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Original article

Time Trend of Occupational Noise-induced Hearing Loss in a Metallurgical Plant With a Hearing Conservation Program

Adalva V. Couto Lopes *, Cleide F. Teixeira, Mirella B.R. Vilela, Maria L.L.T. de Lima

Departamento de Fonoaudiologia, Universidade Federal de Pernambuco – UFPE, Recife, PE, Brazil

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ABSTRACT

Background: This study aimed to analyze the trend of occupational noise-induced hearing loss (ONIHL) in Brazilian workers at a metallurgical plant with a hearing conservation program (HCP), which has been addressed in a previous study.
Methods: All 152 workers in this time series (20032018) participated in the HCP and used personal protective equipment. All annual audiometry records in the company's software were collected from the electronic database. The trend of ONIHL was analyzed with the joinpoint regression model. The hearing thresholds of ONIHL cases at the end of the series were compared with those found in a national reference study.
Results: The binaural mean hearing thresholds at 3, 4, and 6 kHz at the end of the series were higher for ages ≥50 years, exposures ≥85 dB (A), time since admission >20 years, and maintenance workers. Significance was found only in the group divided by age. There was an increasing time trend of ONIHL, though with a low percentage variation for the period (AAPC = 3.5%; $p = 0.01$). Hearing thresholds in this study differed from the reference one.
Conclusion: Despite the unmet expectation of a stationary trend in the study period, the time pace of ONIHL evolution did not follow what was expected for a population exposed to noise. These findings signal to the scientific community and public authorities that good ONIHL control is possible when HCP is well implemented.

1. Introduction

Occupational noise-induced hearing loss (ONIHL) is among the most common occupational health problems [1]. In the manufacturing industry, at least 45% of workers are habitually exposed to noise at work [2]. This condition can be harmful to hearing, with greater danger in systematic 8-hour exposures above 85 dB (A) [1] and it is enhanced if associated with other environmental risk agents such as ototoxic chemical agents [3–6] and vibration [7,8]. The risk becomes even more critical for particularly susceptible individuals [9,10].

ONIHL has been widely characterized as a sensorineural, generally bilateral, permanent lesion, audiometrically configured as a V-shaped notch at high frequencies, progressing gradually according to the time of chronic noise exposure. Its initial impairment is detected based on higher audiometric thresholds at 3 kHz, 4 kHz, and/or 6 kHz [1,11]. Typically, noise exposure alone does not cause losses greater than 75 dB (HL) at high frequencies and greater than 40 dB (HL) at low frequencies. ONIHL progresses more significantly during the first 10 to 15 years of exposure and is interrupted if the exposure ceases [11,12].

Almeida et al. (2000) studied retrospectively three decades of occupational noise exposure [13] in the Social Work Health Service

Adalva V. Couto Lopes: https://orcid.org/0000-0001-7873-7764; Cleide F. Teixeira: https://orcid.org/0000-0001-9869-4431; Mirella B.R. Vilela: https://orcid.org/0000-0001-5113-7144; Maria L.L.T. de Lima: https://orcid.org/0000-0001-8600-0017
* Corresponding author. Departamento de Fonoaudiologia, Universidade Federal de Pernambuco – UFPE, Recife, PE, Brazil.
E-mail address: adalva.lopes@hotmail.com (A.V. Couto Lopes).

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of São Paulo. They diagnosed 222 cases of males with ONIHL in a sample largely made up of metalworkers. These workers' audiometric thresholds were correlated with their age group and noise exposure time in years, being compared with that of a same-age population whose deterioration was only due to age, according to the ISO 1999 standard (1990).

Despite evidence that ONIHL has declined since the 1970s [14], recent studies have demonstrated high ONIHL prevalence in several countries, including 28.8% for 6,557 workers in China [15], 41.1% for 196 workers in Jordan [16], and 48% for 221 workers in Tanzania [17].

Previous studies in Brazilian manufacturing industries suggest a decrease in ONIHL in workers exposed to continuous noise. In the 1990s, the prevalence was 46.2% in the state of São Paulo [18] and 35.7% in Bahia [19]. In the 2000s, it was 21.0% in Goiás [20] and 28.3% in Santa Catarina [21]. A study from the 2010s indicates a prevalence of 28.9% in Amazonas [22].

