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Exploratory analysis of predictive factors for radiographic repair of endo-periodontal lesions: a pilot study

Análise exploratória de fatores preditivos para o reparo radiográfico de lesões endoperiodontais: um estudo piloto

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Resumo

Introdução: A lesão Endo-periodontal (LEP) são condições infecciosas complexas e simultâneas. **Objetivo:** Este estudo teve como objetivo avaliar os fatores associados à reparação radiográfica de lesões endoperiodontais (LEPs), com foco particular em variáveis clínicas, periodontais e sistêmicas, utilizando uma análise de árvore de decisão para identificar os fatores mais influentes. **Material e método:** Este estudo retrospectivo analisou os prontuários de pacientes tratados para LEPs na UNIFAE (2022-2023), que receberam terapia endodôntico-periodontal combinada e foram reavaliados pelo menos seis meses após o tratamento. Foram coletados dados clínicos, demográficos e radiográficos, incluindo profundidade de sondagem (PS), sangramento à sondagem (SS), presença de diabetes, idade e duração do acompanhamento. Os pacientes foram classificados em duas categorias com base em critérios radiográficos e clínicos: reparação completa ou reparação parcial. As análises estatísticas incluíram testes qui-quadrado e t de Student, complementados por um modelo de árvore de decisão (algoritmo CART) para identificar os principais preditores de reparação radiográfica. **Resultado:** O estudo incluiu inicialmente 16 pacientes (18 dentes), mas o acompanhamento foi concluído com apenas sete pacientes (sete dentes), sendo que um acompanhamento mais longo esteve associado à reparação radiográfica completa. A análise de árvore de decisão confirmou o tempo de acompanhamento como o preditor mais forte, seguido por diabetes e doença periodontal. Pacientes com diabetes apresentaram maior probabilidade de reparo parcial. Embora as análises bivariadas não tenham demonstrado diferenças estatísticas, o modelo exploratório destacou a hierarquia potencial dessas variáveis. **Conclusão:** Esses achados sugerem a importância do acompanhamento prolongado e da saúde sistêmica, especialmente o diabetes, no prognóstico do tratamento da periodontite exsudativa, enfatizando a necessidade de monitoramento individualizado e cuidado endodôntico-periodontal integrado. No entanto, esses achados devem ser interpretados com cautela devido ao tamanho limitado da amostra. Estudos prospectivos de grande escala são necessários para confirmar esses preditores.

Descritores: Endodontia; periodontia; diabetes mellitus; cicatrização; árvores de decisão.

Abstract

Introduction: Endo-periodontal lesions (EPLs) are complex conditions with simultaneous endodontic and periodontal infections. **Objective:** This study aimed to evaluate factors associated with the radiographic repair of EPLs, with a particular focus on clinical, periodontal, and systemic variables, using a decision tree analysis to identify the most influential factors. **Material and method:** This retrospective study analyzed records of patients treated for EPLs at UNIFAE (2022-2023), who received combined endodontic-periodontal therapy and were reassessed at least six months post-treatment. Clinical, demographic, and radiographic data were collected, including probing depth (PD), bleeding on probing (BOP), diabetes status, age, and follow-up duration. Patients were classified into two categories based on radiographic and clinical criteria: complete repair or partial repair. Statistical analyses included chi-square and t-tests, complemented by a decision tree model (CART algorithm) to identify the primary predictors of radiographic repair. **Result:** The study initially included 16 patients (18 teeth), but follow-up was completed with only seven patients (seven teeth), with longer follow-up linked to complete radiographic repair. The decision tree analysis confirmed follow-up time as the strongest predictor, followed by diabetes and PD. Patients with diabetes exhibited a higher likelihood of partial repair. Although bivariate analyses did not demonstrate statistical differences, the exploratory model highlighted the potential hierarchy of these variables. **Conclusion:** These findings suggest the importance of prolonged follow-up and systemic health, especially diabetes, in the prognosis of EPL treatment, emphasizing the need for individualized monitoring and integrated endodontic-periodontal care. However, these findings should be interpreted with caution due to the limited sample size. Further large-scale, prospective studies are needed to confirm these predictors.

Descriptors: Endodontics; periodontics; diabetes mellitus; wound healing; decision trees.

