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Application for acoustic assessment: A pilot study in Parkinson's patients

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ABSTRACT

Background: Patients with Parkinson's disease (PD) often experience speech impairment that impacts their daily lives. The evaluation of abnormal voice qualities involves the use of both objective and subjective assessments. Subjective assessments encompass auditory-perceptual assessment and self-reports provided by the patient. On the other hand, objective evaluations include endoscopic images, aerodynamic assessments, and acoustic analyses. In speech therapy for PD patients, acoustic assessment provides accurate information to evaluate acoustic characteristics and support rehabilitation programs. However, access to acoustic assessment instruments is limited in Thailand due to their high price and lack of portability.

Objective: This study aimed to develop an Application for Acoustic Assessment (AAA) and to conduct a pilot study of the application among healthy aging (HA) and aging PD subjects.

Materials and methods: This study was a developmental research design comprising three phases. Phase one focused on the development of the AAA and the evaluation of the accuracy and precision of the application. A comparative analysis was conducted between AAA and Praat, a speech analysis software package, in phase two, among twenty HA. Five acoustic parameters, loudness, jitter, shimmer, high frequency (Hf_0), and low frequency (Lf_0), were used to determine concurrent validity. Phase three compared AAA and Praat with twenty aging PD subjects, examining the concurrent validity and test-retest reliability and comparing the acoustic parameters of HA users with those of the aging PD cohort.

Results: In phase one, the AAA shows vital accuracy ranging from 96.86% to 99.59% and high precision, with a Coefficient of Variation (%CV) of 1.65%-3.78%. In phase two, the concurrent validity of AAA compared with Praat in HA exhibited significant and very strong correlations ($r_s \geq 0.90$, $p<0.001$) in all acoustic parameters, except for shimmer, which showed substantial and robust correlations ($r_s=0.73$, $p<0.001$). In phase three, the concurrent validity of AAA compared with Praat in aging PD subjects exhibited significant and very strong correlations ($r_s \geq 0.90$, $p<0.001$) in loudness, Hf_0, and Lf_0, whereas substantial and robust correlations were shown in jitter ($r_s=0.85$, $p<0.001$) and shimmer ($r_s=0.82$, $p<0.001$). The Intraclass Correlation Coefficient (ICC) exhibited excellent reliability in all acoustic parameters (r>0.90). When comparing the HA and aging PD subjects using AAA, significant differences ($p<0.05$) were observed in all acoustic parameters, except for Lf_0 ($p=0.55$).

Conclusion: The AAA demonstrates high concurrent validity and reliability. It can effectively be utilized for PD group testing as an alternative tool for evaluating acoustic characteristics and aiding in treatment planning.

Introduction

Parkinson's disease (PD) is a neurodegenerative disorder, following Alzheimer's disease (AD) in prevalence, that is predominant among the group of neurodegenerative movement disorders.[1] It is found in approximately 1% of individuals aged over 60 years.[2] In Thailand, the prevalence of PD was 706 per 100,000 people aged over 50 years.[3] Additionally, hypokinetic dysarthria, which is a motor speech disorder, is found in approximately 89% of PD patients.[4,5] This symptom causes phonation, articulation, and prosody abnormalities, leading to hypophonia, monotone speech, reduced speech intelligibility, and imprecise articulation.[5-7] In a study by Rusz *et al*., it was demonstrated that 78% of untreated PD patients show abnormalities in phonation, articulation, and prosody.[8] Additionally, in acoustic parameter tests, a study by Fox and Ramig showed that the PD group exhibited decreased loudness compared to the healthy group.[9] Meanwhile, Suphinnapong *et al*. found that jitter and shimmer were higher in the PD group than in the healthy group.[10] These speech abnormalities lead to difficulties in social interaction and daily activities and a diminished quality of life. Additionally, these communication challenges often lead to a loss of confidence, prompting behaviors that avoid social interaction.[7]

Evaluation of abnormal voice qualities can be divided into subjective and objective evaluation. The subjective evaluation uses auditory-perceptual assessment, where listeners rate voice quality using scales such as GRBAS or CAPE-V, and self-evaluation of voice quality by the patient such as Voice Handicap Index (VHI).[11,12] In contrast, objective evaluation uses instruments to assess voice abnormalities, including endoscopic imaging, aerodynamic assessment, and acoustic assessment.[13] In acoustic assessment, characteristics such as loudness, jitter, shimmer, maximum vocal frequency, and minimum vocal frequency are typically evaluated.[11,13]

