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ORIGINAL RESEARCH

Optimal Treatment Strategies of AIoT Based Wearable Devices for Stroke Walking in the Rehabilitation Training of Ischemic Stroke Patients: A Real-World Cohort Study Using Propensity-Score Matched Analysis

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Purpose: To evaluate the efficacy of stroke walking wearable devices based on artificial intelligence Internet of Things (AIoT) technology in the rehabilitation training of patients with ischemic stroke (IS).

Patients and Methods: A total of 777 patients with IS were recruited and followed up for 6 months. The participants were divided into control (671 cases) and AIoT group (106 cases) according to whether they received AIoT treatment or not. The primary outcomes were Holden walking function grading, lower limb modified Ashworth muscle tone grading, lower limb Brunnstrom grading, joint range of motion, and gait between two groups of patients within 3 days before treatment and 1 month after treatment. Propensity score matching (PSM) analysis was performed based on various factors such as gender, age, and course of illness at admission.

Results: There was no significant difference ($P>0.05$) in Holden walking function grading, lower limb modified Ashworth muscle tone grading, lower limb Brunnstrom grading, joint range of motion, and gait between the two groups before treatment. After one month of treatment, Holden walking function grading, lower limb modified Ashworth muscle tone grading, lower limb Brunnstrom grading, joint range of motion, and gait between the two groups improved compared to before treatment, and the AIoT group was better than the control group, with significance ($P<0.05$). Moreover, logistic regression analysis showed that AIoT based walking wearable devices was independent risk factor for the development of 90-day readmission in patients with IS after rehabilitation training.

Conclusion: AIoT based walking wearable devices for stroke rehabilitation training is feasible and safe with satisfactory therapeutic effects. Moreover, further prospective multicenter trials are warranted before incorporating AIoT into routine rehabilitation training.

Keywords: ischemic stroke, recovery, artificial intelligence internet of things, walking wearable devices

Introduction

Nowadays, ischemic stroke (IS) has become a serious public health problem, especially in the context of an aging population and a gradual trend towards younger patients with IS.[1,2] More medical and health resources need to be invested, and the burden on society and families is increasing. According to existing research, 70% of patients with IS have residual motor dysfunction, especially walking dysfunction, which is the most significant problem affecting their quality of life.[3,4] However, due to the lack of real-time, objective, and quantitative motion parameters, it is difficult for treatment personnel to accurately determine the complex and varied sources of abnormal gait in stroke patients, resulting

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in the inability to achieve targeted training, ultimately leading to slow improvement or even paralysis of walking function.

According to existing evidence from the World Health Organization, approximately 15% of the world's population suffers from some form of disability, particularly motor dysfunction caused by IS, which accounts for 10% to 15%.[5–7] In this context, assistive technologies have made significant progress in artificial intelligence Internet of Things (AIoT) devices, especially AIoT processing and analyzing the large amount of data generated by AIoT devices, and applying artificial intelligence models, which have unparalleled advantages in discovering and generating insights and assisting medical decision-making patterns.[8,9] In addition, AIoT has been applied to assist in overcoming the difficulties encountered by disabled patients in their daily lives, and to promote the recovery and improvement of their physical mobility.

Based on this research, our team found in previous studies that the development of home intelligent rehabilitation devices is the key to the intelligent rehabilitation network, determining whether it can achieve a closed loop. In particular, the development of lightweight and intelligent wearable devices provides new possibilities for post-stroke walking function rehabilitation. Given this situation, this study collected case data of patients with IS treated in our hospital from 2022 to 2025 and used propensity score matching (PSM) method to control for inter group differences. The Holden walking function grading, lower limb modified Ashworth muscle tone grading, lower limb Brunnstrom grading, joint range of motion, and gait status within 3 days before treatment and 1 month after treatment are the main outcome indicators, aiming to evaluate whether AIoT can bring long-term benefits to patients with IS, determine cost-effectiveness, and assess the impact of intervention mode and duration on patient outcome indicators.

Materials and Methods

Patients Selection

We retrospectively collected clinical and follow-up data of patients with IS diagnosed at Department of Rehabilitation, Longgang District Central Hospital of Shenzhen from January 2022 to January 2025. The inclusion criteria are as follows: (1) According to the European Stroke Organisation (ESO) guidelines, patients diagnosed with IS in our hospital;[10] (2) Individuals aged ≥ 18 years old; (3) Patients with a disease course of 1 to 12 months; (4) Patients with significantly reduced limb function and hip joint control muscle strength ≥ level 2; (4) Patients who have clear cognition and are able to cooperate in completing the relevant questionnaires and corresponding training for this study. Exclusion criteria: (1) Patients with unstable vital signs; (2) Patients with combined fractures and joint deformities; (3) Patients who have contraindications or allergic reactions to the equipment or materials used in this study; (4) Patients with combined important organ dysfunction or mental illness; (5) Patients who are unable to cooperate in completing this study. The detailed process of patient inclusion is shown in Figure 1.

