J Oral Res
research in oral sciences

ARTICLE

COMPARATIVE EVALUATION OF DENTAL PULP TESTS IN PULPAL STATUS DIAGNOSTICS.

Evaluación comparativa de pruebas de pulpa dental en el diagnóstico del estado pulpar.

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CITE AS:
Campos RE, Filho PCFS, Resende EF, Oliveira LV & Ambrosano GMB. Comparative evaluation of dental pulp tests in pulpal status diagnostics. J Oral Res.2022;11(2):1-11. doi:10.17126/joralres.2022.014

ABSTRACT:

Introduction: The purpose of this study was to evaluate the effectiveness and compare the accuracy of pulp tests in the diagnosis of teeth pulpal health.

Material and Methods: Traumatized (n=71) and non-traumatized (n=71) teeth from 42 patients were evaluated. Each tooth underwent cold, heat, electric and oximetry tests, followed by radiographic examination and calculation of the sensitivity, specificity, PPV, NPV and accuracy.

Results: Clinical and radiographic examination showed no alteration for the 71 teeth from the intact contralateral group. From the traumatized group, 29 teeth presented complete endodontic treatment, 17 presented periapical alterations that required endodontic treatment and 25 teeth did not present conclusive radiographic alteration. The cold test showed a significantly higher proportion of correct results, while the electric test showed a significantly lower proportion. The data showed higher accuracy for the cold, followed by oximeter and heat tests, while the electric test presented the lowest accuracy. Cold and oximeter tests proved superior over the electric and heat tests, while the electric test showed better parameters when diagnosing diseased pulp.

Conclusion: Combining two pulp tests seems reasonable for improving the pulp diagnoses using both oximeter and cold or oximeter and heat tests to detect healthy pulp; or cold and electric tests to define diseased pulp.

KEYWORDS:

Dental pulp disease; Diagnosis; Pulp Test; Sensitivity and Specificity; Comparative study; Humans.

Received: 11 July 2021 | **Accepted: 01** October 2021 | **Published online:** 30 April 2022.

ISSN Print 0719-2460 - **ISSN Online** 0719-2479. **www.joralres.com/2021**

RESUMEN:

Introducción: El propósito de este estudio fue evaluar la efectividad y comparar la precisión de las pruebas pulpares en el diagnóstico de la salud pulpar de los dientes.

Material y Métodos: Se evaluaron dientes traumatizados (n=71) y no traumatizados (n=71) de 42 pacientes. Cada diente se sometió a pruebas de frío, calor, eléctricas y de oximetría, seguidas de examen radiográfico y cálculo de la sensibilidad, especificidad, VPP, VPN y precisión.

Resultados: El examen clínico y radiográfico no mostró alteración en los 71 dientes del grupo contralateral intacto. Del grupo traumatizado, 29 dientes presentaron tratamiento endodóntico completo, 17 presentaron alteraciones periapicales que requirieron tratamiento endodóntico y 25 dientes no presentaron alteración radiográfica concluyente. La prueba en frío mostró una proporción significativamente mayor de resultados correctos, mientras que la prueba eléctrica mostró una proporción significativamente menor. Los datos mostraron mayor precisión para la prueba de frío, seguida de las pruebas de oxímetro y calor, mientras que la prueba eléctrica presentó la menor precisión. Las pruebas de frío y oxímetro demostraron ser superiores a las pruebas eléctricas y de calor, mientras que la prueba eléctrica mostró mejores parámetros al momento de diagnosticar pulpa enferma.

Conclusión: La combinación de dos pruebas pulpares parece razonable para mejorar los diagnósticos pulpares utilizando tanto el oxímetro como las pruebas de frío u oxímetro y calor para detectar una pulpa sana; o pruebas de frío y eléctricas para definir pulpa enferma.

PALABRAS CLAVE:

Enfermedades de la Pulpa Dental; Diagnóstico; Prueba de la Pulpa Dental; Sensibilidad y Especificidad; Estudio Comparativo; Humanos.

INTRODUCTION.