Despite the scientific contributions of cross-sectional studies, longitudinal ones help analyze trends and identify etiological factors, which are necessary to evaluate and support interventions [23].

Companies implement hearing conservation programs (HCP) as a measure to prevent and control ONIHL. The control of the progressive incidence of ONIHL is an important parameter for monitoring the control of occupational risks, whose measurement is the main indicator of HCP effectiveness [6].

This study hypothesized that well-implemented HCPs have a positive impact on the time trend of ONIHL. Thus, it aimed to analyze the time trend of ONIHL in workers in a manufacturing industry with an HCP and compare observed results to those reported by Almeida et al. [13].

2. Materials and methods

This study was approved by the Ethics Committee of the Federal University of Pernambuco, under evaluation report number 3.824.458, and had the company's consent.

This is a time series (2003-2018) [24] carried out in a large company, with low employee turnover, operating for more than three decades in Pernambuco, Brazil.

This metallurgical plant has had HCP for more than two decades, whose implementation was evaluated in a previous study [25]. In this study, the implementation index was calculated by dividing the number of practices adopted by 46 items evaluated and multiplying it by 100, year by year. It found high and constant rates of good ONHIL prevention practices. The mean score achieved for the period was 88.65% (SD = 0.86). The study also found integrated practices; managers with performance indicators in health and safety at work; systematic audits; investment in human resources and equipment; management software; examinations carried out at the premises; acoustic projects to reduce noise; evaluation of acoustic power when acquiring production machinery; signage in risk areas; periodic lectures; systematic noise dosimetry; supply, requirement, and supervision of the use of certified personal protective equipment (PPE), selected considering their attenuation, sealing, and user satisfaction; annual audiometry meeting technical-legal requirements; strictly followed examination schedules; real-time audiometric monitoring; and flow of causal link investigation.

The inclusion criteria were workers who underwent audiometry in 2018 having participated in the HCP for at least 15 years. Workers' records from 2003 to 2018 were extracted from the company's electronic database, collecting data on hearing thresholds, age, sex, sector, position, occupational risks, level of noise exposure, and date of admission to the company. The study excluded workers with fewer than eight audiometry tests—between 2003 and 2018 and/or a history of occupational exposure to ototoxic chemicals and/or vibration at some point during the study period, regardless of whether the level of exposure was above the regulatory tolerance limit. Thus, the retrospective study encompassed 152 workers.

The population was examined annually. Audiometry tests with transient changes were not analyzed and were excluded from the study. In occasional situations in which the worker underwent more than one annual exam, the study included the last annual audiogram.

For each year of the series, workers were categorized by their mean level of noise exposure, position, age group, and time since admission to the company. Noise exposure categories were classified as i) ≥ 85 dB(A), ii) from 80 to 84.9 dB(A), and iii) <80 dB(A). Position categories were support, maintenance, and production. Age group categories were a) ≥ 50 years, b) 40 to 49 years, and c) ≤ 39 years. The time since admission to the company was categorized as i) ≥ 21 years, ii) 16 to 20 years, iii) 11 to 15 years, and iv) ≤ 10 years. Brazilian standards determine that exposure to 80 dB (A) of noise requires preventive actions [26] and that an 8-hour exposure to continuous noises at 85 dB (A) poses a risk of damage [27].

Regardless of the time since admission to the company, each worker's first audiogram included in the series was defined as the first reference exam – i.e., the one with which the sequential exams were compared [11].

Abnormal audiometry results were considered suggestive of ONIHL [11] when hearing thresholds were above 25 dB (HL) at 3 kHz, 4 kHz, and 6 kHz and higher than at 0.5 kHz, 1 kHz, 2 kHz, and 8 kHz[11], with a typical, unilateral or bilateral, symmetrical, sensorineural notch. Consecutive interaural differences of 20 or more dB (HL) at two frequencies out of 3, 4, and 6 kHz [28] were considered as asymmetry.

The mean annual binaural hearing thresholds of the sequential exams at 3 kHz, 4 kHz, and 6 kHz were compared with the binaural means of the reference exams [28,29]. Progressions were evidenced by changes in auditory thresholds greater than or equal to 15 dB (HL) at either 3 kHz, 4 kHz, or 6 kHz or by changes greater than or equal to 10 dB (HL) between the arithmetic means of the pure-tone thresholds at 3 kHz, 4 kHz, and 6 kHz when comparing annual sequential examinations with the reference. Auditory threshold progressions suggestive of ONIHL were classified as onset or worsening, respectively for new lesions or progress of existing lesions. Sequential examinations with a progression that suggested ONIHL onset or worsening became the new reference for subsequent analyses.

