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E-Health rehabilitation on clinical, quality of life, and functional capacity in cardiovascular disease: preliminary results

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Abstract

This study aims to evaluate the preliminary effects of an e-health-based rehabilitation program delivered by a new technological solution, named eHeart, on functional capacity domains by assessing pre- and post-effects on cardiorespiratory fitness, quality of life, strength, and flexibility. The nine initial patients enrolled in this preliminary study were predominantly male (57%), elderly, with CVD, 4 of whom were diagnosed as HF, mostly with I and II NYHA functional class, and arterial hypertension (100%). Among the standard physical assessment domains changes pre and post-remote rehabilitation utilizing the eHeart technological platform, we observed a substantial increase in the cardiorespiratory capacity after rehabilitation in the number of 6MST steps (89 ± 47 versus 129 ± 48, $p = 0.002$), with a high D Cohen value (41.2) along with a substantial reduction on the resting rate (HR, bpm) (69 ± 10 versus 63 ± 10 bpm, $p = 0.003$) with a D Cohen of 25.4. Other variables (HR peak, SBP rest and peak, DBP rest and peak) did not present a significant difference following the remote protocol ($p < 0.05$). We observed a significant improvement after the rehabilitation in the isometric muscle strength of elbow flexion (13 ± 5 versus 18 ± 7, $p = 0.04$, D Cohen of 6.14) and in quality of life by the EQ-5D-5 L (0.57 ± 0.26 versus 0.71 ± 0.17, $p = 0.04$, D Cohen of 0.16). The conclusion of our study highlights the significant benefits of e-health in improving functional capacity, quality of life, and isometric muscle strength in individuals with CVD. Through 14 sessions, we observed marked improvements in these key health indicators, suggesting that e-health can be a valuable tool in the management of various health conditions.

Keywords Rehabilitation, Quality of life, Functional capacity, Cardiovascular disease

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Introduction

On-site rehabilitation programs have been proven to effectively improve the functional capacity and quality of life of cardiovascular disease (CVD) individuals, facilitating their return to daily activities [1–10]. However, traditional in-person rehabilitation services face limitations, including accessibility barriers, referral, participation adherence, patient motivation, lack of trained personnel, and awareness about CR [2–4].

Telerehabilitation for e-health, which involves delivering rehabilitation services through telecommunication technologies, has emerged as a promising alternative to traditional in-person rehabilitation, offering several advantages, including providing care remotely, overcoming geographical barriers, and improving access to care for individuals in rural or underserved areas [3]. Additionally, effectively improves functional outcomes and patient satisfaction, making it a valuable tool for rehabilitating CVD individuals [3]. A personalized telerehabilitation program demonstrated an increase in peak aerobic capacity and health-related quality of life compared to in-person rehabilitation alone [11]. Similarly, hybrid programs that combine telerehabilitation with in-person approaches show sustained long-term benefits in physical capacity and the management of cardiovascular risk factors [12].

However, the impact of e-health-based rehabilitation programs specifically tailored for individuals with CVD has limited availability. Therefore, this study aims to evaluate the preliminary effects of an e-health-based rehabilitation program delivered by a new technological solution, named eHeart, on functional capacity domains by assessing pre- and post-effects on cardiorespiratory fitness, quality of life, strength, and flexibility. By investigating the effectiveness of e-health-based rehabilitation in CVD patients, we hope to provide valuable insights into the potential benefits of telehealth interventions in improving the health outcomes of individuals with CVD.

We hypothesize that a rehabilitation program based on digital health, implemented through the new technological solution called eHeart, will have positive effects on multiple domains of functional capacity. Specifically, the program is expected to improve cardiorespiratory fitness, quality of life, strength, and flexibility after the intervention.

Methods

This preliminary study involves an initial group of nine patients with CVD. The center responsible for the research was the Laboratory of Exercise Physiology (LabFCE) from the University of Brasilia (UnB), Ceilândia campus (FCE). The Research Ethics Committee approved the study (registration no. CAAE 66968223.2.0000.8093). Patient enrollment was conducted from July to October 2023. The trial was recorded on the REBEC: RBR-10rssrtj. All experiments were performed following relevant guidelines and regulations. Furthermore, all procedures followed the precepts of the Declaration of Helsinki and the Committee for International Harmonization for Human Research.