The occurrence of dental trauma is very high, and the correct approach to treat the pulp is rarely decided immediately after the trauma because the pulp conditions may change over time.[1-3] However, an earlier diagnosis may prevent complications. Patient history, clinical examination, specialized tests, and radiological examination all contribute to properly diagnosing trauma.[4]

The prognosis of the pulp condition is difficult to determine, but it is favorable when the pulp vitality and sensibility are preserved. Sensibility is defined as the ability to respond to a stimulus, whereas vitality implies that a blood supply is present within the tissue.[5] Pulp sensibility tests (thermal and electric) have been used to indirectly determine the pulpal status by assessing the condition of the nerves within the dental pulp.[6-9]

Sensibility test results must be carefully interpreted because they are subjective in nature and both operator- and patient-dependent.[10]

Therefore, consideration of the patient's responses to different testing modalities by the professional is fundamental for understanding and interpreting different diagnostic methods.[11] While sensibility tests are simple and non-invasive, they are not entirely reliable.[12-14] Tests of pulp vitality (*e.g.*, laser Doppler flowmetry (LDF) and pulse oximetry) have been introduced in dental practice to bypass patient perceptions and directly evaluate the blood within the dental pulp.[3,15]

LDF measures the actual flow of blood through the vasculature, whereas pulse oximetry measures the oxygen saturation of arterial blood in a tissue.[10] It is generally accepted that assessment of the blood supply within the dental pulp is the earliest indicator —and may be the only available true indicator— of the actual pulpal status.[16] Immediately after the trauma, sensibility tests commonly

yield false-positive and false-negative responses because injuries can temporarily disable the sensory nerves.[17]

In these cases, the microcirculatory components of the dental pulp may remain normal[12] and respond positively to vitality tests. On the other hand, since the nerve fibers of the pulp are relatively resistant to necrosis,[18] the diseased pulp may continue to respond to sensibility tests, even when its other constituents have degenerated.[19] The power of a test to separate diseased from healthy pulp may be measured in terms of the test's sensitivity, specificity, predictive values, and accuracy.[20,21]

Sensitivity is the ability of a test or technique to identify diseased pulp (without sensibility/vitality), whereas specificity is the ability of a test to identify healthy pulp (with sensibility/vitality).[11,22] The predictive value is the ability of a test to predict the actual diagnosis. The positive predictive value (PPV) is the probability that a positive test result actually represents a diseased pulp, whereas the negative predictive value (NPV) is the probability that a negative test result actually corresponds to a tooth with healthy pulp.[5]

The accuracy of a test is its ability to correctly differentiate between diseased and healthy pulp. To estimate the accuracy of a test, the proportion of true positives and true negatives should be calculated in all the evaluated cases.[22]

Data from the literature indicate that the LDF and pulse oximetry dental pulp tests are the most accurate and the heat pulp test is the least accurate,[23-26] whereas the cool pulp test possesses generally high diagnostic accuracy and is considered the primary pulp testing method in clinical practice.[26-28]

In general, pulp tests are more valid when identifying healthy pulp teeth relative to teeth with diseased pulp.[11] In reality, as the accuracy of a test varies in different situations,[22] each method of pulp testing has its place and these tests are often complementary.[5]

Therefore, the purpose of this study was to show that any test is actually effective in the diagnosis of the pulpal status. The null hypothesis was that there was no difference among the tests in the diagnosis of the pulpal status.

MATERIALS AND METHODS.

The study has been independently reviewed and approved by Research Ethical Committee (CEP-UFU, Protocol # 447/10) of the Federal University of Uberlândia. After the approval, the files from the Clinic of Dental Traumatism of the School of Dentistry were accessed by one operator and searched for people who were treated at the Clinic for dental trauma from the 2011 to 2015 year.

The patients were contacted and invited to take part in the study. Prior to study initiation, the understanding and write consent was obtained from the patients who agreed to take part in the research. Participation was voluntary and declining to participate did not affect patient care.

Those who consented to participate in the study first underwent examination of the contralateral and traumatic teeth to determine if they fit any of the exclusion criteria, namely, color alterations, mobility, carious teeth, large restorations, periodontal disease, immature teeth, or if the patients were aged below 18 and above 60 year. From 42 patients, 142 single- and two-roots teeth were selected and separated into 2 groups: intact contralateral teeth (n=71) and traumatic teeth (n=71).

It must be highlighted that the test performer did not know the pulpal status before testing and that all intact and traumatized teeth were radiographed after testing to define the real pulpal status. Each of the teeth underwent three sensibility tests (cold, heat, and electric) and a vitality test (pulse oximetry), randomly performed by a second blinded operator and alternately applied first in the contralateral and then in the traumatic tooth. When the sensibility tests were performed in the contralateral tooth, the patient was asked to respond by raising a hand as soon as the sensation was perceived and to memorize it as a reference for the tests in the experimental teeth.