Thus, the ONIHL indicator was measured based on the accumulated rate of cases suggestive of ONIHL, calculated by the number of audiometry changes suggestive of ONIHL added to the number of progressions suggestive of ONIHL, divided by the study population, multiplied by 100, year by year.

A comparative analysis was carried out to assess the magnitude of changes suggestive of ONIHL, using as a reference a national study of the natural evolution of ONIHL by Almeida et al. [13], since environmental and hereditary factors and diseases may differ from one country to another [30]. The mean hearing thresholds at 3 kHz, 4 kHz, and 6 kHz of workers with changes suggestive of ONIHL at the end of the series were correlated with their age group and time since admission and compared with the mean hearing thresholds at 3 kHz, 4 kHz, and 6 kHz of the group studied by Almeida et al., with the same age and exposure time [13].

Descriptive statistics were used to characterize the population, the noise exposure profile, and the ONIHL profile. Absolute (n) and relative frequencies (%) were calculated for categorical variables (sex, time since admission, position, and age group), and measures of central tendency (arithmetic means) and dispersion (standard deviations) were calculated for continuous variables (hearing thresholds and noise exposure).

The statistical analysis of the time trend of ONIHL used the joinpoint regression model with the Joinpoint Regress Program, version 4.5.0.1 (US National Cancer Institute, Bethesda, MD, USA). Each joinpoint, when present, indicates a statistically significant change in the slope of the line ($\alpha = 5\%$). Two measures were calculated: a) Annual Percentage Change (APC), which is the percentage variation of the indicator per year within a time segment until an inflection point occurs; and b) Average Annual Percent Change (AAPC), which is the average percentage change of the indicator throughout the study period [31,32].

3. Results

The study evaluated 2,350 audiograms, with a mean of 146.9 (SD ± 3.26) per year. The first reference exams are mostly in the first year of the series, followed by nine in 2004, two in 2005, and one in 2006 (Table 1).

The population comprised 150 males and two females. Their mean age was 33.6 years (SD ± 5.9) at the beginning of the series and 48.4 years (SD ± 5.8) at the end of the series.

Concerning the population's hearing thresholds, Table 2 shows that the binaural mean at 3 kHz, 4 kHz, and 6 kHz at the beginning of the series was 13.5 dB (HL) and 17.5 dB (HL) at the end of the series. Also, binaural means were higher at the end of the series for the age group ≥50 years, for those exposed to noise ≥85 dB (A), for those with more than 20 years since admission, and for those who worked in maintenance.

The Shapiro-Wilk normality test [33] was performed for each group. The p-value was calculated by multiple comparison between the groups with the Kruskal-Wallis nonparametric test [34], and the paired comparison was performed with the Dunn post hoc test [35].

Except for the age group, there was no statistical significance in the binaural mean differences between the groups with the Kruskal-Wallis test. In the Dunn post hoc test, the binaural mean in the group ≥50 years was statistically different from the others. Moreover, there was no statistically significant difference between the groups aged 40 to 49 years and <40 years.

There were 18 changes suggestive of ONIHL (11.8%) in the first reference audiograms and 10 progressions suggestive of ONIHL in sequential exams over the years, six of which were suggestive of onset (3.9%) and four were suggestive of worsening (2.6%) (Table 3).

The distribution of the progression of cases suggestive of ONIHL per category is shown in Table 3. Six cases were found in the group exposed to noise ≥85 dB (A), and four cases in the group exposed to noise from 80 to 84.9 dB (A). Also, there were six cases for time since admission ≥21 years, two cases for 11 to 15 years, and one case in each of the other subgroups of time since admission. Six cases were identified in production, three in maintenance, and one in support. There were nine cases among those 40 to 49 years old and one case for those ≥50 years old.

The regression analysis in the Joinpoint Regress Program showed an increasing time trend in the rate of 11.2% in 2003 and 18.4% in 2018, with a mean variation of 3.5% (AAPC) for the period from 2003 to 2018 ($p = 0.01$). There was a statistically significant change in the slope of the line ($p = 0.01$) in 2016, a variation of 2.3% (APC) in the 2003-2016 segment, and 11.43% (APC) in the time segment from 2016-2018 (Fig. 1).