Ethical Statement

Ethical approval was obtained from the Ethics Committee of the Longgang District Central Hospital of Shenzhen (NO.20241107). This retrospective study did not contain any identifiable human images and was an anonymous data collection that waived patients' written informed consent. The study was conducted in compliance with the Declaration of Helsinki, and all patient data were anonymized and handled with strict confidentiality to protect patient privacy.

AIoT-Related Procedures

Control group: The patients without AIoT stroke walking wearable devices. Routine rehabilitation training will be conducted by therapists, such as stretching training for lower limb spastic muscle groups for 7–8 minutes, 1–2 minutes for each muscle group, passive movement of lower limb joints for 7–8 minutes, 1–2 minutes for each joint, and downward strength training mainly including hip bridge training, single leg weight-bearing training, center of gravity transfer training, position change training, etc. After 15 minutes, each session will last for 30 minutes, with one session in the morning and one session in the afternoon, for a total of one month of training.

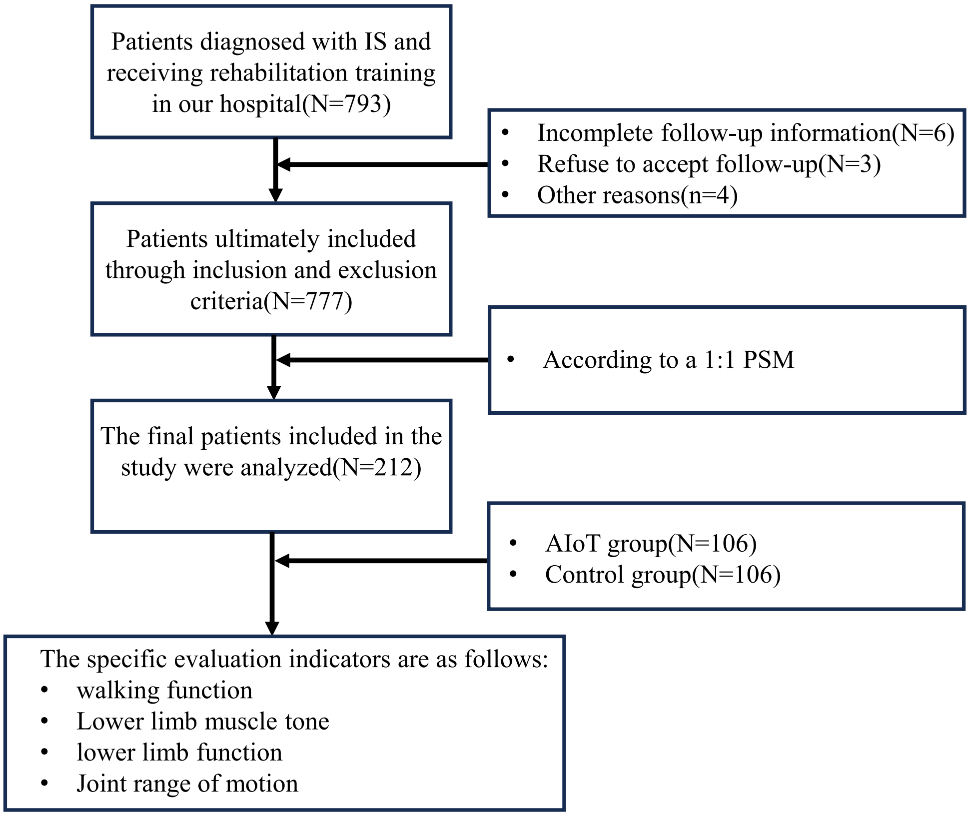

Figure 1 Flow chart for patient with IS inclusion in this study.

AIoT group: In addition to routine rehabilitation training, patients receive walking training using AIoT based stroke walking wearable devices. The equipment composition is detailed in Supplementary Figure 1. Firstly, the device is based on the AIoT stroke walking wearable device, which includes three main parts: mechanical system, automatic control system, and software system. Mainly relying on sensor technology to collect various walking parameters; In addition, the device also relies on an automatic control system to achieve multi joint real-time feedback, adjust abnormal posture and passive motion control conversion, and relies on computer artificial intelligence deep learning algorithms to analyze the logical relationship between multiple parameters in walking motion. At the same time, it is equipped with a set of application(APP) software for synchronous rehabilitation evaluation and treatment functions (appearance patent: 202330862420.0; utility model patent: ZL 2021 2 2,725,800.8). The separable and combinable application of the three components makes it an intelligent walking rehabilitation device that can serve clinical, home, and personal needs simultaneously, forming a three-level intelligent rehabilitation network. Secondly, before conducting rehabilitation training, patients were evaluated for gait and lower limb function using scales such as Holden walking function grading, modified Ashworth muscle tone grading for lower limbs, Brunnstrom grading for lower limbs, active and passive range of motion(ROM) and muscle strength for each joint.[11–13] All data were synchronized to a mobile APP, which automatically recorded their basic walking characteristics. Patients were required to wear devices during daily routine rehabilitation training, with 30 minutes of training each time, once in the morning and once in the afternoon, for a total of one month. Patients undergoing home-based rehabilitation training are evaluated by community health physicians at corresponding time points and receive self training and equipment usage guidance based on the evaluation.