All the tests were performed at the minimum 5-min intervals[19,27] using rubber dam isolation and polyester strips separating the tested tooth. For the electric test, a Pulp Tester (NTC 101 D, ODOUS COML Ltd and Gesund Bio Engenharia Belo Horizonte, MG, Brazil) was used by placing the probe on the labial surface of the tooth, which was lubricated with toothpaste.

When in contact with the tooth, the device turned on automatically and the intensity of the electric current increased slowly up to the moment the patient signaled

by hand, at which point the numerical reading was recorded.[25] The pulp was considered to be healthy if the patient gave a verbal response similar to that given for the contralateral tooth (ranging from 10 and 50) and diseased if no response was given at the maximum intensity of the tester devices, *i.e.*[8]

The cold test was performed using a cotton pellet soaked with Endofrost –50°C (Roeko, Langenau-Alemanha), whereas the heat test used gutta-percha cylinders heated with a naked flame until they were soft and shiny. Both thermal tests were applied on the middle third of the tooth's facial surface for 10 s.4 The tooth surface was coated with Vaseline for the heat test.

The pulse oximetry test was performed using a CMS 60°C TFT Color Pulse Oximeter (CONTEC Medial Systems Ltd, Qinhuangdao, China) connected to a sensor for dental use. The sensor was adapted to be compatible in size with the tooth and to enable parallelism between the emitting diode on the middle third of the facial surface and the receiving diode on the lingual surface. Before testing the tooth, the oxygen saturation in the patient's finger was recorded to check appropriate device function.

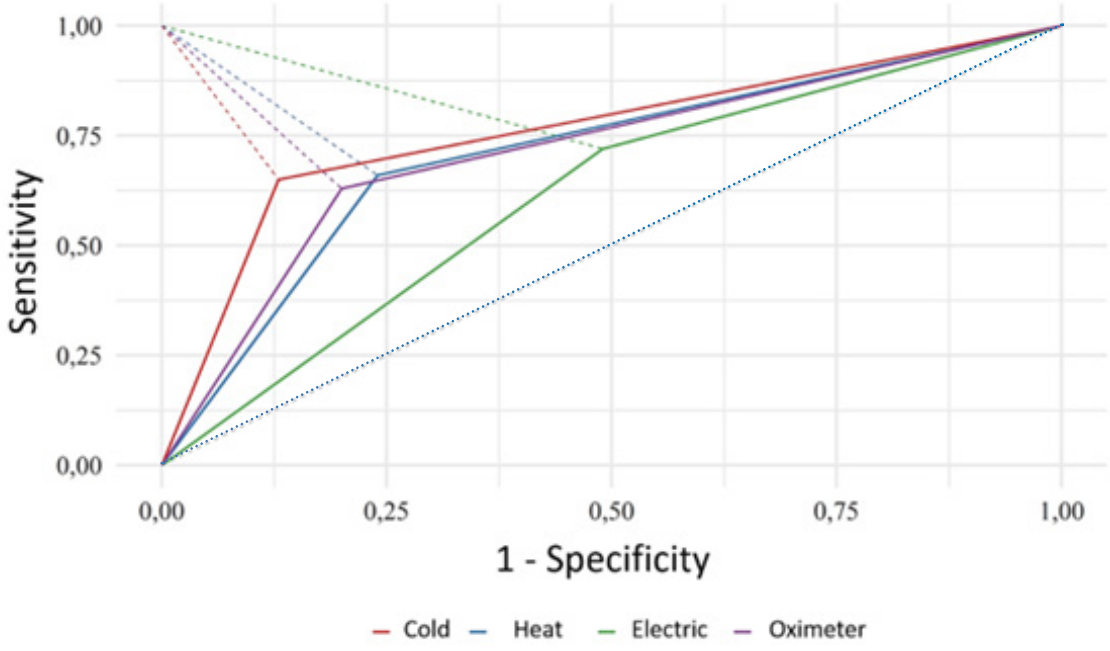
Then, the pulp tester was positioned on the tooth crown, *i.e.*, not in contact with soft tissue, and the patient was instructed to remain still during the test. The test was performed three times on each tooth to avoid extrinsic interferences, and the pulp vitality was considered for oxygen saturation values between 75% and 85%.[3] After concluding the tests all the teeth were submitted to radiographic examination by the first operator in the search for signals of pulp alterations. The sensitivity, specificity, PPV, NPV and accuracy within each test were calculated (Table 1) and the data were submitted to the McNemar and Kappa test at the 5% confidence level (α=0.05) to investigate the agreement of each test with the reference standard (intact contralateral group).