At the end of the series, there were 24 workers with changes suggestive of ONIHL, four of which were cases of worsening. Due to the insignificant number, two workers whose time since admission was 11 to 15 years were not compared with the reference study, one of them aged 40 to 49 years and the other aged ≥50 years.

A sharp difference was found in the mean hearing thresholds at 3 kHz, 4 kHz, and 6 kHz between the 22 cases suggestive of ONIHL and those of the 52 cases of ONIHL in the group with the same age and exposure time studied by Almeida et al. [13], whose mean hearing thresholds were much higher (Table 4).

4. Discussion

The company in question values, encourages, and requires safe behavior, and its workers are engaged in HCP. Other Brazilian studies report different practices. Dantas et al. [36] identified those essentially focused on legal requirements to prevent labor grievances. Gonçalves et al. [37] identified companies with HCP, whose actions were limited to performing audiometry and providing PPE. Despite being deficient, these control measures may have helped reduce the prevalence of ONIHL indicated in previous studies in Brazilian manufacturing companies.

The prevalence of cases suggestive of ONIHL in 2003 was close to the 15.9% found by Guerra et al. [38] in a study in 182 workers aged 19 to 70 years in a metallurgical plant with HCP. Values were higher in companies with partial measures to control noise exposure, as found by Araújo [20], with a 21.1% prevalence of changes suggestive of ONIHL among 187 workers in a metallurgical plant, and Caldart [21], with 28.3% of changes suggestive of ONIHL among 184 workers in a textile company. Thus, studies have already recorded that companies with greater risk control have a lower prevalence of ONIHL.

The prevalence of cases suggestive of ONIHL in 2018 is not in line with the 41.8% prevalence found by Regis et al. [22] for metalworkers with 11 to 20 years of service in Amazonas or with the 41.43% prevalence found by Gonçalves et al. [39] for metalworkers participating in HCP with a mean 16.7 years of exposure in the state of São Paulo. HCP control measures implemented by the study company likely contributed to these observed differences. The population's mean hearing threshold was 17.5 dB (HL) at the end of the series, whose mean age was 48.4 years. Hence, it is below 25 dB (HL) for individuals above 50 years old with more than 20 years of exposure above 85 dB(A) and very close to the mean 15.3 dB (HL) hearing threshold defined by ISO 1999 [30] as expected for 50-year-

Table 1
Number of audiograms in the analysis from 2003 to 2018 in a metallurgical plant in Pernambuco, Brazil ($N = 2{,}350$)

	Period 2003 - 2018																
No. Audiograms	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	Mean SD
Initial references	140	9	2	1													
Sequential exams		139	143	147	147	149	143	144	142	148	149	149	152	146	148	152	
Analyzed	140	148	145	148	147	149	143	144	142	148	149	149	152	146	148	152	146.88 3.26

SD, standard deviation.
Conventional sign used: - non-rounded numerical datum equal to zero.

Table 2
Distribution of binaural mean hearing thresholds at 3 kHz, 4 kHz, and 6 kHz in dB (HL) per age group, levels of noise exposure, time of employment, and position in a metallurgical plant in Pernambuco, Brazil ($N = 152$)

Variables	Period 2003 - 2018									
	1st reference of the series				Last sequential of the series					
	$n = 152$	100%	($\bar{x}$ 3-6)	SD	$n = 152$	100%	($\bar{x}$ 3-6)	SD	Shapiro-Wilk (p)	Kruskal-Wallis (p)
Workers	152	100.0	13.5	7.2	152	100.0	17.5	9.3		
Age group (years)										6×10^{-7}
≥ 50	1	0.7	19.2	0.0	62	40.8	22.0	9.7	0.039	
40 to 49	20	13.2	21.1	8.7	80	52.6	14.8	7.9	3×10^{-4}	
< 40	131	86.2	12.3	6.2	10	6.6	10.5	3.8	0.276	
Noise exposure (dBA)										0.441
NE ≥ 85	77	50.7	13.9	6.9	46	30.3	19.3	10.4	0.006	
NE 80 to 84.9	57	37.5	12.5	5.7	85	55.9	16.4	7.7	0.037	
NE < 80	18	11.8	15.3	11.0	21	13.8	17.8	11.9	0.002	
Time of employment (years)										0.714
> 20	2	1.3	15.4	2.0	98	64.5	17.8	9.7	1×10^{-4}	
16–20	9	5.9	16.4	6.1	35	23.0	17.7	9.4	0.057	
11–15	25	16.4	16.0	11.4	19	12.5	15.3	9.8	0.136	
≤ 10	116	76.3	12.7	5.8	—					
Position										0.131
Support	19	12.5	15.3	10.0	21	13.8	18.2	12.2	0.003	
Maintenance	33	21.7	14.2	6.6	40	26.3	19.1	7.5	0.021	
Production	100	65.8	13.0	6.6	91	59.9	16.6	9.2	4×10^{-4}	

