

Original Research

## Breaking Cognitive Barriers: Comparing Neurobic and Aerobic Approaches in Dementia Care

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### Abstract

The study aimed to compare the effects of neurobic and aerobic approaches in Dementia care. Dementia is a progressive brain disorder that leads to a decline in cognitive abilities, including thinking, reasoning, and memory. In India, it is estimated that 74% of adults aged 60 and older are affected, totaling around 8.8 million individuals. Neurobics refers to exercises designed to enhance oxygen flow and invigorate the brain by engaging in novel activities, situations, or experiences. This may include attending live performances, trying a new sport, exploring new locations, or taking a different route home. Conversely, aerobic exercise, such as walking or jogging, focuses on oxygen consumption to satisfy the body's metabolic needs. Both neurobics and aerobics support the elderly by fostering cognitive and physical health, respectively. This study seeks to raise awareness about how exercise can help prevent the onset of cognitive decline in older adults. This cross-sectional comparative study was conducted in elderly homes around Anakaputhur, Chennai, over 6 months, with an intervention duration of 12



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weeks. A total of 50 participants aged 60 years and above were selected using simple random sampling. Both male and female participants were included in the study. Inclusion criteria: individuals with mild to moderate dementia as diagnosed by a neurologist on the Dementia severity scale score 18-36, the ability to follow simple instructions, the capability for light to moderate physical activity, and no history of psychiatric disorders. Exclusion criteria included severe dementia (Dementia severity scale score 37-54), severe cardiovascular disease, uncontrolled psychiatric conditions, mobility issues, and severe hearing or vision loss. Based on the inclusion and exclusion criteria, the participants were randomly divided into two equal groups of 25 each: one group underwent neurobics training, and the other underwent aerobics training. Both groups participated in 30-minute sessions, five times per week, for 12 weeks. The intervention aimed to enhance cognitive function and memory. Pre- and post-intervention assessments were conducted using standardized tools, including the Montreal Cognitive Assessment (MoCA), the Informant Questionnaire on Cognitive Decline in the Elderly (IQCODE), and the Digit Span Test. On comparing pre- and post-test within Group A and Group B, the Group B intervention was found to be more effective than Group A on IQCODE, MoCA, and Digit span test, with significant differences in mean values at  $P < 0.05$ .

### **Keywords**

Dementia; neurobics; aerobics; cognition

## **1. Introduction**

Cognitive function gradually deteriorates as the human brain gradually loses tissue starting in the third decade of life [1]. According to the World Health Organization's (WHO) ICD-10 classification of mental and behavioural disorders, dementia is a syndrome that arises from a brain disease that is often chronic or progressive in character. Memory, reasoning, comprehension, computation, learning, language, and judgment are among the higher cortical processes that are impaired. These disabilities frequently coexist with shifts in motivation, social conduct, or emotional regulation [2]. Dementia is a collection of symptoms linked to underlying illnesses including Alzheimer's disease, frontotemporal dementia, Lewy body dementia, and vascular dementia rather than a single illness [3]. Patients rarely exhibited symptoms such as catastrophic reactions, nighttime wandering, suspicious behavior, and communication difficulties. However, caregivers reported experiencing feelings of anger, depression, and fatigue [4].

According to estimates, there were 50 million dementia sufferers worldwide as of 2018, and by 2050, that figure is expected to triple. In developing nations (China, India, Latin America, and others), the proportion of older people is rising quickly, and dementia is the leading cause of impairment in these areas [5]. According to a nationwide representation research on late-life cognition and dementia in India, 74% of adults 60 and older had dementia, which translates to 8.8 million people. The prevalence of dementia was greater in rural than in urban areas and was higher among women than men [6]. The prevalence rate was higher in North America and Europe (1,123 cases per 10,000 people) than in Asia (523 instances per 10,000 people), South America, and Africa (275 cases per 10,000 people) [5]. The main causes of dementia are Vascular dementia, Alzheimer's disease, Lewy

bodies, Pick's disease, progressive supra-nuclear palsy, corticobasal degeneration, and Idiopathic Parkinson's disease, hepatic encephalopathy, pulmonary encephalopathy, and other less common causes include brain tumor, normal pressure hydrocephalus, subdural hematoma [7]. Psycho-behavioral disturbances (aggressiveness, inappropriate shouting, and incontinence) are common in dementia patients. Psychiatric disorders (delusions, anxiety, sadness, and hallucinations), and psychomotor disorders (pain and agitation). Language is significantly impacted by advanced dementia, with palilalia and echolalia occasionally occurring along with a severe loss of fluency. Complete mutism is possible. To varying degrees, all memory systems are impacted [8].

