could be that the diffraction of the red and infrared lights by the tooth enamel and dentin can cause a decrease in the measured values.

Moreover, in this study, canines required higher current to evoke a sensation compared to the other teeth. This may be explained by their thicker dentin compared to the other teeth and the pulp chamber size could be another factor. A greater electrical current is needed to produce a response in teeth with large pulps than in teeth with small pulps. This observation is supported by the findings that canines, which have relatively large

pulps, have a higher response threshold than do teeth with relatively small pulps, such as lateral and central incisors. (14,18)

According to EPT, we placed the electrode along the cervical half of the tooth but when compared with other studies which electrode was placed in the incisal region, our results show higher values. This may be explained due to the lower concentration of neural elements, which decreases progressively form incisal edge to the cervical and radicular areas. It may be that threshold values are related to the course of dentinal tubules. (14–17)

To create a non-invasive and more comfortable method for the patient, we started from the premise that the cold test would be the gold-standard. So, it would be the most accepted criterion to determine the diagnosis (reversible or irreversible pulpitis).

We tried to determine if there would be a risk score that would calculate the vitality of the pulp without inconvenience to the patient, without the need to subject the patient to the discomfort associated with the cold test.

Logistic regression was implemented to assess the chance of negative cold test based on oxygen saturation, and then adjusted for the number of surfaces restored, electric test and teeth bpm. Irreversible pulpitis showed 3 times more chance of negative cold test when compared with normal pulp and pulp necrosis showed 5 times more chance of negative cold test, when compared with normal pulp.

A risk score was then created by adding the coefficients of each category when existing in the patient. Basically, when the patient arrives at the appointment, we record the oxygen saturation, the number of surfaces restored, the electrical test value and the bpm value. Adding all these values we get the patient's score.

After that, we calculated the sensitivity and specificity for the obtained score and we concluded that using this risk score we get almost perfect values, we make a minimum error of 4.3% for sensitivity and 7.6% for specificity.

So, with the investment capacity to assess oxygen saturation in clinical practice, together with the other variables (number of surfaces restored, electric test and teeth bpm), the specificity and sensitivity values are good enough to be able to rely on the risk score over

the cold test. This provides a more comfortable diagnosis and ensures the patient's well-being.

6. Conclusions

Within the limitation of this study, the following conclusions can be drawn:

- This study confirms the potential use of pulse oximetry as a test for pulp vitality and demonstrated that the method determined the level of blood oxygen saturation of the pulp;
- Oxygen saturation levels were inversely proportional to the severity of the disease;
- There was no statistical correlation between the level of blood oxygen saturation obtained from the index finger and that obtained from the teeth of patients;
- Considering the oxygen saturation, a meaningful statistical difference was found, suggesting higher $SatO_2$ for teeth without any surface restored, compared with teeth with at least one surface restored. For the electric test we found no statistical difference between restored and not restored teeth. Our findings are concordant with literature in confirming that dental restoration may hinder the passage of the light from the oximeter;
- Risk score suggested excellent precision, we propose RS > -2.12 for detecting a negative cold test with sensitivity of 95.7% and specificity of 92.4%;
- Pulse oximeter is an objective, very sensitive and non-invasive method that should be used, if we have that investment capacity, as a complement of electric and cold sensibility tests as a routine method for assessing the pulp vitality;
- 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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Attachments

1.

CESPU
INSTITUTO UNIVERSITÁRIO
DE CIÊNCIAS DA SAÚDE

Comissão de Ética

Exmo. Senhor Investigador
Paulo Manuel Cruz Miller

N/Ref.*: 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, CrI, no dia 17/06/2021.

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

Com os melhores cumprimentos.

CESPU
Rua Central de Gandra, 1317
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T. +351 224157100 • F. +351 224157101

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

CESPU

2.

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

1

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

2