Recruitment was based on the snowball method, utilizing social and scientific communities. The inclusion criteria were: (1) Diagnosis of CVD, confirmed through prior clinical and echocardiogram assessment; stratifying patients according to New York Heart Association (NYHA) functional class; (2) Clinically stable for at least 1 month; (3) Age over 45 years old; (4) Able to climb steps without assistance; (5) With access to a smartphone and internet. The exclusion criteria were: (1) Complex ventricular arrhythmias; (2) Patients with NYHA functional class IV; (3) Patients with grade 3 or 4 on the Canadian Cardiovascular Society (CCS) Angina; (4) Previous severe lung or pleural disease; (5) Severe anemia; (6) Decompensated diabetes mellitus or metabolic diseases; (7) Orthopedic disease, peripheral vascular insufficiency, or previous neurological disease that impairs the ability to perform the exercises; and (8) Cognitive impairment.

eHeart app's main steps

The eHeart App includes main areas where the patients had access, including (1) eligibility screening, (2) patient scheduling and communication tool with health care professionals, (3) clinical assessment and health record, (4) mental health assessment, (5) baseline physical assessment, (6) exercise prescription, (7) tailored exercises session and monitoring, 6) health behavior and education contend, (8) follow-up physical assessment, with the option to conclude the program or to receive an updated exercise prescription.

eHeart standard clinical and physical assessments

The eHeart app includes standard clinical and physical assessment through standardized and validated questionnaires and tests, allowing remote application, including:

1) Screening and clinical assessment utilizing standardized forms.
2) Mental health assessment utilizes the Mini-Mental State Examination.
3) Standard physical assessment includes:

3a) 6-min step test and the timed 4-m walk at the participant's average pace from the SPPB for the cardiorespiratory capacity,
3b) The timed repeated chair sit-to-stand test from the Short Physical Performance Battery (SPPB) for muscle strength,

3c) the 10-s balance tests, with feet side-by-side, semi-tandem, and full-tandem from SPPB for balance capacity,
3d) the functional reach and the sit and reach tests for flexibility.

Complementary clinical and physical assessments

For clinical safety and scientific comparisons, patients were assessed through additional on-site clinical and physical assessments, including:

1) Screening and clinical assessment, including.

1a) Complementary medical examination,
1b) Routine Left ventricular systolic, diastolic function and right ventricular systolic function through Echocardiography,
1c) Pulmonary function through Spirometry.
1d) Cardiopulmonary exercise test (CPET).

2) Complementary physical assessment includes:

3a) CPET for cardiorespiratory capacity,
3b) Flexion and extension isometric quadriceps strength (IQS) and hand grip strength through isometric dynamometer assessment for muscle strength.

Content for individualized exercise prescription

To ensure the individuality of prescriptions, remote sessions were programmed according to 5 exercise prescription criteria, including (a) exercise intensity, (b) exercise complexity, (c) exercise domains to be worked on, (d) weekly and total prescription frequency, and (e) duration of sessions.

In Fig. 1, some application steps are presented on Fig. 1A: home page with an illustration of the cycle the participant is enrolled in, the levels of each domain, and the session in which they are. Figure 1B illustrates a part of the screening phase where the participant is asked about the health conditions to indicate "yes," "no," or "I don't know." Fig. 1C illustrates the information before starting the rehabilitation session so that the participant can indicate their vital signs (blood pressure, heart rate, and peripheral oxygen saturation). Figure 1D contains the screen to start the videos with the rehabilitation session exercises.

As a fundamental part of creating a cardiovascular rehabilitation program via e-health, it was necessary to develop various assessments, prescriptions, and monitoring content. A library of exercises was made with different intensities (criterion 1) and complexities (criterion 2), health education content, and guidance videos regarding assessments, directing each patient, according to their verified clinical condition, to the most individualized prescription. This exercise library was created based on prior