RESULTS.

Original quantity of positive and negative responses within each test is presented. (Table 2)

After clinical and radiographic examination no alteration was observed for the 71 teeth from the intact contralateral group. From the traumatic group, 29 teeth presented com-plete endodontic treatment, 17 presented

Figure 1. Comparative accuracy among the tests using the ROC curves.



ISSN Print 0719-2460 - ISSN Online 0719-2479.

Table 1. Formulas used for calculation of pulp tests parameters.

		TRUTH		
		Traumatized teeth	Intact teeth	Total
TESTED	Positive	TP	FP	TP+FP
	Negative	FN	TN	FN+TN
	Total	TP+FN	FP+TN	TP+FP+FN+TN

TP: True Positive. **FP:** False Positive. **FN:** False Negative. **TN:** True Negative. **Sensitivity:** TP/TP+FN; Specificity=TN/FP+TN; **PPV:** TP/TP+FP. **NPV:** TN/FN+TN. **Accuracy:** (TP+TN)/(TP+TN+FP+FN).

Table 2. Original number of positive/negative responses within each test used for calculation of test parameters.

	COLD			HEAT			ELECTRIC			OXIMETER		
	Traumatized teeth	Intact teeth	Total	Traumatized teeth	Intact teeth	Total	Traumatized teeth	Intact teeth	Total	Traumatized teeth	Intact teeth	Total
Positive	46	9	55	47	17	64	51	35	86	45	14	59
Negative	25	62	87	24	54	78	20	36	56	26	57	83
Total	71	71	142	71	71	142	71	71	142	71	71	142

Table 3. Tests parameters values, McNemar (*p*) and Kappa (k) results within each group.

PARAMETER	TEST			
	Cold (*p*=0.0061)* (*k*=0.52) (%)	Heat (*p*=0.2743) (*k*=0.42) (%)	Electric (*p*=0.0431) a (*k*=0.22) (%)	Oximeter (*p*=0.0578) (*k*=0.43) (%)
SENSITIVITY	65	66	72	63
SPECIFICITY	87	76	51	80
PPV	84	73	59	76
NPV	71	69	64	69
ACCURACY	76	71	61	72

*: True Positive. **a:** Proportion of correct results significantly decreased. **PPV:** Positive predictive value. **NPV:** Negative predictive value.

Table 4. Comparison among results of pulp tests from this study and others reported in the literature.

PARAMETER	TEST													
	Cold				Heat			Electric				Oximeter		
	This study	Ref 6 (%)	Ref 20 (%)	Ref 24 (%)	This study	Ref 20 (%)	Ref 24 (%)	This study	Ref 6 (%)	Ref 20 (%)	Ref 24 (%)	This study	Ref 20 (%)	Ref 8 (%)
SENSITIVITY	65	84	87	88	66	78	86	72	82	72	76	63	97	93
SPECIFICITY	87	88	84	100	76	67	100	51	88	93	100	80	95	100
PPV	84	93	81	100	73	62	100	59	93	89	100	76	94	---
NPV	71	73	87	90	69	79	89	64	71	80	83	69	99	---
ACCURACY	76	85	84	94	71	72	93	61	84	82	89	72	97	---

PPV: Positive predictive value. **NPV:** Negative predictive value.

periapical alterations that required endodontic treatment and 25 teeth which did not present radiographic alteration had the pulpal status considered as healthy. Results of all calculated parameters, McNemar (*p*) and Kappa (*k*) values within each group are presented. (Table 3)

The McNemar test indicated a statistically significant difference for the cold test (p=0.0061) indicating higher proportion of correct results (83.6%). Significant difference was also indicated for the electric test (p=0.0431), but with a lower proportion of correct results (59.3%). No differences were found for the heat (p=0.2743) and oximeter (p=0.0578) tests.