One commonly used tool for acoustic assessment is the Computerized Speech Lab (CSL™), which can evaluate various acoustic characteristics. However, its high price and lack of portability remain limiting factors in Thailand.[14] In contrast, the Dr. Speech tool offers a more affordable alternative to CSL™ and can assess acoustic characteristics. However, it, too, remains relatively costly in Thailand. Alternatively, Praat, an open-source software package, is commonly used for acoustic analysis in research and clinical settings. It has the advantage of being free of charge, offering many features for acoustic analysis, and allowing customization through scripts. However, it requires regular updates to ensure uninterrupted functionality, cannot display results in real-time, and has a complex graphical user interface.[15]

Therefore, this study aims to develop an Application for Acoustic Assessment (AAA), a non-profit tool for evaluating voice abnormalities in Parkinson's patients. This application will assess acoustic parameters such as loudness, voice quality (jitter and shimmer), and pitch [high frequency (Hf_0) and low frequency (Lf_0)]. It is designed to be compatible with multiple operating systems, portable on Android smartphones or tablets, user-friendly, and cost-effective for a pilot study group.

Materials and methods

Study design

This research was developmental, aiming to develop AAA. The purpose of AAA is to evaluate acoustic characteristics, including loudness, jitter, shimmer, Hf_0, and Lf_0, in healthy aging (HA) and aging PD subjects.

This study was divided into three phases: 1) developing the AAA and assessing its accuracy and precision in a laboratory setting, 2) evaluating the concurrent validity of the AAA in HA subjects, and 3) investigating the concurrent validity and reliability of the AAA in aging PD subjects. The acoustic parameters between AAA and Praat were also compared between the HA and PD groups. The testing protocol was conducted following the standards set by the American Speech-Language-Hearing Association (ASHA).[13] All data collection occurred in a soundproof room using an ATR-2500X-USB microphone positioned 8 cm from the mouth. The AAA acoustic data were collected via a tablet (Teclast M40Pro, Android 11), while the Praat data were collected using a laptop computer (Praat version 6.1.51).

Phase 1: Development of AAA

The researchers designed the layout of the AAA by studying the operational principles of currently employed tools for acoustic assessment and conducting a literature review. Then, the ideas were discussed with the advisor, and the selected ideas were used to develop the AAA together with a co-advisor at the Biomedical Engineering Institute (BMEI), Chiang Mai University. The AAA was designed to evaluate loudness, jitter, shimmer, Hf_0, and Lf_0 using an Android tablet. The researchers utilized the openSMILE 3.0 program,[16] software designed for extracting sound features from audio and music signals.

The researchers studied the accuracy and precision tests of the AAA at the BMEI Lab, Chiang Mai University, by performing vocal tasks. These tasks involved sustained phonation of /ah/ in a comfortable voice, at maximum loudness, average speech volume, high pitch, and low pitch, with each phonation lasting at least 3 to 5 seconds (Table 1). A comparison was conducted between AAA and Praat to assess accuracy. Each vocal task was repeated 10 times with a 1-minute rest during the precision test before moving on to the next test.

Table 1. List of the vocal tasks.

Task code	Speech data
[TASK 1]	Sustained phonation of /ah/ as loud as possible in a comfortable voice as constant and long as possible, at least 3-5 sec. This task was performed in one breath.
[TASK 2]	Sustained phonation of /ah/ at a normal speech volume in a comfortable pitch with loudness as constant and long as possible, at least 3-5 sec. This task was performed in one breath.
[TASK 3]	Sustained phonation of /ah/ at the highest pitch in a comfortable voice as constant and long as possible, at least 3-5 sec. This task was performed in one breath.
[TASK 4]	Sustained phonation of /ah/ at the lowest pitch in a comfortable voice as constant and long as possible, at least 3-5 sec. This task was performed in one breath.