Dementia's clinical condition often manifests in three main ways. Firstly, cognitive impairment which is often presented by memory loss with other deficits such as aphasia, apraxia, agnosia, reduced attention and executive design, functional decline, which is manifested by progressive difficulty in performing activities of daily living. Behavioral and psychological symptoms are manifested by mood and personality changes, such as depression, apathy, agitation, and anxiety [9]. Cholinesterase Inhibitors (ChEIs) are the mainstay of the treatment of Dementia [10]. Physiotherapy interventions for individuals with dementia include recall strategies (such as mnemonic techniques, cueing, chunking, and the method of loci), as well as aerobic exercise, flexibility training, proprioceptive neuromuscular facilitation (PNF), balance training, strength training, and gait training [11].

Neurobiologist Lawrence C. Katz coined the term "neurobics," referring to brain aerobics, with the theory that mental exercise, particularly those that involve the brain in new ways, can promote the development of new neurons and dendrites [12].

These are the activities that have a positive impact on the Cognitive abilities of the elderly. Regular brain exercises will stimulate the centers of the alert systems in the brain stem, keeping them active and preventing loss of intellectual power [13]. Neurobic exercises activate new brain circuits and enhance neurotrophin production, strengthening nerve connections and helping nerve cells and synapses stay stronger [14]. Neurobic exercises for the brain include activities that combine physical senses. The exercises include sensory stimulation (Brushing our teeth with our nondominant hand), social and verbal challenges, Memory booster, Multisensory integration, Creativity, and Visualization [15].

Aerobic exercise is a physical activity that increases heart rate and primarily relies on oxygen to produce energy and improve cardiovascular endurance. Common examples include walking, running, cycling, swimming, and dancing. Aerobic exercise can play a role in the management and prevention of many conditions, such as coronary artery disease, obesity, depression, and diabetes [16]. Aerobic exercise may protect brain health by altering brain chemistry and helping ward off disease. People who are physically active in early life have less prevalence of dementia in late life [17]. They are crucial in preventing and delaying the decrease in brain volume. It may improve signal activation in the cingulate gyrus, enhance functional connectivity within the hippocampus, halt the volume loss of the anterior cingulate cortex (ACC), and dramatically reduce the atrophy of the medial temporal lobe [18]. The Montreal Cognitive Assessment is the primary tool used to evaluate dementia; it provides the initial means of identifying moderate cognitive impairment, a condition that often progresses to dementia [19].

Multiple cognitive areas, such as memory, language, executive function, visuospatial abilities, computation, abstraction, attention, concentration, and orientation, are evaluated by the straightforward 10-minute MoCA paper-and-pencil exam [20]. When detecting MCI, this method is

more sensitive than the MMSE [21]. This is a psychometrically valid and reliable instrument for cognitive screening in patients with dementia [22]. The IQCODE is frequently used as a dementia screening tool, especially when a person is unable to participate in direct cognitive testing or has low literacy and education [23]. It can be used to assess the cognitive state of the aged population and has strong psychometric properties [24]. This study investigates the impact of aerobics and neurobics on dementia sufferers.

## **2. Methodology**

This is a cross-sectional comparative study. These were held in senior living facilities in the Chennai neighborhood of Kundrathur. It took about 6 months to complete this research. It took nearly 6 months to complete this study. Following institutional review board approval of study No. 24, 30 participants were chosen in accordance with the inclusion criteria. The study included subjects in the age group of 60 years and above who are graded as having Dementia. Both males and females were included in the study. After gaining their agreement, which was officially signed to ensure the confidentiality of their personal information, the subjects were extensively informed about the benefits of participating in the study. Individuals with mild to moderate dementia, as diagnosed by a neurologist (Dementia severity scale score 18-36), the ability to follow simple instructions, the capability for light to moderate physical activity, and no history of psychiatric disorders were included in the study. Randomization was done using a simple random sampling technique. Using lottery techniques, the individuals were randomly split into two groups: Group A consisted of odd numbers, while Group B consisted of even numbers. Mildly cognitively impaired individuals receive treatment via aerobic and neurobic exercises five days a week for 12 weeks, lasting 30 minutes per session. Aerobic and neurobics exercises are used to prevent early cognitive impairment in the elderly. The Digit span test, IQCODE, MoCA, and a mobile gaming app were used to evaluate the subjects. Both the pre-test and post-test readings were noticed and recorded.