Follow-Up

The following indicators were evaluated within 3 days before treatment and 1 month after treatment.

Holden walking function rating is as follows: (i)completely relying on a wheelchair for movement (Level 0); (ii) requires one person to continuously assist or use crutches to walk (Level I); (iii)requires one person to occasionally assist or walk with a cane (Level II); (iv)Able to walk independently on a flat surface, but prone to falling (Level III); (v)Able to walk independently on a flat surface, but requires one person to assist on a slope or step (Level IV); (vi)Can walk completely independently (Level IV).

Ashworth muscle tone grading for lower limb improvement is as follows: (i)No increase in muscle tone (Grade 0); (ii) Mild increase in muscle tone, with minimal resistance to sustained passive movement during passive flexion and extension of the affected area (Grade I); (iii)Mild increase in muscle tone, presenting minimal resistance when continuous passive movement is less than 50% (Grade I+); (iv)muscle tone significantly increases, and muscle tone significantly increases when continuous passive movement exceeds 50% (Grade II); (v)Severe increase in muscle tone, difficulty in passive movement (Grade III); (vi)The affected part is stiff and unable to move (Grade IV).

Brunnstrom classification of lower limbs is as follows: (i)Soft paralysis (Grade I); (ii)mild spasms and combined reactions (Grade II); (iii)Moderate spasms and inability to move joints freely (Grade III); (iv)Mild spasms and ability to complete partial separation movements (Grade IV); (v)No spasms, capable of completing all separation actions (Level V); (vi)motor coordination is slightly worse than normal (Grade VI).

Joint range of motion: The ROM tool was used to evaluate the range of motion of the knee and hip joints, with three repeated measurements taken and the average value taken.

Gait condition: Measure, calculate, and compare step size, stride length, and pace.

Statistical Analysis

We used SPSS 26.0 software and R software (4.3.2) for statistical analysis of the data. Count data is described as "percentage (%)" and chi square test is used to compare the differences between groups. Quantitative data that conforms to a normal distribution are described as "mean ± standard deviation", and *t*-test is used to compare differences between groups; Non normally distributed quantitative data are described as "median (quartiles) [M (P25, P75)]", and the comparison of differences between two groups is performed using Mann Whitney *U*-test. The propensity score matching (PSM) extension program was used to match propensity scores between two groups of patients using a 1:1 nearest neighbor matching method, and the goodness of the matching results was ensured by defining clamp values. Using a multiple logistic regression model to analyze the cause and predictors of 90-day readmission in patients with IS after discharge, with $P<0.05$ indicating statistical significance.

Results

Patient Characteristics

A total of 793 hospitalized patients with IS were collected, and 777 patients were actually included. According to whether they received AIoT stroke walking wearable device treatment after hospitalization, they were divided into AIoT group (N=106) and non-AIoT group (N=671). As shown in Table 1 and Supplementary Figure 2, after propensity score matching, a total of 106 pairs of patients were successfully matched. Among them, there were 57 males and 49 females in the AIoT group, with an age range of 63.5 years and a disease duration of 5 months. There were also 57 males and 49 females in the control group, with an age range of 63 years and a disease duration of 5 months. There was no significant statistical difference between the two groups ($P>0.05$).

Improvement of Holden's Walking Function Grading

As shown in Table 2, after one month of treatment, the Holden walking function grading of both groups improved compared to before treatment, and the improvement effect of AIoT was significantly better than that of the control group ($P<0.05$). It is worth mentioning that after receiving AIoT stroke walking wearable device training, the proportion of grade IV patients significantly increased, with a statistically significant difference compared to the control group ($P<0.05$). Seven patients reached grade V, with one assessed as grade II before treatment and the other assessed as grade I. This indicates that training with AIoT wearable devices for stroke walking can achieve better improvement in the walking function of patients with IS.

Table 1 The Pre and Post PSM Clinical Characteristics of Patients with IS Undergoing AIoT Rehabilitation Training or Not