Phase 2: Test of concurrent validity in HA

In this phase, concurrent validity testing was conducted among HA within the Faculty of Associated Medical Sciences, Chiang Mai University. Twenty HA were purposively selected based on the following inclusion criteria: 1) aged between 50 to 75 years; 2) understanding and use of Thai as their primary language for speaking, reading, and writing; 3) no neurological diseases, cognitive impairment, hearing loss, vision problems, or abnormal speech according to medical records; and 4) able to independently provide consent to participate in the research. Each of the acoustic parameters was evaluated with the same vocal tasks as those in phase one, first with AAA, then followed by Praat. Tests were conducted in the soundproof room at the Speech Clinic, Department of Occupational Therapy, Faculty of Associated Medical Sciences, Chiang Mai University. Each test was performed three times, and the best results were selected for analysis. The microphone was positioned 8 cm from the mouth. There was a 1-minute rest period between each task and a 5-minute rest before proceeding to the next test. Participants were excluded if they were unable to complete the testing process.

Phase 3: Test of concurrent validity and reliability in PD subjects

In this phase, concurrent validity and reliability testing were conducted by purposively selecting twenty PD subjects from the Parkinson's Clinic at the Northern Neuroscience Center, Faculty of Medicine, Chiang Mai University, and the Neurology Clinic, Department of Medicine, Mukdahan Hospital. The inclusion criteria were as follows:

1) Aged between 50 and 75 years.
2) Diagnosis as PD by a neurologist.
3) Using Thai as the primary language for speaking, reading, and writing.
4) No symptoms of Parkinsonism were observed that could be attributed to diseases other than Parkinson's disease.
5) No history of hearing loss or, if applicable, usage of a hearing aid meeting the standards recommended by an audiologist.
6) There is no history of vision problems, or if vision problems are present, the use of eyeglasses to aid vision is permitted.
7) No depression based on obtaining a score of <7 from 9 questions on the depression screening assessment (9Q) with either no symptoms of depression or very few symptoms (total score <7).[17]
8) No cognitive impairment was determined by using the Mental State Examination T10 (MSET10);[18] without meeting the criteria for suspected cognitive impairment, inclusion is based on the cutoff point criteria for scores as follows: for aging adults not attending school, a score of ≤14; for aging adults attending primary school, a score of ≤17; for aging adults attending education beyond primary school, a score of ≤22.
9) Must be capable of independently providing consent to participate in the research.

Subsequently, the test proceeded as in phase two. There were two additional rounds of testing to determine the test-retest reliability in the AAA section. In this phase, we compared the acoustic parameters of HA subjects from phase two with those obtained from the PD subjects in phase three. Participants were excluded if they were unable to complete the testing process

Statistical analysis

All data underwent statistical analysis using SPSS (IBM Corp. Released 2022. IBM SPSS Statistics for Mac, Version 29.0. Armonk, NY: IBM Corp).[19] In phase one, we utilized accuracy and precision to examine the AAA. In phases two and three, concurrent validity between AAA and Praat was analyzed using Spearman's correlation. In phase three, the test-retest reliability of AAA was assessed using the Intraclass Correlation Coefficient (ICC) with a two-way mixed effects model for multiple raters/measurements. The Wilcoxon signed-rank test was used to compare acoustic parameters between the HA and PD subjects.

Results

Phase 1: *Development of the AAA*

The AAA is divided into two main parts: the processing part and the display and recording part. The processing part was developed using openSMILE version 3.0.[16] The variables selected for evaluation included loudness, jitter, shimmer, Hf_0 and Lf_0. The audio data was imported using a condenser microphone (ATR-2500X-USB) (Figure 1).

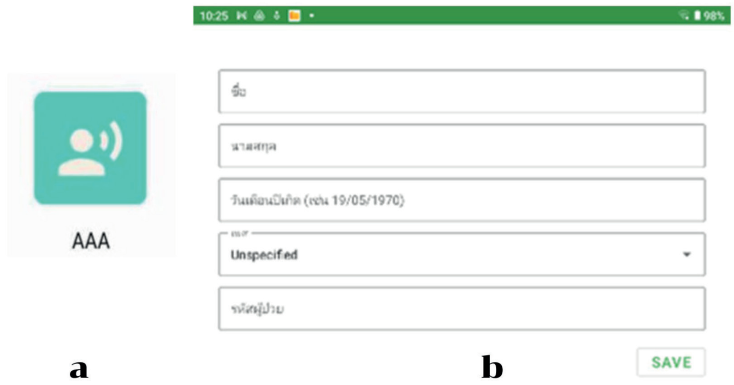

Figure 1. *Condenser microphone (ATR-2500-USB). a: AAA icon, b: participant data recording part.*