### **2.1 Ethics Statement**

The research is conducted responsibly and transparently, protecting the integrity of the study, the researchers, and the scientific community. The study was conducted in accordance with the Declaration of Helsinki. The study was approved by the institutional review board IRB no: BPT IV Year C Sec, 24/PHYSIO/IRB/2024-2025. Verbal and written informed consent was obtained from the patient to participate in the study, including permission for publication, prior to performing the procedures.

## **3. Intervention**

### **3.1 Group A**

Aerobic members were given aerobic exercises for 5 days each week, 30 minutes per session for 12 consecutive weeks, with pre-values recorded. Warmup – 5 minutes - Marching in Place – 1 minute, Arm swing, Torso Twists – 2 minutes, Main Exercise (20 Minutes) Seated Jacks – 5 minutes, Seated Marching (Alternating Legs) – 5 minutes, Sit to Stand – 5 minutes, Indoor Walking – 5 minutes, cool down (5 Minutes).

### 3.2 Group B

Neurobics members were given neurobics exercises for 5 days each week, 30 minutes per session, for 12 consecutive weeks, with pre-values recorded. Seated marching while counting, Word Recall Game, Draw a shape with the non-dominant hand, Memorize a new phone number, Double doodle.

### 4. Data Analysis

Statistics for both descriptive and inferential analysis were used to tabulate and examine the gathered data. A 95% confidence interval was established for every analysis, and a significance level of  $P < 0.05$  was applied to all the parameters when evaluating them using the statistical software for social science (SPSS) version 24. The data's normality was assessed using the Shapiro-Wilk test. The data in this study were found to be regularly distributed on the dependent values at  $P > 0.05$ , according to the Shapiro-Wilk test. The comparison of MoCA scores between Group A and Group B is presented in Table 1. Table 2 shows the comparison of IQCODE scores between Group A and Group B. There was no significant difference in pre-test scores between Group A ( $3.75 \pm 0.267$ ) and Group B ( $3.88 \pm 0.276$ ) ( $t = -1.29$ ,  $p = 0.207$ ). In contrast, the post-test scores revealed a statistically significant difference, with Group B ( $4.31 \pm 0.261$ ) scoring higher than Group A ( $3.79 \pm 0.240$ ) ( $t = -5.70$ ,  $p = 0.001$ ). As shown in Table 3, there was no significant difference in digit span scores between Group A ( $2.06 \pm 1.60$ ) and Group B ( $2.10 \pm 1.57$ ) during the pre-test ( $t = -0.069$ ,  $p = 0.945$ ). However, the post-test comparison demonstrated a statistically significant improvement in Group B ( $3.98 \pm 1.74$ ) compared to Group A ( $2.42 \pm 1.54$ ) ( $t = -2.58$ ,  $p = 0.001$ ). Table 4 presents the within-group comparison of MoCA scores between pre-test and post-test. Both Group A and Group B showed statistically significant improvements. Group A improved from  $14.46 \pm 1.40$  to  $16.06 \pm 1.22$  ( $t = -6.80$ ,  $p = 0.001$ ). In contrast, Group B improved from  $14.93 \pm 1.22$  to  $18.22 \pm 1.26$  ( $t = -9.12$ ,  $p = 0.001$ ), indicating that both interventions were effective, with a greater magnitude of improvement observed in Group B. The pre-test mean scores showed no statistically significant difference between Group A ( $14.46 \pm 1.40$ ) and Group B ( $14.93 \pm 1.22$ ) ( $t = -0.969$ ,  $p = 0.341$ ). However, in the post-test, a statistically significant difference was observed, with Group B ( $18.20 \pm 1.26$ ) demonstrating higher scores than Group A ( $16.06 \pm 1.22$ ) ( $t = -4.69$ ,  $p = 0.001$ ), indicating greater improvement in Group B. The parametric test was therefore used. The independent t-test, also known as the Student t-test, was used to determine the statistical difference between the groups, and the paired t-test was used to determine the statistical difference within the groups.