The Kappa values ranged from 0.22 (fair agreement) to 0.52 (moderate agreement), which indicated low levels of agreement between sensitivity and specificity. The graphic comparison among the tests using the ROC curves is shown. (Figure 1)

Once the real pulpal status from each tooth was defined after clinical and radiographic examination, comparisons were made with each test response in order to define the level of false responses for each test. Within the intact group all pulp statuses were considered healthy and the incidence of false negative responses was 10.3% for cold, 22.3% for heat, 69.0% for electric and 17.4% for oximetry test.

Within the traumatized group, for the 29 teeth with endodontic treatment no false positive responses were recorded. For the 17 teeth presenting periapical alterations thus requiring endodontic treatment there was 11.1% of false positive response for cold and heat while 10.5% were observed for electric and oximeter tests. For the 25 traumatized teeth with pulpal status considered healthy, 4% of false negative responses were observed for cold, 68% for electric and 16% for oximetry test. No false negative for the heat test was recorded.

DISCUSSION.

The current gold standard for determining the actual pulpal status is histological examination of the dental pulp, which requires tooth extraction.

Unlike the gold standard, a reference standard does not necessarily identify the target condition with 100% accuracy,[15] as the accuracy of a test varies for different diseases and in different contexts.[22] A critical review of the literature suggests that LDF is the most accurate diagnostic method for determining the pulpal status and came close to serving as the gold standard.[15]

However, the routine use of LDF is expensive, time-consuming, and not readily available to most professionals. Therefore, this study focused on the tests that are most frequently used for diagnosing pulpal status and the reference standard was based on the results from the intact contralateral group. As the McNemar statistical analysis showed a significant difference for the cold and electric tests, the null hypothesis was partially rejected. The cold and oximeter tested results did not differ from the results expected as reference standard, *i.e.*, the results from the pulp tests were likely to detect the actual pulpal status.

Pulp vitality testing proved superior to pulp sensibility testing for early and accurate assessments of the pulpal status of traumatized teeth.[15] However, given that pulp tests are not entirely effective at identifying teeth with pulp disease, comparisons within sensibility and between the sensibility and vitality tests may help in the diagnosis of pulpal status. Due to the ease of use and low cost, thermal tests are believed to be the most common tests used in dental practice. Responses to thermal stimuli are based on hydrodynamics and, therefore, require that dentinal tubules be open to allow fluid flow, according to hydrodynamic theory.[6]

The electric test requires a device to stimulate the nerve fibers by applying an electric current. The shortcomings of the thermal and electric tests are their dependence on subjective responses from patients and the difficulty of interpreting their results, resulting in a high number of false-positive and false-negative responses. A comparison between the results from the current study and those of three other studies reported in the literature is presented. (Table 4)

Compared to our results, the results from the three compared sensibility studies (Table 4) showed mostly higher values, for all the parameters, for the cold test, followed by the electric and heat tests. When comparing the sensibility tests with the oximeter test, the oximeter results were generally higher for all the parameters.

Although few complete investigations of pulse oxi-

ISSN Print 0719-2460 - ISSN Online 0719-2479.

meters are found in the literature, the oximetry results appear to be superior to those of the sensibility tests. However, the oximeter test must be performed in a more meticulous fashion concerning the occurrence of false-positive responses. Most of the values observed in the current study were lower than those of the other studies presented. (Table 4)

The comparison shows that results can vary from study to study; it must be noted that each study was performed with different populations, diseases, and contexts. For example, as the 71 teeth from the intact contralateral group lacked clinical and radiographic alterations, a 100% specificity and NPV were expected for all the tests. However, healthy pulp may not respond to the test (false-negative) or diseased pulp may respond to the test (false-positive). The intrinsic differences between tests, the patients' subjective responses, patient ages, aged pulps with reduced volumes, immature teeth, and types of dentition and trauma are some factors that may affect the test results. Therefore, instead of simply comparing the results with those of other studies, it would be better to evaluate the results within the study.

The data presented (Table 3) indicated that the cold test had the highest accuracy (76%), followed by the oximeter (72%), heat (71%), and electric (61%) tests. The cold test showed a 65% sensitivity rate and 84% PPV rate, which indicated that it moderately detected a diseased pulp but had high precision. The electric sensitivity (72%) was the highest among all the tests but the 59% PPV was the lowest, which demonstrated moderate occurrence of false-negative responses. Both the heat and oximeter tests presented moderate sensitivity rates and substantial precision in the diagnosis of diseased pulp. Regarding the specificity and NPV, both the cold (87% and 71%) and oximeter (80% and 69%) tests effectively detected healthy pulp with substantial precision, followed by the heat test (76% and 69%). The electric test presented the lowest rates of specificity (51%), although the 64% NPV was substantial. The cold and oximeter tests proved able to detect the healthy pulp better than the heat and electric tests.