INTRODUCTION

Endo-periodontal lesions are complex pathological conditions that simultaneously affect the pulp and periodontal tissues of the same tooth, due to their close anatomical and functional interrelations, and pose challenges for diagnosis and treatment due to shared microbial profiles challenges for diagnosis and treatment owing to shared microbial profiles and interconnected anatomical pathways[1,2]. These communications occur through structures such as the apical foramen, lateral and accessory canals, furcation canals, exposed dentinal tubules, as well as in cases of perforations and fractures[3]. Through these pathways, irritants and infectious agents—including bacteria, fungi, viruses—and inflammatory by-products can migrate between the pulp and periodontium[3,4]. Additionally, etiological factors such as foreign bodies (dentin or cementum chips, filling materials), cholesterol crystals, Russell bodies, Rushton hyaline bodies, and Charcot-Leyden crystals have been implicated[4]. As a result, pulp infections may trigger a direct inflammatory response in the periodontal tissues and vice versa[5].

Historically, Simon et al.[6] proposed the most widely adopted classification for endo-periodontal lesions, based on the primary source of infection. This system included: (1) primary endodontic lesions, (2) primary endodontic lesions with secondary periodontal involvement, (3) primary periodontal lesions, (4) primary periodontal lesions with secondary endodontic involvement, and (5) true combined lesions. However, identifying the original source is often clinically challenging. To address this, the 2017 World Workshop on the Classification of Periodontal and Peri-Implant Diseases and Conditions proposed a new system that emphasizes the current disease status over etiology[7,8]. This system divides lesions into: (1) endo-periodontal lesions with root damage (including root fractures, perforations, and external resorptions), and (2) endo-periodontal lesions without root damage, which are further classified into (2a) in patients with periodontitis and (2b) in patients without periodontitis. These are additionally graded based on periodontal involvement (Grade 1: narrow deep pocket on one root surface; Grade 2: wide deep pocket on one root surface; Grade 3: deep pockets on two or more root surfaces)[7,8].

Accurate diagnosis of endo-periodontal lesions is critical yet often complex, particularly in the absence of historical clinical records that clarify disease chronology[9,10]. Patients may present with acute apical abscesses draining along periodontal ligaments, mimicking primary periodontal disease[11]. Therefore, comprehensive clinical evaluation, including anamnesis, intraoral examination, digital palpation, vertical and horizontal percussion tests, mobility assessment, periodontal probing, pulp vitality tests, periapical radiographs, cone-beam computed tomography, and fistulography is essential for differential diagnosis[12,13].

Despite advances in diagnosis and treatment, the prognosis of endo-periodontal lesions remains uncertain and highly individualized. It depends on extrinsic factors such as biofilm virulence and disease extent, and intrinsic factors like host tissue response and systemic health[14]. Effective treatment demands an integrated endodontic and periodontal approach; isolated intervention in one specialty is insufficient for comprehensive healing[15]. Endodontic therapy provides probing depth reduction, clinical attachment level gain, and bleeding on probing decrease[16], while periodontal therapy controls inflammation and fosters soft tissue regeneration[17]. Post-treatment follow-up is thus indispensable, with evaluations typically recommended between 2 and 12 months to assess tissue healing and the success of combined therapies[18].

In this context, multivariate statistical approaches such as decision tree analysis offer promise for identifying clinical and patient-related variables that predict treatment outcomes in endo-periodontal lesions. By elucidating these exploratory factors, it is possible to enhance evidence-based decision-making and refine clinical protocols[15]. Thus, the objective of this pilot study was to identify exploratory factors associated with the successful repair of endo-periodontal lesions through decision tree analysis, thereby contributing to improved prognostic assessment and personalized treatment planning in clinical practice.

MATERIAL AND METHOD

Study design and ethical approval

This was an observational, retrospective, and analytical study approved by the Institutional Ethics Committee (CAAE: 75532623.2.0000.5382), in accordance with the Declaration of Helsinki and Brazilian Resolution CNS 466/12.

Sample selection

Dental records of patients treated by undergraduate students at a School of Dentistry Clinic between 2022 and 2023 were reviewed. Inclusion criteria comprised patients aged between 18 and 85 years who had undergone combined endodontic and periodontal treatment for endo-periodontal lesions, regardless of systemic conditions or chronic medication use. Exclusion criteria included patients outside the specified age range, those who did not complete treatment, failed to return for follow-up, lacked contact information, or had not reached the minimum six-month post-treatment period.