Variables	**Before PSM**			**P-Value**	**After PSM**			**P-Value**
	Overall (N=777)	**AIoT (N=106)**	**Non-AIoT (N=671)**		**Overall (N=212)**	**AIoT (N=106)**	**Non-AIoT (N=106)**	
Age (median [IQR])	61.00 [52.00, 69.00]	63.50 [52.00, 70.00]	61.00 [52.00, 69.00]	0.339	63.00 [52.00, 70.00]	63.50 [52.00, 70.00]	63.00 [52.25, 69.75]	0.946
Gender (%)								
Male	400 (51.5)	57 (53.8)	343 (51.1)	0.686	114 (53.8)	57 (53.8)	57 (53.8)	1
Female	377 (48.5)	49 (46.2)	328 (48.9)		98 (46.2)	49 (46.2)	49 (46.2)	
COD (median [IQR]),month	5.00 [2.00, 7.00]	5.00 [2.00, 7.00]	5.00 [2.00, 7.00]	0.879	5.00 [2.00, 7.00]	5.00 [2.00, 7.00]	5.00 [2.25, 7.00]	0.772
LOS (%),day								
<3	398 (51.2)	49 (46.2)	349 (52.0)	0.316	110 (51.9)	49 (46.2)	61 (57.5)	0.131
≥3	379 (48.8)	57 (53.8)	322 (48.0)		102 (48.1)	57 (53.8)	45 (42.5)	
BMI (median [IQR]),kg/m2	24.80 [22.00, 27.50]	24.40 [21.72, 26.98]	24.80 [22.20, 27.60]	0.245	24.75 [21.90, 27.15]	24.40 [21.72, 26.98]	25.00 [22.42, 27.48]	0.295
Hypertension (%)								
Yes	389 (50.1)	46 (43.4)	343 (51.1)	0.17	90 (42.5)	46 (43.4)	44 (41.5)	0.889
No	388 (49.9)	60 (56.6)	328 (48.9)		122 (57.5)	60 (56.6)	62 (58.5)	
Diabetes (%)								
Yes	372 (47.9)	52 (49.1)	320 (47.7)	0.875	112 (52.8)	52 (49.1)	60 (56.6)	0.336
No	405 (52.1)	54 (50.9)	351 (52.3)		100 (47.2)	54 (50.9)	46 (43.4)	
Smoking (%)								
Yes	384 (49.4)	48 (45.3)	336 (50.1)	0.417	99 (46.7)	48 (45.3)	51 (48.1)	0.783
No	393 (50.6)	58 (54.7)	335 (49.9)		113 (53.3)	58 (54.7)	55 (51.9)	
Drinking (%)								
Yes	378 (48.6)	47 (44.3)	331 (49.3)	0.395	105 (49.5)	47 (44.3)	58 (54.7)	0.17
No	399 (51.4)	59 (55.7)	340 (50.7)		107 (50.5)	59 (55.7)	48 (45.3)	
AF (%)								
Yes	392 (50.5)	49 (46.2)	343 (51.1)	0.406	103 (48.6)	49 (46.2)	54 (50.9)	0.583
No	385 (49.5)	57 (53.8)	328 (48.9)		109 (51.4)	57 (53.8)	52 (49.1)	
IAS (%)								
Yes	406 (52.3)	54 (50.9)	352 (52.5)	0.853	105 (49.5)	54 (50.9)	51 (48.1)	0.784
No	371 (47.7)	52 (49.1)	319 (47.5)		107 (50.5)	52 (49.1)	55 (51.9)	
CS (%)								
Yes	396 (51.0)	58 (54.7)	338 (50.4)	0.467	116 (54.7)	58 (54.7)	58 (54.7)	1
No	381 (49.0)	48 (45.3)	333 (49.6)		96 (45.3)	48 (45.3)	48 (45.3)	
PVD (%)								
Yes	391 (50.3)	46 (43.4)	345 (51.4)	0.153	96 (45.3)	46 (43.4)	50 (47.2)	0.679
No	386 (49.7)	60 (56.6)	326 (48.6)		116 (54.7)	60 (56.6)	56 (52.8)	
ASITN/SIR (%)								
I~II	399 (51.4)	54 (50.9)	345 (51.4)	1	107 (50.5)	54 (50.9)	53 (50.0)	1
III~IV	378 (48.6)	52 (49.1)	326 (48.6)		105 (49.5)	52 (49.1)	53 (50.0)	
DWI (%)								
High	387 (49.8)	53 (50.0)	334 (49.8)	1	103 (48.6)	53 (50.0)	50 (47.2)	0.783
Low	390 (50.2)	53 (50.0)	337 (50.2)		109 (51.4)	53 (50.0)	56 (52.8)	
HD (%)								
Yes	400 (51.5)	59 (55.7)	341 (50.8)	0.411	111 (52.4)	59 (55.7)	52 (49.1)	0.409
No	377 (48.5)	47 (44.3)	330 (49.2)		101 (47.6)	47 (44.3)	54 (50.9)	
CRI (%)								
Yes	396 (51.0)	55 (51.9)	341 (50.8)	0.921	117 (55.2)	55 (51.9)	62 (58.5)	0.407
No	381 (49.0)	51 (48.1)	330 (49.2)		95 (44.8)	51 (48.1)	44 (41.5)	

Abbreviations: IQR, interquartile range; COD, Course of disease; LOS, Length of Stay; BMI, Body mass index; AF, Atrial fibrillation; IAS, Intracranial artery stenosis; CS, Carotid stenosis; PVD, Peripheral vascular disease; ASITN/SIR, American Society of Interventional and Therapeutic Neuroradiology/Society of Interventional Radiology; DWI, Diffusion weighted imaging; HD, Heart disease; CRI, Chronic renal insufficiency.