**Table 1** Comparison of the MoCA score between Group A and Group B in pre- and post-test.

Test	Group A		Group B		t-test	df	Significance
	MEAN	S.D.	MEAN	S.D.			
Pre-test	14.46	1.40	14.93	1.22	-0.969	28	0.341*
Post-test	16.06	1.22	18.20	1.26	-4.69	28	0.001**

(\*  $P > 0.05$  - Not Significant) & (\*\*  $P \leq 0.05$  - Significant).

**Table 2** Comparison of IQCODE score between Group A and Group B in pre- and post-test.

Test	Group A		Group B		t-test	df	Significance
	MEAN	S.D.	MEAN	S.D.			
Pre-test	3.75	0.267	3.88	0.276	-1.29	28	0.207*
Post-test	3.79	0.240	4.31	0.261	-5.70	28	0.001**

(\*  $P > 0.05$  - Not Significant) & (\*\*  $P \leq 0.05$  - Significant).

**Table 3** Comparison of digit span score between Group A and Group B in pre- and post-test.

Test	Group A		Group B		t-test	df	Significance
	MEAN	S.D.	MEAN	S.D.			
Pre-test	2.06	1.60	2.10	1.57	-0.069	28	0.945*
Post-test	2.42	1.54	3.98	1.74	-2.58	28	0.001**

(\*  $P > 0.05$  - Not Significant) & (\*\*  $P \leq 0.05$  - Significant).

**Table 4** Comparison of MoCA score within Group A and Group B between pre-test and post-test.

Groups	Pre-test		Post-test		t-test	Significance
	MEAN	S.D.	MEAN	S.D.		
Group A	14.46	1.40	16.06	1.22	-6.80	0.001**
Group B	14.93	1.22	18.22	1.26	-9.12	0.001**

(\*\*  $P \leq 0.05$  - Significant).

## 5. Results

The post-test analysis revealed that both Groups A and B improved their cognitive performance. On the MoCA, participants in Group B demonstrated greater gains, achieving a mean score of  $18.20 \pm 1.26$  compared to Group A's  $16.06 \pm 1.22$ , with the difference reaching statistical significance ( $P < 0.05$ ), thereby disproving the null hypothesis. Similarly, both groups exhibited significant improvements in IQ scores, but Group B again outperformed Group A, with mean values of  $4.31 \pm 0.261$  and  $3.79 \pm 0.240$ , respectively ( $P < 0.05$ ).

The Digit Span Test results followed the same pattern: while both groups showed post-test improvement, Group B achieved a higher mean score of  $3.98 \pm 1.74$  compared to  $2.42 \pm 1.54$  in Group A, which was statistically significant ( $P < 0.05$ ). Overall, these findings indicate that although both neurobic and aerobic approaches contributed to cognitive improvements, the intervention applied to Group B was more effective across all measured cognitive domains.

## 6. Discussion

Although the present study was designed in the context of dementia care, the cognitive scores obtained from the participants particularly the Montreal Cognitive Assessment (MoCA) scores

ranging from approximately 14 to 18 suggest that most participants were experiencing mild to moderate cognitive impairment rather than advanced dementia. Mild cognitive impairment (MCI) represents a transitional stage between normal aging and dementia, characterized by measurable cognitive decline that does not yet severely impair daily functioning. Therefore, the findings of the present study should be interpreted primarily in relation to early cognitive decline and MCI populations, where preventive and rehabilitative interventions such as aerobic and neurobic exercises may play an important role in delaying further progression of cognitive deterioration.

The efficiency of aerobic and neurobic exercise in the treatment of dementia was examined in the current study. The results were obtained after 12 weeks of comparison. Beginning in the third decade of life, the human brain gradually loses tissue, resulting in a decline in cognitive function [1]. Dementia is a collection of symptoms linked to underlying illnesses, including Lewy body dementia, Alzheimer's disease, frontotemporal dementia, and vascular dementia, rather than a single illness [3].

Neurobics are the activities that have a positive impact on the Cognitive abilities of the elderly. Regular brain exercises stimulate neural circuits involved in attention, memory, and executive functioning. In this context, the term "intellectual power" refers to higher cognitive abilities such as reasoning, problem-solving, memory processing, attention, and decision-making, which are essential for maintaining independent functioning in older adults [13].