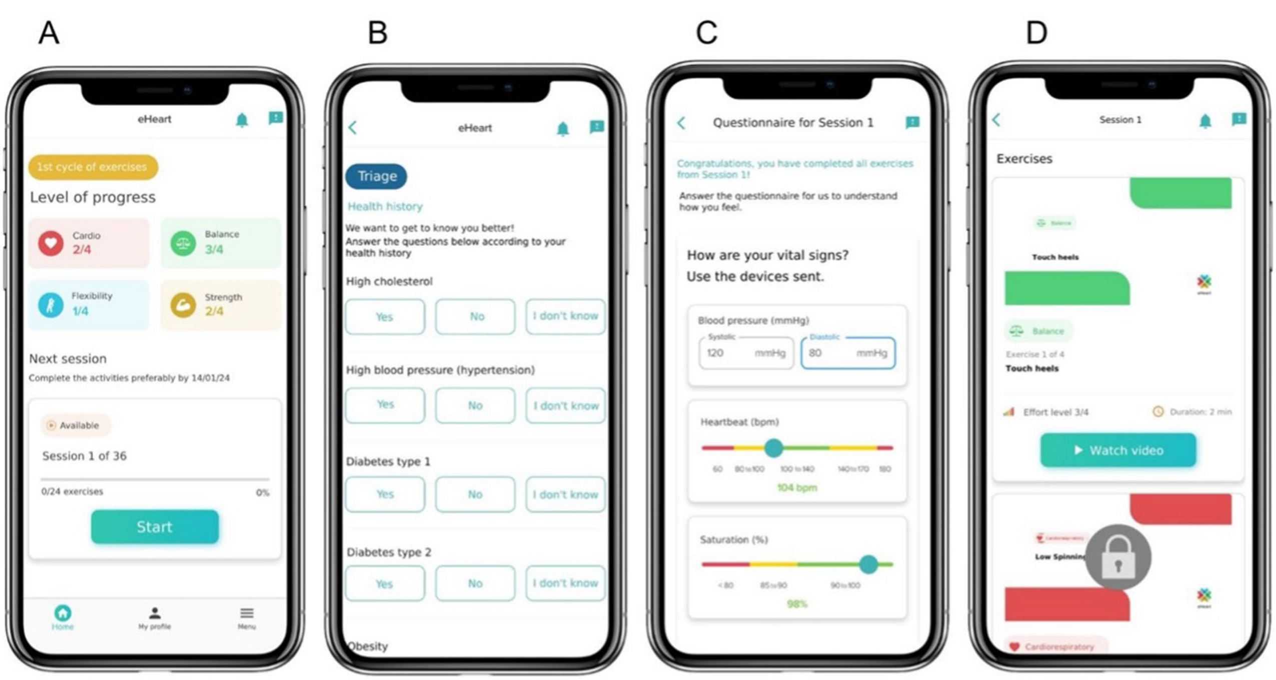

Fig. 1 Some phases of the application. A: home page with illustration of the cycle the participant is in the levels of each domain. B: illustrates a part of the screening phase where the participant is asked about the health conditions to indicate "yes", "no" or "I don't know". C: illustrates the information before starting the rehabilitation session to for the participant to indicate their vital signs (blood pressure, heart rate and peripheral oxygen saturation). D: the screen to start the videos with the telerehabilitation session exercises

planning of the exercises to be used, and the researchers subsequently produced the audiovisual content to meet the demands of a cardiovascular rehabilitation program in 4 Domains of prescription regarding the type of exercise (criterion 3), these being: (a) Cardiorespiratory, (b) Strength, (c) Balance, and (d) Flexibility.

The weekly frequency criterion (criterion 3) was carried out thrice weekly for three months, totaling 36 sessions. Each training session lasted between 40 and 60 min (criterion 4). Similarly, all treatment intensities (criterion 1) were allocated into four categories: (1) Moderate/A, (2) Moderate/B, (3) High/A and (4) High B in addition to the exercise complexity (criterion 2): (1) Adaptation, (2) Beginner, (3) Intermediate, and (4) Advanced. Regarding periodization (criterion 6), the sessions were organized into six stages: (1) Warm-up, (2) Strength exercises, (3) Balance, (4) Flexibility, (5) Cardiorespiratory, and finally, (6) Cool-down.

In addition, 128 videos regarding several topics were produced and created, including (a) rehabilitation program welcome message and opening (1 video), (b) clinical and physical assessment (5 videos), (c) health behavior and education (5 videos), (d) exercise prescriptions in all four intensities and four complexity levels (111 videos) and (e) rehabilitation program closing and follow-up.