In the display and recording part, the display section is shown as a graph and can record audio for replay. Evaluation is conducted based on the processing part (Figure 2). Data is stored under user accounts in the recording section, and evaluation results are recorded for each assessment. The data are stored on the tablet's internal storage. In this study, the Teclast M40Pro running

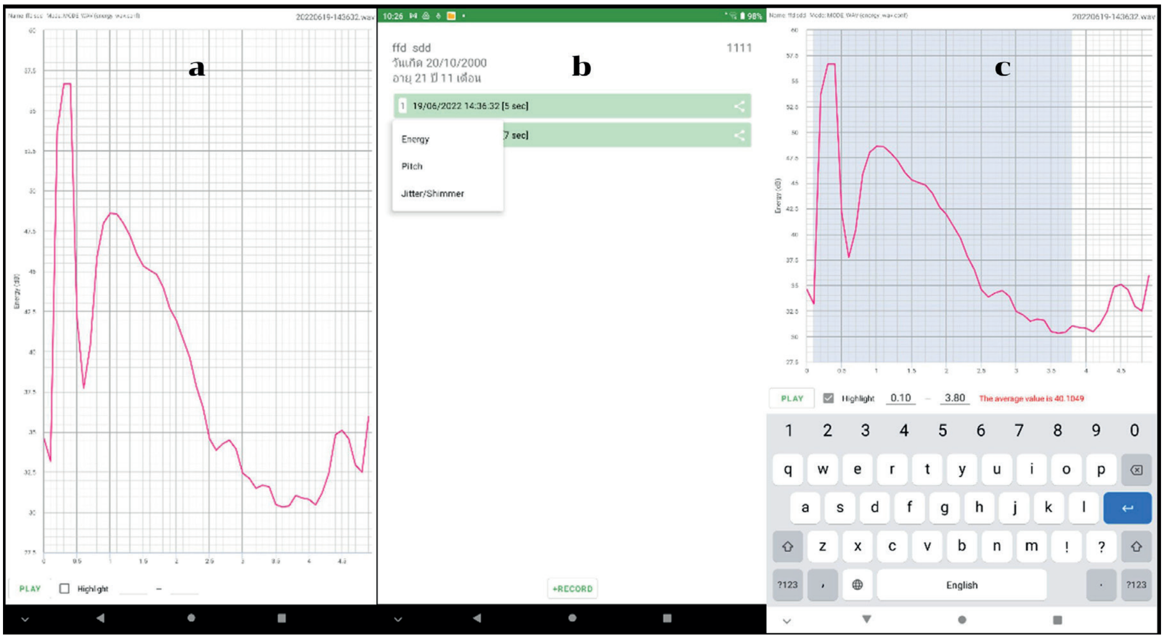

Figure 2. *An example of an AAA in the display section. a: test results graph, b: display of acoustic parameters for analysis, c: selection of the times period for analysis.*

Android 11 was utilized.

Assessing the accuracy of AAA involves calculating the percentage of accuracy compared to Praat.[20] The results show that the AAA achieved a percent accuracy ranging from 96.86 to 99.59, indicating that AAA has a similar value to Praat, which also exceeds 95% accuracy. In the precision test, we calculated the Coefficient of Variation (%CV) to assess the precision of the AAA.[20] The results show that the %CV for the AAA ranges from 1.65 to 3.78, within the acceptable limit of 5%, indicating that it can be used in clinical assessment.

Phase 2: *Test concurrent validity in HA*

Spearman's correlations were conducted between AAA and Praat to assess the concurrent validity of the acoustic parameters in HA group aged 50-70 years (9 males, 11 females) (Table 2).[21] The results demonstrated significant and strong correlations, mainly observed in loudness (r_s=0.94, p<0.001), jitter (r_s=0.94, p<0.001), Hf_0 (r_s=0.98, p<0.001), and Lf_0 (r_s=0.98, p<0.001). Additionally, a significant and strong correlation was demonstrated in shimmer (r_s=0.73, p<0.001) (Table 3).

Table 2. Demographic data of participants.

	HA (N=20)		PD (N=20)	
Number (N)	M	F	M	F
	9	11	15	5
Age (year)	61 (5.49)		64 (5.54)	
Age min-max (year)	50-70		54-74	

Note: age is expressed by mean (SD), M: male, F: female

Table 3. Concurrent validity in the HA and PD groups.