Ashworth Muscle Tone Grading for Lower Limb Improvement

After one month of treatment, both groups showed improvement in lower limb modified Ashworth muscle tone grading compared to before treatment, and the improvement in muscle tone grading in the AIoT group was significantly better than that in the control group ($P<0.05$). As shown in Table 3, it can be observed that after receiving AIoT stroke walking wearable device training, the proportion of patients with grade V and IV significantly decreased, and in the AIoT group, the proportion of Grade I increased from 25 (23.6%) cases before treatment to 40 (37.7%) cases, indicating that AIoT stroke walking wearable devices have a significant promoting effect on improving muscle tension in patients with IS.

Table 2 Assessment of Holden Walking Function Classification Undergoing AIoT Rehabilitation Training Before and After PSM

Holden Walking Function Classification	Before PSM			P-Value	After PSM			P-Value
	Overall (N=777)	AIoT (N=106)	Non-AIoT (N=671)		Overall (N=212)	AIoT (N=106)	Non-AIoT (N=106)	
Before treatment (%)								
0	11 (1.4)	4 (3.8)	7 (1.0)	0.092	5 (2.4)	4 (3.8)	1 (0.9)	0.102
I	256 (32.9)	31 (29.2)	225 (33.5)		64 (30.2)	31 (29.2)	33 (31.1)	
II	238 (30.6)	38 (35.8)	200 (29.8)		64 (30.2)	38 (35.8)	26 (24.5)	
III	256 (32.9)	29 (27.4)	227 (33.8)		73 (34.4)	29 (27.4)	44 (41.5)	
IV	7 (0.9)	2 (1.9)	5 (0.7)		2 (0.9)	2 (1.9)	0 (0.0)	
V	9 (1.2)	2 (1.9)	7 (1.0)		4 (1.9)	2 (1.9)	2 (1.9)	
One month after treatment (%)								
0	7 (0.9)	5 (4.7)	2 (0.3)	<0.001	5 (2.4)	5 (4.7)	0 (0.0)	<0.001
I	131 (16.9)	4 (3.8)	127 (18.9)		23 (10.8)	4 (3.8)	19 (17.9)	
II	250 (32.2)	29 (27.4)	221 (32.9)		65 (30.7)	29 (27.4)	36 (34.0)	
III	350 (45.0)	33 (31.1)	317 (47.2)		83 (39.2)	33 (31.1)	50 (47.2)	
IV	31 (4.0)	28 (26.4)	3 (0.4)		28 (13.2)	28 (26.4)	0 (0.0)	
V	8 (1.0)	7 (6.6)	1 (0.1)		8 (3.8)	7 (6.6)	1 (0.9)	

Table 3 Assessment of Improved Ashworth Muscle Tone Grading Undergoing AIoT Rehabilitation Training Before and After PSM

Improved Ashworth Muscle Tone Grading	Before PSM			P-Value	After PSM			P-Value
	Overall (N=777)	AIoT (N=106)	Non-AIoT (N=671)		Overall (N=212)	AIoT (N=106)	Non-AIoT (N=106)	
Before treatment (%)								
0	5 (0.6)	2 (1.9)	3 (0.4)	0.022	3 (1.4)	2 (1.9)	1 (0.9)	0.142
I	186 (23.9)	25 (23.6)	161 (24.0)		55 (25.9)	25 (23.6)	30 (28.3)	
I+	169 (21.8)	19 (17.9)	150 (22.4)		37 (17.5)	19 (17.9)	18 (17.0)	
II	202 (26.0)	20 (18.9)	182 (27.1)		53 (25.0)	20 (18.9)	33 (31.1)	
III	207 (26.6)	37 (34.9)	170 (25.3)		60 (28.3)	37 (34.9)	23 (21.7)	
IV	8 (1.0)	3 (2.8)	5 (0.7)		4 (1.9)	3 (2.8)	1 (0.9)	
One month after treatment (%)								
0	188 (24.2)	26 (24.5)	162 (24.1)	0.164	55 (25.9)	26 (24.5)	29 (27.4)	0.044
I	241 (31.0)	40 (37.7)	201 (30.0)		64 (30.2)	40 (37.7)	24 (22.6)	
I+	239 (30.8)	33 (31.1)	206 (30.7)		67 (31.6)	33 (31.1)	34 (32.1)	
II	30 (3.9)	2 (1.9)	28 (4.2)		9 (4.2)	2 (1.9)	7 (6.6)	
III	56 (7.2)	2 (1.9)	54 (8.0)		11 (5.2)	2 (1.9)	9 (8.5)	
IV	23 (3.0)	3 (2.8)	20 (3.0)		6 (2.8)	3 (2.8)	3 (2.8)	

Improvement in Brunnstrom Classification of Lower Limbs

As shown in Table 4, compared with before treatment, there was a certain improvement in the Brunnstrom grading of the lower limbs in both groups after one month of treatment, and the improvement effect of the AIoT group was significantly better than that of the control group ($P<0.05$). Among them, there were only 4(3.8%) patients with grade V and VI in the AIot group before treatment, and after 1 month of treatment, 32 (30.2%) and 33 (31.1%) patients recovered to grade V and VI, respectively. This indicates that AIoT stroke walking wearable devices can significantly improve the recovery of lower limb motor function in patients with ischemic stroke during rehabilitation training.