Data collection and evaluated parameters

Eligible patients were invited to return for clinical and radiographic reassessment after signing the informed consent form. Evaluations were performed at least six months following completion of treatment.

The following parameters were recorded:

- **Demographic and systemic data:** age, sex, affected tooth, systemic health conditions, smoking habits, continuous medication use.
- **Endodontic clinical parameters:** history of caries, inadequate restorations, spontaneous pain, exudate, fistula, thermal test response, pain on vertical and horizontal percussion, mobility, and swelling.
- **Periodontal clinical parameters:** probing depth, clinical attachment loss, gingival bleeding, tooth mobility, use and frequency of dental floss, presence of pain.

- **Radiographic findings:** thickening of the periodontal ligament space, diffuse or circumscribed periapical lesions, condensing osteitis, and defect morphology around endo-periodontal lesions (conical or J-shaped pattern).

Treatment reassessment

Patients were reexamined for the following aspects:

1. Type of therapy performed (extraction, endodontic treatment associated with periodontal therapy).
2. Probing depth and bleeding on probing.
3. Radiographic appearance (complete or partial repair, persistent or worsening lesion).
4. Pain on vertical and horizontal percussion.
5. Time elapsed since completion of endodontic and periodontal therapies.

Statistical analysis

▪ Demographic and clinical data

Data were analyzed using GraphPad Prism version 5.0 (GraphPad Inc., USA). Normality was assessed, followed by the application of parametric tests. After reassessment, patients were categorized into two groups: those who achieved complete repair and those with partial repair. For categorical variables, data were presented as counts and comparisons between groups were performed using the chi-square test. For numerical variables, data were expressed as means and standard deviations, with group comparisons conducted using the Student's t-test.

Exploratory analysis of factors associated with repair of endo-periodontal lesions: decision tree analysis

To analyze factors associated with the outcome "Radiographic Aspects" following the treatment of endo-periodontal lesions (EPLs), a decision tree model was employed. This supervised learning method classifies outcome categories based on predictor variables, providing an interpretable framework that illustrates how each factor may influence the outcome. A decision tree model was constructed as an exploratory analytical approach to visualize potential relationships between clinical and systemic variables and radiographic repair outcomes. The decision tree was constructed using the DecisionTreeClassifier algorithm from the Scikit-Learn library in Python. Predictor variables included probing depth (PD ≥4 mm with BOP), PD (in mm), bleeding on probing (BOP), pain on vertical percussion, follow-up time (in months), presence of diabetes, and smoking status. The outcome variable "Radiographic Aspects" was binarized into two categories: "Complete repair" and "Partial repair." Accuracy and classification reports were used to evaluate model performance, while feature importance metrics identified the most influential variables in predicting outcomes. Results were visualized through a decision tree plot, facilitating the interpretation of critical variables and decision points. This method was selected for its capacity to handle both categorical and continuous data, as well as for its interpretability, which directly highlights the most relevant variables associated with the outcome.

RESULT

Records from 16 patients were analyzed, totaling 18 teeth affected by endo-periodontal lesions (EPLs). However, only seven patients returned for follow-up visits, resulting in seven teeth effectively reassessed after the observation period. Cases were categorized as either complete repair or partial repair (Figure 1) based on the presence of an intact lamina dura, probing depth (PD) ≤ 4 mm, osseous healing in the periapical region, and absence of percussion pain[19].

Figure 1. (A) Periapical radiograph of tooth #34 before completion of endodontic and periodontal treatments. (B) Periapical radiograph of tooth #34 after 10 months, demonstrating partial repair with persistence of the periapical lesion. (C) Periapical radiograph of tooth #15 prior to treatment. (D) Periapical radiograph of tooth #15 after 18 months, showing evidence of complete repair.

Clinical and radiographic findings

In all reassessed teeth, endodontic treatments exhibited features consistent with success, showing no obturation gaps, perforations, canal deviations, resorptions compromising apical sealing, or restorations with microleakage[20]. Comparing groups, patients in the complete repair group had a mean age of 53 ±6.0 years, mean PD of 2 ±1.52 mm, and only 33.3% exhibited PD ≥ 4 mm with bleeding on probing (BOP). In contrast, the partial repair group had a mean age of 60 ±16.6 years, PD ≥ 4 mm with BOP in 50% of cases, and an average BOP of 75%. Regarding diabetes, the comorbidity was present in 33.3% of complete repair cases and in 50% of partial repair cases. Mean follow-up time was longer in complete repair cases (17 ±6.0 months) compared to partial repair cases (11 ±2.08 months, Figure 2). Statistical tests revealed no significant differences between groups ($p > 0.05$).