After initial contact and downloading of the App from the appropriate digital Store (https://linktr.ee/eheartapp), the patients received an individual access code to access and utilize the App in a user (patient) login area, with the possibility of "navigate" in all areas of the eHeart App, including (1) screening, (2) clinical evaluation, (3) physical evaluation, (4) exercise prescription and (5) one cycle of the exercises session, allowing the participant to participate for 15 session and be remotely assessed at baseline and 5 weeks later, providing them the capability of answering the standardized usability questionnaire.

Measurement

Quality of life

The EQ-5D-5 L defines 243 possible health states. Each health state generated can be converted into a unique EQ-5D-5 L score or index, which incorporates social preferences for health states [13].

Short Physical Performance Battery (SPPB) [14].

a. Balance Test: The participant will be instructed to remain in each of three positions for 10 s.
b. Sitting down and getting up from a chair: A chair without arms or backs, with a rigid seat, stabilized and placed against the wall, with a height from floor to seat of 47 cm, will be used. Subjects will begin in the sitting position on the chair and, on command, will stand up and sit back down as many times as possible within 30 s.
c. Gait Speed Test: Three or four meters will be marked on the ground with masking tape for the walking speed test.

Physical assessments

CPET protocol was conducted using a Corival stationary bicycle (Lode, Netherlands) as the ergometer. Standardization included environmental temperature control and proper calibration of the METALYZER 3B metabolic analyzer (CORTEX Biophysik, Germany) following the manufacturer's instructions [15]. Analysis of ventilation and gas exchange measures, including HR: heart rate; WR: work rate; $\dot{V}O_2$: oxygen uptake; RER: respiratory exchange ratio; VE: Minute ventilation; VCO_2: carbon dioxide production; VE/VCO_2 slope: linear relation between minute ventilation and carbon dioxide production; SBP: Systolic blood pressure, and DBP: Diastolic blood pressure.

Six-minute step test

Before the test, patients were instructed to remain seated for five minutes at rest. Meanwhile, a physiotherapist explained the test to the patient [16]. The test was based on the criteria of the *American Thoracic Society (ATS 2002)* [17]. Patients were instructed to climb up and down as many steps as possible for six minutes with free cadence or even stop the test if the subject felt the need, so one of the physiotherapists noted when the patient stopped during the test or returned.

Handgrip strength

Three measurements were performed using a digital hand-held dynamometer (Instrutherm®, Brazil), standing position for each hand, at 1-min intervals, with the elbow straight and fully extended, alternating between dominant and non-dominant sides. Each arm's maximum value was derived, while HGS was defined as the highest value of the six attempts [18].

Rehabilitation protocol

The volunteers began by receiving access to the first module of content. In this module, a total of five videos provided information regarding the initial assessments, demonstrating and guiding how the evaluations for each domain would be conducted.

At the same time, the patient received a set with standardized materials for evaluation and training, consisting of (1) three elastic tube pairs with standardized resistance (E-lastic, E-sport soluções esportivas, Rio de Janeiro, Brazil); (2) an oximeter for peripheral oxygen and pulse rate assessment (G-TECH, Beijing, China); (3) a standardized step with 20 cm of high, specially designed for cardiorespiratory and flexibility assessment according to the scientific literature (eHeart step prototype n. 4, Di

Salvatori, Ceilandia, Brazil); (4) a portable digital manual dynamometer (DM-90, Instrutherm, São Paulo, Brazil); and (5) a digital blood pressure measurement device (G-TECH, Zhejiang, China).

The patients received an initial individualized exercise prescription based on the information obtained during the evaluation. Each week, participants were provided with a health education video on topics related to cardiovascular health management. The exercises were performed using the materials provided in the pre-sent kit. The prescription for each of the exercise sessions (14 sessions) was provided through individualized videos. These included exercises focusing on balance, cardiorespiratory fitness, peripheral muscle strength, and flexibility, performed three times per week, with at least one recovery day in between sessions (See Table 1).

Patients were also monitored weekly through engagement and standardized messages via an app, requesting feedback about each exercise session. This feedback included biological data collected during the training sessions (Heart Rate, Perceived Exertion, and Oxygen Saturation).