SD, standard deviation. ($\bar{x}$ 3-6) = binaural auditory threshold means at 3, 4, and 6 kHz.
Conventional sign used: - non-rounded numerical datum equal to zero.
Source: The authors.

Table 3
Distribution of the frequency of ONIHL per level of exposure, time of employment, position, and age group from 2003 to 2018 in a metallurgical plant in Pernambuco, Brazil ($N = 152$)

	Period 2003–2018																	
Indicators	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	Total	
No. of ONIHL																	Nº	%
Reference with ONIHL	17	1															18	11.8
ONIHL onset							1			1				1	2	1	6	3.9
ONIHL worsening							1					1			1	1	4	2.6
No. of ONIHL per noise exposure in dBA																		
NE ≥ 85	11						1					1			2	2	17	11.2
NE 80 to 84.9	3	1					1			1				1	1		8	5.3
NE < 80	3																3	2.0
No. of ONIHL per employment in years																		
>20	1													1	3	2	7	4.6
16–20	1									1							2	1.3
11–15	5	1					1					1					8	5.3
≤10	10						1										11	7.2
No. of ONIHL per position																		
Support	2													1			3	2.0
Maintenance	3	1					1			1					1		7	4.6
Production	12						1					1			2	2	18	11.8
No. of ONIHL per age group in years																		
≥50												1					1	0.7
40 to 49	6	1					2			1				1	3	2	16	10.5
<40	11																11	7.2

ONIHL = Suggestive of ONIHL and suggestive of onset or worsening at 3, 4, and 6 kHz.
Conventional sign used: - non-rounded numerical datum equal to zero.
Source: The authors.

old men with no otological or noise-exposure history. This finding suggests that the study population's impact on hearing acuity was lower than expected for a population exposed to noise – i.e., it suggests that noise exposure is well controlled in the plant approached in this study.

Audiograms before the start of the series were not analyzed. There may have been changes suggestive of ONIHL in reference audiograms since the workers' admission. There were 10 progressions suggestive of ONIHL in the 152 workers from 2003 to 2018. Regis et al. [22] evaluated 793 workers from a metallurgical plant without HCP and found an incidence of 19.7% of progressions in hearing thresholds suggestive of ONIHL onset, which is higher than in the present study. The binaural measure may have partially contributed to this difference, which, however, can be particularly justified by the HCP control measures developed in the company, thus reinforcing its importance.

This study found progression for those exposed to levels of 80 to 84.9 dB (A), which corroborates the findings of Oliva et al. [40] and Rabinowitz et al. [41], who also demonstrated the existence of hearing threshold changes in exposures below 85 dB (A).

Regarding the time trend of ONIHL, a change in the growth rate was observed from 2016 to 2018, with a statistically significant