However, all the tests showed deficiency in the diagnosis of diseased pulp, corroborating the statement that pulp tests are more valid in determining healthy pulp than in identifying diseased pulp.[11] In general, the results were coherent within each test as 46 teeth (64% of 71%) presented complete endodontic treatment or periapical alterations that required endodontic treatment and were likely detected within the sensitivity parameter.

The other 25 traumatic teeth in which the diagnosis from the tests was doubtful and no clinical and/or radiographic alterations were found, went additional observation. The moderate levels of the Kappa test indicated that the cold, heat and oximeter tests are more able to detect healthy pulp than diseased pulp. On the other hand, despite its higher sensitivity value to detect diseased pulp, the electric test presented the lowest Kappa level (fair agreement) in relation to its specificity.

The accuracy comparison among the tests is illustrated. (Figure 1) The lines´s vertices indicate the sensitivity (y-axis) and specificity (x-axe). The nearer the vertice is to the 1.0 unit in the y-axis the better the test is, thus both presenting high sensitivity and specificity. The cold test (red line) seems superior to the other tests in both sensitivity and specificity, with moderate difference in the specificity.

Compared to the heat (blue line), the oximeter test (purple line) presented minor superiority in the specificity and minor inferiority in the sensitivity. The electric test (green line) showed moderate specificity and substantial sensitivity with values lower than the other tests.

Some limitations were considered when performing the present study. The accuracy and applicability of conventional pulp tests vary depending on the type of injury and the age of the patient.[13,19] The trauma type and intensity could not be recorded in the current study. Sensibility tests are difficult to administer or inconclusive when used with children[27] as they cannot always describe subjective symptoms or a response to a stimulus[29] thus resulting in likely false responses. Hence, patients under 18 years were excluded. The results of the tests would be improved whether three parameters might be well controlled: patients age, pulp size and time after trauma.

The pulp size and patients age are closely related. The lower the age the higher the pulp size. Thus, performing the tests in teeth with similar age/pulp size are likely

to improve the tests along with traumatic teeth tested within a similar time after the trauma.

The challenge would be to have a sample gathering the three parameters in a matched study. The study focused on the thermal, electric and oximeter tests because they are cheaper, less time consuming and ready to be used by the professionals. However, due to the incidence of false responses observed for all the tests in the current study, combining two tests would lead to a more faithful pulp diagnosis.

Although not readily available, Cone Beam Computed Tomography (CBCT) and magnetic resornance imaging (MRI) would certainly be useful in the pulp healthy diagnosis; CBCT have reached very high levels of de-finition and reduction of the radiation dose, also in the examination of soft tissues;[30] MRI has the advantage of not using ionizing radiation, avoiding the biological damage to the patient, and would indicate the pulpal status based on the content of water in the pulp.[31]

CONCLUSION.

Cold and oximeter tests proved superior over the electric and heat tests for diagnosing healthy pulp. However, the electric test showed better parameters when diagnosing diseased pulp. Combining two tests seems reasonable for improving the accuracy of pulpal status diagnoses using both oximeter and cold or oximeter and heat tests to detect healthy pulp; or cold and electric tests to define diseased pulp.

Any single test result should be conclusive when defining the pulp status. Combining at least two tests along with clinical and radiographic evaluation is recommended. Persisting doubt about the pulpal status diagnostic a discerning control should be performed up to a clear definition

ISSN Print 0719-2460 - ISSN Online 0719-2479.

Conflict of interests:

The authors deny any conflicts of interest.

Ethics approval:

Research Ethical Committee of the Federal University of Uberlândia (Protocol # 447/10).

Funding:

The study was conducted with authors' own financial sources.

Authors' contributions:

Campos RE: Conceptualization, Methodology, Writing (review and editing), Project Administration.
Filho PCFS: Validation, Formal Analysis, Writing (original draft).
Resende EF, Oliveira LV: Investigation, Resources.
Ambrosano GMB: Statistics

Acknowledgements:

None.

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