	HA (N=20)					PD (N=20)				
	Median (min, max)		Median difference	r_s	*p* value	Median (min, max)		Median difference	r_s	*p* value
	AAA	Praat				AAA	Praat			
Loudness (dB)	68.75 (61.34, 75.53)	68.52 (62.01, 77.66)	0.23	0.94	<0.001**	65.56 (54.63, 72.16)	64.61 (54.67, 71.74)	1.05	0.95	<0.001**
Jitter (%)	0.49 (0.30, 0.68)	0.46 (0.30, 0.64)	0.03	0.94	<0.001**	0.53 (0.18, 1.52)	0.48 (0.18, 1.47)	0.05	0.85	<0.001**
Shimmer (%)	4.93 (2.73, 7.28)	5.40 (3.22, 7.65)	-0.47	0.73	<0.001**	6.21 (3.26, 13.19)	6.59 (2.06, 13.14)	-0.38	0.82	<0.001**
Hf_0 (Hz)	254.89 (167.67, 440.45)	241.79 (163.74, 445.93)	13.10	0.98	<0.001**	214.18 (152.50, 307.21)	159.09 (153.03, 315.77)	55.09	0.94	<0.001**
Lf_0 (Hz)	179.65 (95.61, 227.07)	179.40 (81.45, 229.56)	0.25	0.98	<0.001**	162.11 (115.88, 217.09)	138.15 (120.60, 218.60)	23.96	0.98	<0.001**

*Note : *p<0.05, **p<0.001*

Phase 3: *Test of concurrent validity and reliability in PD subjects*

In the PD group aged 54-74 years (15 males, 5 females) (Table 2), significant and very strong correlations between AAA and Praat using Spearman's correlation were mainly observed in loudness (r_s=0.95, *p*<0.001), Hf_0 (r_s=0.94, *p*<0.001), and Lf_0 (r_s=0.98, *p*<0.001). Additionally, significant and robust correlations were demonstrated in jitter (r_s=0.85, *p*<0.001) and shimmer (r_s=0.82, *p*<0.001) (Table 3). ICC[22] was used to assess the test-retest reliability of AAA in the PD group. Significant and excellent ICC were demonstrated in all acoustic parameters (Table 4).

Table 4. Test-retest reliability of the acoustic parameters in PD using AAA.

Test-retest reliability (%)	Intraclass correlation[b]	95% CI		F Test with true value 0			
		Lower	Upper	Value	df1	df2	sig
Loudness (dB)	0.98[c]	0.95	0.99	49.04	19	38	0.00*
jitter (%)	0.95[c]	0.90	0.98	22.69	19	38	0.00*
shimmer (%)	0.95[c]	0.91	0.98	23.85	19	38	0.00*
Hf_0 (Hz)	0.99[c]	0.97	0.99	95.30	19	38	0.00*
Lf_0 (Hz)	0.98[c]	0.97	0.99	76.58	19	38	0.00*

Note: Two-way mixed effects model where people effects are random, and measures effects are fixed, b: type C intraclass correlation coefficients using a consistency definition, The between-measure variance is excluded from the denominator variance, c: this estimate is computed assuming the interaction effect is absent because it is not estimable otherwise.

Comparisons of the acoustic parameters between HA and aging PD subjects using the Wilcoxon signed rank test revealed significant differences in all acoustic parameters except for lf_0 (179.65 Hz vs. 162.11 Hz, *p*=0.55), whereas Loudness (68.75 dB vs. 65.56 dB, *p*<0.001), and Hf_0 (254.89 Hz vs. 214.18 Hz, *p<0.*001) were higher in HA than in the aging PD subjects. Additionally, jitter (0.49% vs. 0.53%, *p*=0.04) and shimmer (4.93% vs. 6.21%, *p*=0.03) were lower in HA than in the aging PD subjects (Table 5).

Table 5. Acoustic analysis for HA and PD using AAA.