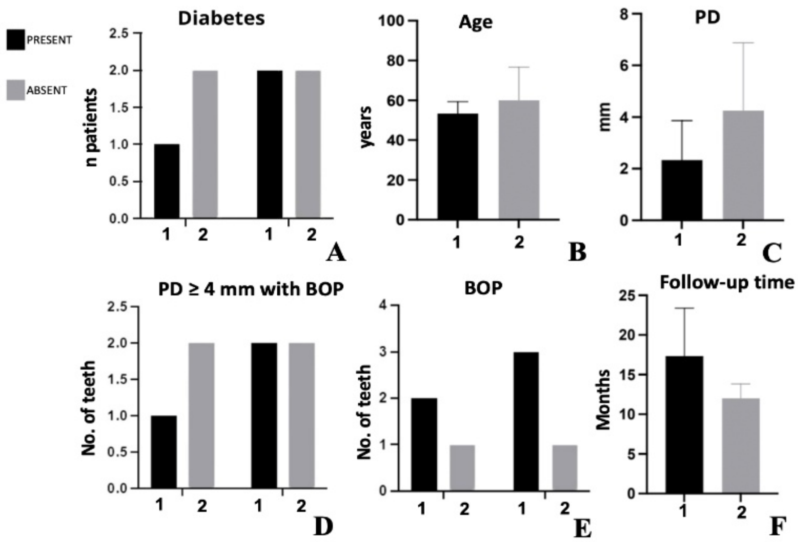

Figure 2. Comparison of clinical and systemic variables according to the type of radiographic bone repair. (A) Diabetes status; (B) Age; (C) Probing depth (PD); (D) Number of teeth involved; (E) Bleeding on probing (BOP); and (F) Follow-up time. Bars represent mean values for each variable according to the repair outcome. Categories: 1 = partial repair and 2 = complete repair. Error bars represent the standard deviation.

Exploratory factors identified through decision tree analysis

The decision tree suggested a hierarchical structure among the evaluated variables, with follow-up time appearing as the first splitting variable, followed by probing depth and diabetes status. These findings should be interpreted as exploratory patterns rather than definitive predictors, given the small sample size. Follow-up time emerged as the most relevant predictor, accounting for approximately 53% of the model, followed by presence of diabetes (39%) and probing depth in mm (8%). Other variables, such as isolated PD ≥ 4 mm with BOP, BOP alone, and vertical percussion pain, showed low influence on the outcome. The model indicated that longer follow-up periods were associated with a higher probability of complete repair, while diabetes and increased PD tended to relate to partial repair outcomes (Figure 3).

DISCUSSION

The main findings of this study identified follow-up duration as the most decisive factor for complete repair of endo-periodontal lesions, followed by the presence of diabetes mellitus and probing depth, as demonstrated by the decision tree analysis. Patients monitored for longer periods showed a higher likelihood of achieving complete osseous repair, with an average of 17 months to reach this outcome, corroborating the tree's estimate of approximately 16 months. This aligns with the literature. A recent study that used cone beam computed tomography to evaluate predictors of periapical bone healing in teeth with large periapical lesions following nonsurgical root canal treatment reported a mean healing time of 19 months for most of the cases analyzed[21]. Additionally, a systematic review and meta-analysis of randomized controlled trials assessing the efficacy of non-surgical periodontal treatment (NSPT) in patients with systemic conditions demonstrated significant reductions in mean probing depth, mean clinical attachment loss, and the percentage of sites with bleeding on probing, primarily observed after 3 months. These findings suggest that NSPT is an effective procedure for managing periodontitis even in patients with concurrent systemic conditions[22]. However, follow-ups may extend up to 5 years depending on case complexity[23,24]. Unlike some studies that report less pronounced temporal variations, the clear influence of prolonged monitoring here underscores the importance of extended follow-up, especially in populations with systemic risk factors.