Mammen AA et al. have summarized that physiotherapy treatment for Dementia includes Recall strategies (Mnemonic Strategies, cueing, chunking, Method of Loci), Aerobic exercise, flexibility exercise, Proprioceptive neuromuscular facilitation, balance training, strength training, gait training, etc. [11]. Ballard et al. have claimed that mental exercise can promote the development of new dendrites and neurons, particularly when it engages the brain in innovative ways [12]. Raj D et al. have claimed that older persons with MCI living in the community may benefit more from the neurobic exercise intervention in terms of both subjective and objective memory than those who participated in the conventional brain exercise program. Thus, nurses and multidisciplinary teams can employ the neurobic exercise program to improve memory function in older adults with MCI [15].

Patani KA et al. have stated that Neurobic exercises activate new brain circuits and enhance neurotrophin production, thereby strengthening nerve connections and helping nerve cells and synapses to stay stronger [14]. Wiyakarn Sanghuachang et al. reported that the neurobic exercise intervention could improve subjective and objective memory among community-dwelling older adults with MCI more than a traditional brain exercise program. Therefore, the neurobic exercise program can be used by nurses and multidisciplinary teams to enhance memory performance among older adults with MCI [25].

Pornpat Hengudomsub et al. reported that at three and six weeks, the intervention group's IQCODE relative change score decreased dramatically, suggesting improvement in cognitive decline, and their COMT relative change score significantly increased, suggesting improvement in cognitive function. The participants thought the intervention was beneficial and expressed great pleasure with the activities as a whole. For elderly persons living in Thai communities, the neurobic exercise intervention proved both practical and acceptable [26]. Haritri Bisht et al., have determined from the data that both groups showed considerable improvement in young adult memory, with conventional neurobic exercises being statistically more effective. In both outcome measures, the Post Graduate Institute Memory Scale and the MMSE, statistically significant differences were

observed in the control group as compared with the experimental group [27].

Li MY et al. have claimed that it is crucial for preventing and delaying decreases in brain volume. Aerobic exercise may improve signal activation in the cingulate gyrus, enhance functional connectivity within the hippocampal region, halt the volume loss of the anterior cingulate cortex (ACC), and considerably reduce atrophy of the medial temporal lobe [18]. Graff-Radford et al. have stated that aerobic exercise protects brain health by altering brain chemistry and warding off disease. People who are physically active in early life have less prevalence of dementia in late life [17].

David J Madden et al. have proposed that long training durations or cohort differences between physically active and inactive people are the causes of aerobic exercise-related improvements in older persons' cognitive performance [28]. Edward S Bliss et al. have noted a connection between older people's cerebrovascular and cognitive function and the interplay between cardiometabolic parameters that may directly affect these functions and regular, lifetime aerobic exercise training [29]. Kamran Yazdanbakhsh et al. have determined that cognitive rehabilitation is an effective way to enhance cognitive abilities, as it significantly affects the neural activity of brain regions linked to cognitive abilities and enhances their performance [30].

Chien-Ning Tseng et al. showed that a 6-week fitness program involving 60 minutes of exercise at least three times a week improved cognitive function. The effectiveness of multicomponent exercise in enhancing cognitive function, especially in healthy older adults, should be investigated in larger trials with more exacting techniques [31]. Daniel L Murman et al. have claimed that leading a healthy lifestyle can help delay the onset of cognitive symptoms in the context of age-related disorders and slow the rate of cognitive deterioration linked with aging [32].

MTS Golino stated that neurobics exercises promote neuroplasticity and improve cognitive function. These activities boost blood flow to the brain, supplying vital nutrients and oxygen, and they also cause the brain to produce neurotrophic factors, such as brain-derived neurotrophic factor, which support the growth and survival of brain cells. Memory and executive function are two cognitive talents that this technique can help preserve or perhaps enhance. It may also lower the danger of dementia and cognitive decline [33].

The study's limitations include its small sample size, limited power for subgroup analyses, and generalizability. Blinding challenges and potential performance bias: participants might respond differently depending on their assigned intervention type. The duration of 6 months is relatively short compared to neurodegenerative progression; long-term sustainability remains unknown.

Neurobic fidelity: diverse sensory-stimulation activities may vary in intensity and engagement, complicating standardization. Further research direction can be larger, multicenter RCTs to confirm efficacy and allow subgroup analyses by dementia subtype and baseline mobility. Longer follow-up (12-24 months) to assess durability and disease-modifying potential. Mechanistic neuroimaging studies comparing cerebral blood flow, BDNF levels, and gray matter volume changes post-exercise vs neurobic. Hybrid interventions combining aerobic and neurobic approaches to explore potential additive effects. Dose-response trials for neurobic intensity/duration, analogous to MET-min/week research in exercise.