Table 1 Clinical characteristics of the patients submitted to a e-health

Variables	*N* = 9
Sex, men	5 (57)
Age (years)	62 ± 9
Weight (kg)	75 ± 1
BMI, kg/m^2	27 ± 4
NYHA II	4 (44)
Comorbidities, n(%)	
Diabetes	4 (44)
Arterial hypertension	9 (100)
Echocardiogram	
LVEF (%)	64 ± 30
LVEF < 50%	4 (45)
TAPSE	21 ± 3
CPET	
Peak VO_2 (kg/L/min)	18 ± 6
Predicted VO_2 peak (%)(11)	40 ± 1
HR peak (bpm)	124 ± 15
VE/VCO_2 slope	37 ± 9
VE/VCO_2 slope > 34, (%)	4 (44)
VE peak (l/min)	61 ± 27
O_2 pulse (mL/beat)	11 ± 4
WR peak (W)	105 ± 41

Notes NYHA: New York Heart Association; LVEF: left ventricular ejection fraction; TAPSE: tricuspid annular plane systolic excursion; CPET: cardiopulmonary exercise testing; HR: heart rate; WR: work rate; VO_2: oxygen uptake; RER: respiratory exchange ratio; VE: Minute ventilation; VCO_2: carbon dioxide production; VE/VCO_2 slope: linear relation between minute ventilation and carbon dioxide production; SBP: Systolic blood pressure, DBP: Diastolic blood pressure.

Statistical analysis

Following the Shapiro-Wilk test to assess data normality, continuous variables were presented as mean and standard deviation (mean ± SD) and categorical in absolute frequency and percentages (n (%)). We compared continuous variables utilizing the paired Student's t-test and the categorical. Cohen's D value was used to evaluate the effect size, Small effect: 0.2 to < 0.5; Medium effect: 0.5 ≤ 0.8; Large effect: ≥0.8 [19]. A p-value > 0.05 was accepted as statistically significant. Cohen's D value was used to evaluate the effect size, considering the e-health. The analysis was conducted using the SPSS Statistics Software, Version 20, for MAC, IBM, and Brazil.

Results

We initially evaluated 20 patients, but we lost 11 patients due to dengue ($n = 1$), COVID-19 ($n = 4$), non-compliance with rehabilitation ($n = 5$) and cardiovascular procedures ($n = 1$). During the rehabilitation process, only nine patients completed the protocol. The initial nine patients enrolled. The nine initial patients enrolled in this preliminary study were predominantly male (57%), elderly, with CVD, 4 of whom were diagnosed as HF, mostly with I and II NYHA functional class, and arterial hypertension (100%).

Among the standard physical assessment domains changes pre and post-remote rehabilitation utilizing the eHeart technological platform, we observed a substantial increase in the cardiorespiratory capacity after rehabilitation in the number of 6MST steps (89 ± 47 versus 129 ± 48, $p = 0.002$), with a high D Cohen value (41.2) along with a substantial reduction on the resting rate (HR, bpm) (69 ± 10 versus 63 ± 10 bpm, $p = 0.003$) with a D Cohen of 25.4. Other variables (HR peak, SBP rest and peak, DBP rest and peak) did not present a significant difference following the remote protocol ($p < 0.05$).

We observed a significant improvement after the rehabilitation in the isometric muscle strength of elbow flexion (13 ± 5 versus 18 ± 7, $p = 0.04$, D Cohen of 6.14) and in quality of life by the EQ-5D-5 L (0.57 ± 0.26 versus 0.71 ± 0.17, $p = 0.04$, D Cohen of 0.16) (Table 2).

Discussion

This study evaluated the effect of an e-health-based rehabilitation program, utilizing a new technological solution named e-Heart, on functional capacity, quality of life, and isometric muscle strength in individuals with CVD. We found that after 14 sessions, patients showed marked improvement in functional capacity, resting heart rate, quality of life, and elbow flexion. Evaluating the effect of e-health-based rehabilitation programs on functional capacity in individuals with cardiovascular disease is crucial due to persistent symptoms such as fatigue and