Table 4 Assessment of Brunnstrom Classification of Lower Limbs Undergoing AIoT Rehabilitation Training Before and After PSM

Brunnstrom Classification of Lower Limbs	**Before PSM**			**P-Value**	**After PSM**			**P-Value**
	Overall (N=777)	**AIoT (N=106)**	**Non-AIoT (N=671)**		**Overall (N=212)**	**AIoT (N=106)**	**Non-AIoT (N=106)**	
Before treatment (%)								
I	244 (31.4)	34 (32.1)	210 (31.3)	0.242	65 (30.7)	34 (32.1)	31 (29.2)	0.424
II	246 (31.7)	31 (29.2)	215 (32.0)		66 (31.1)	31 (29.2)	35 (33.0)	
III	262 (33.7)	35 (33.0)	227 (33.8)		74 (34.9)	35 (33.0)	39 (36.8)	
IV	15 (1.9)	2 (1.9)	13 (1.9)		2 (0.9)	2 (1.9)	0 (0.0)	
V	6 (0.8)	2 (1.9)	4 (0.6)		3 (1.4)	2 (1.9)	1 (0.9)	
VI	4 (0.5)	2 (1.9)	2 (0.3)		2 (0.9)	2 (1.9)	0 (0.0)	
One month after treatment (%)								
I	163 (21.0)	6 (5.7)	157 (23.4)	<0.001	29 (13.7)	6 (5.7)	23 (21.7)	<0.001
II	196 (25.2)	3 (2.8)	193 (28.8)		37 (17.5)	3 (2.8)	34 (32.1)	
III	266 (34.2)	3 (2.8)	263 (39.2)		42 (19.8)	3 (2.8)	39 (36.8)	
IV	69 (8.9)	29 (27.4)	40 (6.0)		34 (16.0)	29 (27.4)	5 (4.7)	
V	47 (6.0)	32 (30.2)	15 (2.2)		36 (17.0)	32 (30.2)	4 (3.8)	
VI	36 (4.6)	33 (31.1)	3 (0.4)		34 (16.0)	33 (31.1)	1 (0.9)	

Range of Motion and Gait of Lower Limb Joints

We compared the recovery effects of hip and knee joint mobility in patients before and after treatment, as shown in Table 5. After one month of treatment, the hip and knee joint mobility in both groups increased compared to before treatment, and the recovery effect of the AIoT group was significantly better than that of the control group ($P<0.05$). At the same time, as shown in Table 6, after one month of treatment, the stride length, stride length, and stride speed of both groups increased compared to before treatment, and the recovery effect of stride length, stride length, and stride speed in the AIoT group was significantly better than that in the control group ($P<0.05$). Collectively, AIoT stroke walking wearable devices can improve joint mobility and walking conditions to a certain extent in the rehabilitation training of ischemic stroke patients.

AIoT is the Top Protective Predictors of 30-Day Readmission

Using the generalized linear regression in Table 7 to construct the optimal prediction model, we identified the most important predictive factors for 30 day readmission. According to the variable importance score based on univariate and multivariate logical analysis, the top 9 predictive factors for 90-day readmission were AIoT stroke walking wearable devices, age, length of stay,BMI, atrial fibrillation, intracranial artery stenosis, carotid stenosis, ASITN/SIR, and diffusion weighted imaging (P<0.05). This analysis shows that receiving AIoT stroke walking wearable device treatment is significantly correlated with readmission to patients with IS within 90 days.

Table 5 Assessment of Range of Motion of Lower Limb Joints Undergoing AIoT Rehabilitation Training Before and After PSM

Variables		**Before PSM**			**P-Value**	**After PSM**			**P-Value**
		Overall (N=777)	**AIoT (N=106)**	**Non-AIoT (N=671)**		**Overall (N=212)**	**AIoT (N=106)**	**Non-AIoT (N=106)**	
HJROM,cm	Before treatment (median [IQR])	8.22 [7.70, 8.69]	8.09 [7.61, 8.71]	8.24 [7.70, 8.69]	0.319	8.18 [7.62, 8.73]	8.09 [7.61, 8.71]	8.30 [7.64, 8.82]	0.361
	One month after treatment (median [IQR])	9.85 [9.67, 10.07]	12.70 [11.03, 13.97]	9.81 [9.64, 9.98]	<0.001	10.08 [9.81, 12.69]	12.70 [11.03, 13.97]	9.83 [9.66, 9.99]	<0.001
KJROM,cm	Before treatment (median [IQR])	12.87 [12.15, 13.78]	12.87 [12.29, 13.67]	12.87 [12.10, 13.80]	0.803	12.92 [12.23, 13.73]	12.87 [12.29, 13.67]	12.98 [12.21, 13.74]	0.978
	One month after treatment (median [IQR])	26.52 [25.52, 27.63]	30.02 [29.32, 30.80]	26.21 [25.32, 27.20]	<0.001	28.41 [26.25, 30.02]	30.02 [29.32, 30.80]	26.24 [25.37, 27.22]	<0.001

Abbreviations: IQR, interquartile range; HJROM, Hip joint range of motion; KJROM, Knee joint range of motion.