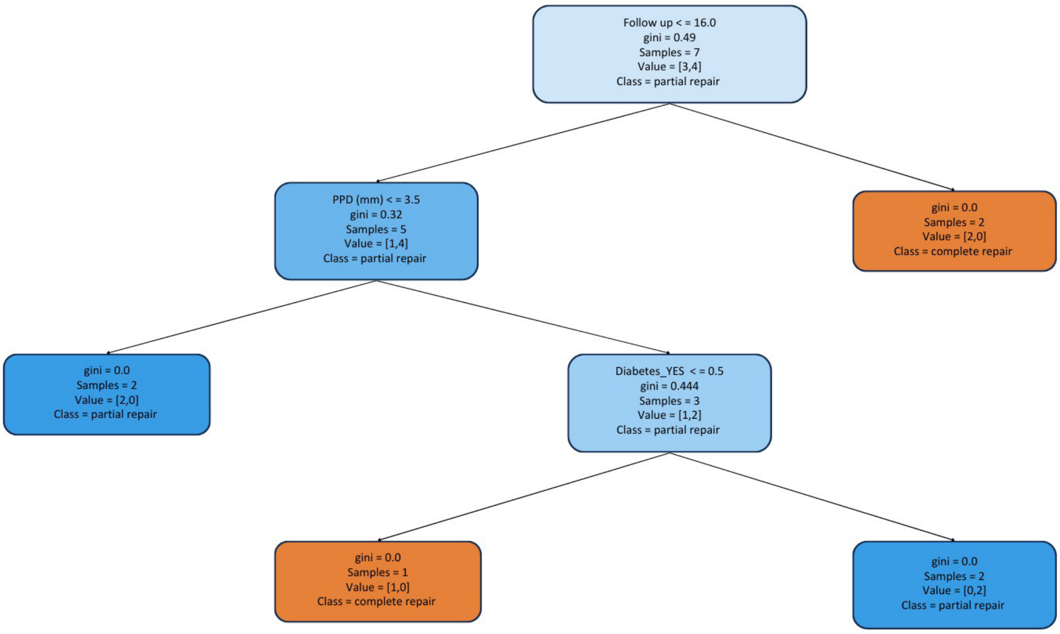

Figure 3. Decision tree model predicting radiographic repair outcomes in endo-periodontal lesions. The decision tree illustrates the hierarchical influence of clinical and systemic variables on treatment outcomes. The root node indicates that follow-up time (months) was the primary predictor. Cases with follow-up >16 months were classified as complete repair, whereas shorter follow-up was associated with partial repair. Among cases with shorter follow-up, probing depth (PPD, mm) was the second predictor, followed by the presence of diabetes mellitus. Each node displays the Gini index (measure of node impurity used to determine the best split), samples (number of cases included in that node), value (distribution of cases between outcome categories), and class (predicted outcome: partial or complete repair). Terminal nodes represent the final classification of cases according to the combination of predictors.

Diabetes mellitus emerged as the second most relevant factor in the predictive model, present in half of the cases that evolved toward partial repair. This is justified by well-established mechanisms whereby diabetes alters inflammatory and immune responses, leading to increased osteoclasts and reduced numbers of osteoblasts and bone formation[25]. These results are consistent with studies linking diabetes to greater bone loss and less predictable periodontal[26] and periapical regeneration[27], reinforcing the need for individualized approaches in such patients.

Regarding age, patients who exhibited partial repair were generally older, supporting findings by Lossrdörfer et al.[28] that aging compromises osteoblast gene expression and the response to parathyroid hormone, thereby decreasing osteocalcin production and impairing alveolar bone repair capacity. This indicates that aging alone may influence the prognosis of endo-periodontal lesions, although the small sample size of this study limits the strength of this conclusion.

Periodontal parameters also impacted outcomes, as cases classified as partial repair showed a higher frequency of bleeding on probing and PD ≥ 4 mm, indicating active periodontitis at the time of reassessment. According to the 2017 World Workshop on the Classification of Periodontal and Peri-Implant Diseases and Conditions[7], periodontitis is defined by clinical attachment loss ≥

3 mm detected at two or more non-adjacent interproximal sites. The same workshop's Group 1 further states that bleeding on probing between 10% and 30% indicates localized periodontitis, while levels above 30% define generalized disease[29]. These parameters help explain why, even with combined treatments, periodontal health at follow-up was a critical determinant for partial osseous repair in some cases.