When the MoCA Score, IQ Score, and Digit Span Score of Groups A and B are compared before and after the test, there is a significant difference in the mean values at  $P \leq 0.05$ . The precise mean values of these outcome measures demonstrate that, when group A and group B's pretest and posttest results are compared, group B's dementia patients significantly outperform group A. When

paired with  $P$ , the significant mean value is larger than or equal to 0.05. Thus, our investigation demonstrates that Group B and Group A's post-test results differ significantly. However, forgetfulness has significantly decreased in both groups. Compared with Group A, Group B engages in more everyday activities.

These findings are consistent with previous research emphasizing the role of cognitive stimulation in enhancing neural plasticity. Ballard et al. reported that mentally stimulating activities that engage the brain in novel ways may promote the development of new dendrites and neuronal connections, thereby supporting cognitive function in older adults. Similarly, Raj et al. demonstrated that neurobic exercise programs significantly improved both subjective and objective memory performance among community-dwelling older adults with mild cognitive impairment.

The mechanisms underlying these improvements may involve increased neural activation and neurotrophin production. Patani et al. suggested that neurobic exercises stimulate the formation of new neural circuits and enhance the production of neurotrophic factors, thereby strengthening synaptic connections and supporting neuronal survival. Recent evidence by Sanghuachang et al. [25] further supports this view, reporting that structured neurobic exercise interventions can significantly enhance memory performance in elderly individuals with mild cognitive impairment.

Aerobic exercise has also been widely recognized for its neuroprotective benefits. Li et al. highlighted that regular aerobic activity can improve functional connectivity within the hippocampus and cingulate cortex while slowing the atrophy of brain regions associated with memory and executive function. Graff-Radford similarly reported that individuals who maintain higher levels of physical activity throughout their lifespans have a lower prevalence of dementia in later life.

Although both interventions demonstrated beneficial effects, the greater improvements observed in the neurobic group in the present study suggest that combined cognitive-sensory stimulation may produce stronger cognitive benefits than physical activity alone. This may be because neurobic exercises simultaneously engage multiple cognitive domains, including attention, memory, language, and sensory integration, thereby stimulating broader neural networks.

Overall, the findings support the growing body of literature indicating that targeted cognitive stimulation programs, particularly neurobic exercises, may serve as effective non-pharmacological interventions for improving cognitive function and delaying the progression of cognitive decline among older adults with mild cognitive impairment.

## **7. Conclusion**

The present study found that neurobic exercises are highly effective in improving cognition in patients with dementia. The study's results suggested that both aerobics and neurobics are effective. Still, Group B neurobics is found to be more effective in reducing dementia symptoms than Group A, who were trained in aerobics.

Hence, it is concluded that neurobics exercise results in more improvement in reducing dementia symptoms and improving cognition.

## **8. Future Scope**

A large sample size is recommended, as the study recruited only a small one. Aerobic and Neurobic interventions were compared, and the same can be done using audiovisual aids or along

with other intervention protocols. The samples were followed for only 12 weeks; a longer follow-up is recommended, as they are of the geriatric population. Outcomes may be evaluated by using more outcome measures. Age groups are limited to 60 years and above; wider age groups can be included to analyze their effect. This can raise awareness among the geriatric population, and the exercise protocols can be taught as a preventive protocol from the age of 50.

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## **Author Contributions**

Dr. Rajalaxmi Visvanathan, Kavya Vembudurai: Conceptualization, Writing – Original Draft, Methodology. Kavya Vembudurai: Data Collection, Drafting. Janaga Ranjani Sankar, Dr. Sugasri Sureshkumar: Writing – Review and Editing, Methodology. Dr. Sridevi Gopathy: Writing – Original Draft, Formal Analysis. Dr. Meena Gupta, Dr. Mohan Kumar Govindharaj: Drafting. All authors have read and approved the published version of the manuscript.

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## **Competing Interests**

The authors have declared that no competing interests exist with respect to the research, authorship and publication of this article.

## **AI-Assisted Technologies Statement**

Artificial intelligence (AI) tools were used solely for basic grammar correction and language refinement in the preparation of this manuscript. Specifically, OpenAI's ChatGPT was employed to improve the readability and linguistic clarity of the English text. All scientific content, data interpretation, and conclusions were developed independently by the author. The authors have thoroughly reviewed and edited the AI-assisted text to ensure its accuracy and accept full responsibility for the content of the manuscript.

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