	HA (N=20) Median (min, max)	PD (N=20) Median (min, max)	Median difference	95% confident interval Lower	95% confident interval Upper	*p* value
Loudness (dB)	68.75 (61.35, 75.54)	65.56 (54.63, 72.16)	3.19	-7.61	-1.85	<0.001**
Jitter (%)	0.49 (0.30, 0.68)	0.53 (0.18, 1.52)	-0.04	0.00	0.20	0.04*
Shimmer (%)	4.93 (2.73, 7.28)	6.21 (3.26, 13.19)	-1.28	0.14	2.91	0.03*
Hf_0 (Hz)	254.89 (167.67, 440.45)	214.18 (152.50, 307.21)	40.71	-74.80	-16.36	<0.001**
Lf_0 (Hz)	179.65 (95.61, 227.07)	162.11 (115.88, 217.09)	17.54	-31.93	15.36	0.55

*Note: *p<0.05, **p<0.001*

Discussion

In this study, we developed and designed an AAA for instrumental assessment of voice by ASHA.[15] In laboratory testing, the AAA has high accuracy and precision higher than 95% or 0.95, which is widely accepted in medical research.[23]

The concurrent validity of the acoustic characteristics in AAA compared with Praat in both the HA and PD groups demonstrated significant and very strong correlations, except for shimmer in the HA group and jitter and shimmer in the PD group, which showed substantial and robust correlations (Table 3). In the test-retest reliability analysis, the AAA also demonstrated significant and excellent ICC in all acoustic parameters of the PD group (Table 4). In the test results, it was found that the results obtained from AAA were almost all higher than those from Praat, as per the study by Maryn *et al*., which demonstrated that, in a comparison between Praat and the Multi-Dimensional Voice Program (MDVP), the results obtained from Praat were lower than those from MDVP.[24] As observed in the study by Vaz-Freitas *et al*. Praat, MDVP, VoiceStudio, and Dr. Speech were tested, and the results obtained from Praat were consistently lower.[25] Previous studies suggest that Praat generally yields lower measurements than other programs, except for jitter and shimmer, for which Praat has higher measurements than Dr. Speech. These findings are consistent with the results of this current research. This demonstrates that AAA can be used for acoustic assessment on par with other instruments. Additionally, the researcher plans to collaborate with BMEI to develop AAA to enhance tools such as tremor voice analysis. This collaboration seeks to achieve more comprehensive results by including data collection on subjects with other types of voice disorders, such as hoarseness, amyotrophic lateral sclerosis, and presbyphonia, in future studies.

The main abnormalities in the PD group include the following: 1) a decrease in loudness, which is attributed to incomplete closure of the vocal cords, creating space between the vocal folds; 2) tremor, breathiness, and hoarseness of voice, as it was also found that higher jitter and shimmer were present due to decreased flexibility and reduced coordination of vocal cord movement; and 3) speaking in a monotone with no pitch and having lower frequencies than usual, which is a condition caused by a decreased ability to control the air pressure under the larynx, which affects pitch control.[8-9,26] In this study, when comparing the results obtained from the AAA between the HA and PD groups, voice abnormalities in PD with significant differences in all acoustic parameters except for Lf_0 were demonstrated (Table 5). In a study by Fox and Ramig, it was shown that there was a decrease in loudness in the PD group compared to the HA group.[26] Furthermore, in the study by Suphinnapong et al., the PD group exhibited significantly higher levels of jitter and shimmer compared to the healthy group,[10] whereas the decrease in Hf_0 and Lf_0 can be attributed to the limited pitch control of PD.[26]

Limitations

The present study did not investigate the duration or severity of Parkinson's disease, including other symptoms in patients. Additionally, this study only collected data from the PD group and did not include different groups of patients with voice disorders.

Conclusion

This research aimed to develop and test an AAA that evaluates acoustic characteristics, including loudness, jitter, shimmer, Hf_0, and Lf_0, by sustaining the vowel /ah/. The test results indicate that the AAA can effectively assess voice abnormalities associated with aging PD subjects in this pilot study. In this regard, the AAA is convenient for mobility as it is utilized via a tablet, which is a portable device. The program incurs no cost as it was developed using open-source technology and yields accurate evaluation results. The researchers anticipate this AAA will be an alternative tool for evaluating acoustic characteristics. Finally, researchers should focus on gathering data from other voice disorder groups in future work.

Ethical approval

This study was approved by the Research Ethics Committee of the Faculty of Associated Medical Sciences, Chiang Mai University (Approval ID: AMSEC-65EX-027), the Research Ethics Committee of the Faculty of Medicine, Chiang Mai University (Study code: None-2565-0004 Research ID:0004), and the Ethics Committee for Human Research of Mukdahan Hospital (Approval ID: MEC 25/66). All participants received the complete necessary information related to the research, and informed written consent was obtained before their enrollment into the study.

Conflict of interest

The authors declare that they have no conflicts of interest.

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