From an endodontic perspective, all reassessed cases met the criteria for clinical success. These criteria are defined as the absence of symptoms and clinical signs of disease, such as tooth mobility, sinus tract, along with the preservation of tooth function. Radiographically, periapical healing should be evidenced by a reduction or resolution of any previously observed periapical radiolucency. Moreover, the placement of an optimal definitive restoration is essential to the long-term success of root canal treatment[30].

Nevertheless, this study has notable limitations. The final sample was restricted to only seven patients, substantially limiting statistical power and the ability to generalize findings. Furthermore, bivariate statistical analysis did not reveal significant differences between groups, meaning that the interpretation of predictors was primarily based on the exploratory decision tree, which by nature may suffer from overfitting—especially in small samples—and does not provide confidence intervals for the relative importance of variables. Another limitation relates to the imaging method used for follow-up, as only periapical radiographs were available. Although cone-beam computed tomography (CBCT) provides greater diagnostic accuracy for the detection of periapical and periodontal bone defects, current evidence recommends that its use should be restricted to cases in which conventional radiography does not provide sufficient diagnostic information, due to higher radiation exposure[31,32].

Thus, these findings should be regarded as exploratory and indicative, requiring validation in future studies with larger patient cohorts.

Potential selection bias cannot be ruled out, as patients who returned for follow-up may inherently have higher adherence and self-care profiles, which positively influence outcomes. The study also did not implement additional controls to minimize information bias, such as inter-examiner calibration or blinded radiographic evaluations, which could have strengthened the methodological rigor.

The results of this study indicate that follow-up duration and the presence of diabetes were the most relevant factors associated with radiographic outcomes following treatment of endo-periodontal lesions. Patients monitored over longer periods showed a higher likelihood of achieving complete osseous repair, suggesting that treatment success may be directly related to the length of clinical follow-up. In contrast, the presence of diabetes was associated with a greater probability of partial repair, underscoring the impact of systemic conditions on periodontal healing processes.

These findings hold practical significance, as they can assist in identifying patients who require more rigorous monitoring and adjustments to therapeutic protocols, particularly those with diabetes or additional periodontal risk factors. Moreover, these results guide health professionals in formulating individualized follow-up strategies aimed at maximizing the chances of complete radiographic repair and long-term stability.

However, it is important to interpret these conclusions with caution, given the small sample size and the exploratory nature of the statistical model employed. Therefore, future studies with prospective designs, larger cohorts, and additional multivariate analyses are necessary to confirm and expand upon these findings. Ultimately, this analysis reinforces the importance of considering clinical, periodontal, and systemic characteristics in post-treatment prognosis, consolidating the integration of periodontics and endodontics as a cornerstone for therapeutic success.

CONCLUSION

Within the limitations of this pilot study, the exploratory analysis suggests that follow-up time may play an important role in the radiographic repair of endo-periodontal lesions, with diabetes status and probing depth also emerging as potentially relevant variables. Although these findings should be interpreted with caution due to the small sample size, they highlight the possible influence of systemic and clinical factors on treatment outcomes. The decision tree approach proved useful as an exploratory tool to visualize the hierarchy of variables associated with repair outcomes and may contribute to the development of hypothesis-generating exploratory models. Future multicenter studies with larger samples and more robust statistical approaches are necessary to validate these preliminary observations and better define prognostic factors for the repair of endo-periodontal lesions.

AUTHORS' CONTRIBUTIONS

Hisadora Fernandes Carvalho Lopes and Laura Morais Affonso: contributed to the original drafting of the manuscript, performed data collection, and were responsible for proofreading and editing. Gabrielly Caruso Catalano: participated in the original manuscript writing and data collection. Fernanda Ferrari Esteves Torres: was responsible for the conceptualization, development of the methodology, and overall project management. Thamiris Cirelli: contributed to the conceptualization, data curation, statistical analysis, acquisition of funding, research oversight, methodological design, and project coordination. All authors reviewed and approved the final version of the manuscript and agree to be accountable for all aspects of the work. Hisadora Fernandes Carvalho Lopes, Laura Morais Affonso - These authors contributed equally to this work and share first authorship.

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CONFLICTS OF INTERESTS

The authors declare that there is no conflict of interest related to this study.

DATA AVAILABILITY

The contents underlying the research text are included in the manuscript.

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