Table 2 Patient response baseline and post e-health

Standard and Comprehensive Physical Capacity Assessment Domains	Baseline (*n* = 9)	Post (*n* = 9)	*P* value	D Cohen
Quality of life				
EQ-5D-5 L (score geral)	0.57 ± 0.26	0.71 ± 0.17	**0.03**	0.16
Cardiorespiratory capacity				
6MST				
Steps	89 ± 47	129 ± 48	**0.02**	0.83
HR rest (bpm)	69 ± 10	63 ± 10	**0.03**	0.83
SBP rest (mmHg)	130 ± 14	131 ± 21	0.81	0.82
DBP rest (mmHg)	83 ± 15	83 ± 12	0.93	0.02
HR peak (bpm)	110 ± 18	108 ± 13	0.79	0.09
SBP peak (mmHg)	160 ± 23	158 ± 20	0.58	0.18
DBP peak (mmHg)	91 ± 18	88 ± 14	0.36	0.32
Muscle strengh				
Timed repeated sitting down and getting up from a chair from SPPB	3.8 ± 0.3	3.8 ± 0.2	0.34	0.33
HGS (kg/f)	27 ± 11	29 ± 14	0.33	0.32
Isometric muscle strength				
Knee flexion (kg)	19.7 ± 9.7	23.7 ± 8.5	0.09	0.27
Elbow flexion (kg)	13.4 ± 5.4	18.4 ± 7.8	**0.04**	0.48
Balance Capacity				
SPPB balance Test	3.4 ± 1.0	3.6 ± 1.0	0.16	0.18
SPPB total	10 ± 2	11 ± 1	0.11	0.45
SPPB sitting down and getting up from a chair	3.8 ± 0.3	3.8 ± 0.2	0.34	0.33
SPPB flexibility	3.0 ± 1.4	3.5 ± 0.7	0.17	0.44

Notes: Student's T-test; SBP: systolic blood pressure; DBP: diastolic blood pressure; HR: heart rate; HGS: hand-grip strength. HR: heart rate; SBP: Systolic blood pressure, DBP: Diastolic blood pressure and SSPB: Short Physical Performance Battery

reduced exercise tolerance, which can significantly impact functional capacity.

Clinical studies have demonstrated comparable effectiveness between center-based and home-based cardiac rehabilitation programs in enhancing lifestyle and wellness perceptions among cardiac patients, regardless of their revascularization status or clinical history of acute myocardial infarction [20]. A systematic review confirmed the equivalent efficacy of home-based and center-based cardiac rehabilitation programs in improving lifestyle and clinical outcomes for patients with a history of heart failure, revascularization, or myocardial infarction [20].

Furthermore, the reduction in HR at rest represents an improvement in the prognosis of the disease, as resting heart rate is central to cardiac output and an important marker of outcome in cardiovascular diseases [21]. Therefore, telerehabilitation helps to prevent, manage, and treat diseases using high-quality software programs. This evidence-based behavioral treatment is delivered online to increase healthcare access and effectiveness. Health monitoring gradually expands from hospitals and treatment centers to the digital world. Understanding how e-health interventions can improve functional capacity in these individuals is essential for developing effective rehabilitation strategies. This study demonstrated the effectiveness of the eHeart app for cardiopulmonary rehabilitation. The main limitations of the study were patient adherence to the study protocol.

The conclusion of our study highlights the significant benefits of e-health in improving functional capacity, quality of life, and isometric muscle strength in individuals with CVD. Through 14 sessions, we observed marked improvements in these key health indicators, suggesting that e-health can be a valuable tool in the management of various health conditions. These findings support the growing body of evidence supporting the efficacy of e-health in delivering effective care to patients, particularly in situations where traditional in-person care may not be feasible or accessible. Further research and implementation of telerehabilitation programs could greatly benefit patients, healthcare providers, and healthcare systems alike, offering a cost-effective and convenient alternative to traditional rehabilitation methods.

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Author contributions
Cássia da Luz Goulart, Marcela Lopes Alves, Fernando D'Angelo Medeiros, Robson Fernando Borges, Maurício Milani, Luciana Bartolomei Orru D'Ávila, Claudia Cristina Conde Holanda Sobral, Ana Cleides, Graziella França B. Cipriano e Gerson Cipriano Junior: All authors reviewed the manuscript.

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Data availability
The datasets used or analyzed during the current study are available from the corresponding author upon reasonable request.

Declarations

Ethics approval and consent to participate
The study was approved by the Research Ethics Committee of the University of Brasília (registration number CAAE 66968223.2.0000.8093). Patient enrollment was conducted from July to October 2023. The trial was recorded on the REBEC: RBR-10rssrtj. All experiments were performed following relevant guidelines and regulations. Furthermore, All participants provided written informed consent before enrollment in the study, in accordance with the ethical principles outlined in the Declaration of Helsinki and the Committee for International Harmonization for Human Research.

Consent for publication
Not Applicable.

Competing interests

The authors declare no competing interests.

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