Table 6 Assessment of Stride Undergoing AIoT Rehabilitation Training Before and After PSM

Variables		Before PSM			P-Value	After PSM			P-Value
		Overall (N=777)	AIoT (N=106)	Non-AIoT (N=671)		Overall (N=212)	AIoT (N=106)	Non-AIoT (N=106)	
SL, cm	Before treatment (median [IQR])	27.40 [25.36, 29.34]	27.32 [25.24, 29.43]	27.42 [25.36, 29.34]	0.833	27.68 [25.38, 29.62]	27.32 [25.24, 29.43]	28.03 [25.90, 29.63]	0.408
	One month after treatment (median [IQR])	38.49 [35.48, 41.22]	48.58 [45.22, 50.76]	37.55 [34.90, 40.05]	<0.001	42.26 [37.65, 48.56]	48.58 [45.22, 50.76]	37.61 [34.64, 40.43]	<0.001
Stride, cm	Before treatment (median [IQR])	55.56 [52.59, 58.59]	55.40 [52.12, 57.89]	55.59 [52.66, 58.75]	0.152	55.37 [52.54, 58.29]	55.40 [52.12, 57.89]	55.36 [52.73, 59.09]	0.173
	One month after treatment (median [IQR])	76.83 [72.64, 79.92]	91.58 [89.02, 93.46]	75.58 [72.14, 78.56]	<0.001	83.80 [76.53, 91.58]	91.58 [89.02, 93.46]	76.51 [73.89, 78.90]	<0.001
Pace, m/min	Before treatment (median [IQR])	55.44 [53.31, 57.49]	55.60 [53.62, 57.68]	55.42 [53.26, 57.47]	0.707	55.55 [53.54, 57.66]	55.60 [53.62, 57.68]	55.43 [53.50, 57.62]	0.905
	One month after treatment (median [IQR])	83.01 [80.11, 85.89]	90.17 [88.12, 92.03]	82.18 [79.85, 84.91]	<0.001	87.00 [82.40, 90.15]	90.17 [88.12, 92.03]	82.39 [79.91, 85.07]	<0.001

Abbreviations: IQR, interquartile range; SL, Step length.

Table 7 Univariate and Multivariate Analyses of Prognostic Factors Associated with 90-Day Readmission in Patients with IS

Variables	Univariate			P-Value	Multivariate			P-Value
	95% CI	Lower	Upper		95% CI	Lower	Upper	
Age	1.12	0.36	2.25	<0.05	1.21	0.44	2.65	<0.05
Gender								
Male	1							
Female	0.92	0.13	2.18	>0.05				
COD	1.23	0.56	2.87	>0.05				
LOS								
<3	1							
≥3	2.24	0.87	3.94	<0.05	2.19	0.52	3.87	<0.05
BMI	1.06	0.71	3.07	<0.05	1.21	0.56	3.13	<0.05
Hypertension								
Yes	1							
No	0.56	0.22	4.08	<0.05				
Diabetes								
Yes	1							
No	0.71	0.23	2.19	>0.05				
AF								
Yes	1							
No	0.83	0.23	2.67	<0.05	0.77	0.06	2.63	<0.05
IAS								
Yes	1							
No	0.69	0.18	2.34	<0.05	0.72	0.23	2.59	<0.05
CS								
Yes	1							
No	0.71	0.21	2.29	<0.05	0.69	0.17	2.37	<0.05
PVD								
Yes	1							
No	0.68	0.12	3.52	<0.05				
ASITN/SIR								
I~II	1							
III~IV	2.35	0.99	5.16	<0.05	2.21	0.68	4.92	<0.05

(*Continued*)

Table 7 (Continued).

Variables	Univariate			P-Value	Multivariate			P-Value
	95% CI	Lower	Upper		95% CI	Lower	Upper	
DWI								
High	1							
Low	0.89	0.18	2.76	<0.05	0.72	0.21	3.15	<0.05
HD								
Yes	1							
No	0.77	0.13	2.08	>0.05				
CRI								
Yes	1							
No	0.63	0.11	2.27	>0.05				
AIoT								
Yes	1							
No	1.58	0.21	3.97	<0.05	1.72	0.31	4.28	<0.05

Abbreviations: 95% CI, 95% confidence interval; COD, Course of disease, LOS, Length of Stay, BMI, Body mass index, AF, Atrial fibrillation, IAS, Intracranial artery stenosis, CS, Carotid stenosis, PVD, Peripheral vascular disease, ASITN/SIR, American Society of Interventional and Therapeutic Neuroradiology/Society of Interventional Radiology, DWI, Diffusion weighted imaging, HD, Heart disease, CRI, Chronic renal insufficiency.