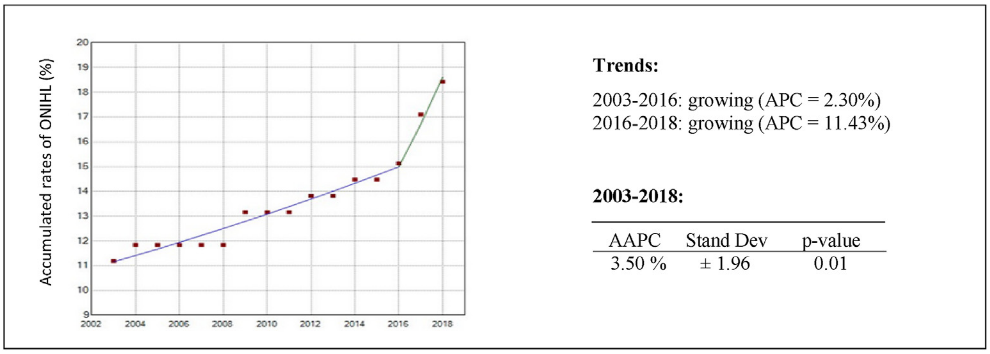

Fig. 1. Time trend of ONIHL in a metallurgical plant between 2003 and 2018 in Pernambuco, Brazil ($n = 152$). AAPC = Average annual percentage change, APC = Annual percentage change, ONIHL = Reference audiometry suggestive of ONIHL and progression of auditory thresholds suggestive of ONIHL (onset and worsening). Note: Annual percentage changes rounded to integers.

Table 4
Mean hearing thresholds in dB (HL) at 3, 4, and 6 kHz, per age group and time of noise exposure, of the best ear of workers with changes suggestive of ONIHL at the end of the series, compared with Almeida et al. (2000) [13] in a metallurgical plant in Pernambuco, Brazil ($N = 22$)

Indicators	3 kHz		4 kHz		6 kHz	
	Mean	SD	Mean	SD	Mean	SD
≥ 50-year age group and > 20-year exposure						
Almeida et al. ($n = 16$)	48.8	14.9	54.7	13.2	59.1	21.8
Study ($n = 11$)	18.6	9.1	28.2	8.9	27.3	10.7
Difference	30.1		26.5		31.8	
≥ 50-year age group and 16-to-20-year exposure						
Almeida et al. ($n = 6$)	47.5	15.1	50.0	15.5	46.7	25.4
Study ($n = 3$)	31.7	10.3	33.3	9.4	26.7	4.7
Difference	15.8		16.7		20.0	
40-to-49-year age group and > 20-year exposure						
Almeida et al. ($n = 30$)	39.8	16.3	48.2	15.5	49.3	18.9
Study ($n = 8$)	25.0	13.2	33.8	5.5	23.1	6.1
Difference	14.8		14.4		26.2	

SD, standard deviation.
Source: The authors.

increase in the annual percentage variation, which went from 2.3% to 11.4%. Two important aspects can be considered. The first is that this change in the development trend of the series, which had previously been stationary, suggests greater vulnerability in the population during this period, signaling the importance of investigating risk factors related to ONIHL. Is the increase in ONIHL cases from 2016 to 2018 associated with increased occupational noise exposure or with changes in company policy? The second aspect is that despite the increasing time trend, its pace did not follow what was expected for an exposed population, whose hearing thresholds would be much higher in the natural evolution of ONIHL [13].

The limitations of this study include the lack of otological complaint records, other audiological records, the partial inclusion of the effects of presbycusis in the evolutionary criteria [11], and the lack of conclusion on the causal link of cases suggestive of ONIHL.

5. Conclusion

The risk of ONIHL is only eliminated by removing noise. Despite the increasing time trend of ONIHL and the unmet expectation of a stationary trend in the study period, the mean percentage variation in the period was low. The time pace of ONIHL evolution did not follow what was expected for a population exposed to noise, whose hearing thresholds would be much higher in the natural evolution of ONIHL. We consider that the findings make a valuable contribution to public health, in the sense of signaling to workers, businesspeople, professionals, the scientific community, and public authorities that good ONIHL control is possible when HCPs are well implemented.

Research data for this article

Due to the nature of this study, the companies were assured that raw data would remain confidential and would not be shared (Data not available; the data that has been used is confidential).

CRediT authorship contribution statement

Adalva Virgínia Couto Lopes: Writing – review & editing, Writing – original draft, Visualization, Validation, Resources, Project administration, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Cleide Fernandes Teixeira:** Visualization, Validation, Methodology, Investigation, Formal analysis, Conceptualization. **Mirella Bezerra Rodrigues Vilela:** Visualization, Validation, Software, Resources, Methodology, Formal analysis, Conceptualization. **Maria Luiza Lopes Timóteo de Lima:** Visualization, Validation, Supervision, Resources, Methodology, Investigation, Funding acquisition, Formal analysis, Conceptualization.

Conflicts of interest

The authors have no conflict of interest to declare.

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