Discussion

Stroke is one of the main causes of death and disability in humans. Epidemiological survey results show that 70% to 80% of stroke patients have various symptoms and signs of neurological damage, which makes it difficult for patients to independently complete daily activities, reduces their quality of life, and brings economic burden and mental pressure to patients and their families.[14,15] In clinical practice, rehabilitation training for patients with IS is a systematic and phased process that requires personalized plans based on the patient's specific situation. Early rehabilitation activities are an important way to improve functional impairment in stroke patients, but there are no clear standards and opinions on the optimal start time, dosage, and frequency of activities.[16,17] While it is widely acknowledged that early rehabilitation interventions ought to be initiated within a 24-to-48-hour window following a stroke, it is equally critical that such interventions are tailored into personalized activity regimens, as they must take into account variables like the patient's stroke subtype, clinical severity, and physiological tolerance.[18]

In this study, we focused on the walking dysfunction in stroke patients after treatment, and provided rehabilitation training guided by gait analysis systems in clinical practice to promote the recovery of walking function. Although gait analysis systems and other devices can provide walking motion parameters, they are bulky, expensive, require multiple people to collaborate, time-consuming, and laborious. They lack correlation analysis between multiple parameters such as angle, force, and tension in walking motion, making it difficult to achieve synchronous evaluation and treatment, which limits their clinical application. At the same time, how to ensure the homogeneity of treatment between different hospitals and the continuity of treatment between hospitals and families during the long process of rehabilitation for stroke patients is also an important challenge in clinical practice, which urgently requires the development of new technologies and equipment.

The Mechanism of Early Rehabilitation Activities Improving Neurological Function After Stroke

Previous studies have shown that after stroke, local ischemia and hypoxia in the brain lead to irreversible neuronal damage, and patients often experience functional impairments in various aspects such as cognition, sensation, and movement.[19,20] Under the combined effect of brain self repair and early rehabilitation activities, stroke patients can achieve good rehabilitation outcomes. The self repair of the brain is closely related to brain plasticity, and structural plasticity and functional plasticity are important mechanisms for the recovery of neurological function after stroke.[21,22]

Early rehabilitation activities can promote neurological function recovery by affecting the structural and functional plasticity of the brain. Previous studies have found that early rehabilitation activities can upregulate the number of neural stem cells, promote stem cell differentiation into neurons, increase axonal regeneration and activate new connections between surviving neurons, promote the function of damaged brain tissue in surviving brain regions, and also promote remodeling of the motor cortex and distant areas around infarction, improving nerve damage.[23–25] Ischemic penumbra is ischemic brain tissue that has lost its original function around the cerebral infarction lesion, but retains intact cell morphology and has potential for recovery.[26] Research has also shown that early rehabilitation activities improve motor function by activating astrocytes in the ischemic penumbra, promoting their transformation into neurons, reducing neuronal apoptosis in the infarct margin, and increasing the number of new neurons.[27,28]

At present, although there are many studies on the mechanism of stroke rehabilitation, the specific mechanism is still unclear. The plasticity of the brain gradually decreases over time with stroke, and the ischemic penumbra exists for a short period of time, resulting in a narrow effective time window for neuronal repair and limited repair ability.[28,29] Therefore, it is particularly important to explore the optimal intervention timing for early rehabilitation activities. In this study, our device innovatively integrates interaction inhibition theory, motion chain mode, and motion dynamics shaping principle, transforming the distal lower limb from an open chain to a closed chain motion during the step phase, enhancing control of the knee and ankle joints. More importantly, by inhibiting the interaction between knee and ankle muscles, we can alleviate spasms, alter abnormal patterns of knee overexcitation and ankle plantarflexion and inversion. The walking device provides stable and continuous joint control, combined with remote data transmission function, to help patients reconstruct correct walking dynamics.

Development of Early Rehabilitation Activity Plan

Three months after a stroke is a critical period for neurological recovery, during which rehabilitation activities can significantly improve patients' neurological dysfunction, but progress is slow thereafter.[30,31] Therefore, identifying the optimal starting time for rehabilitation activities is crucial for the rehabilitation outcomes of stroke patients. Studies have shown that rats with middle cerebral artery occlusion receive moderate intensity rehabilitation activities at 24, 48, 72, and 96 hours after stroke.[32,33] The results indicate that starting moderate intensity rehabilitation activities within 24 hours of stroke onset is not conducive to neurological function recovery. But some studies have also found that starting rehabilitation activities within 24 hours of a stroke can inhibit neuronal apoptosis, reduce stroke volume, and improve neurological function.[34,35] Researchers generally believe that early rehabilitation activities should be started as early as possible, but existing research results cannot determine the optimal start time for early rehabilitation activities.

In this study, we administered AIoT based stroke walking wearable devices combined with routine rehabilitation training to patients diagnosed with IS within one month. The results showed that patients who used AIoT based stroke walking wearable devices had better walking and lower limb functions than those who only received routine rehabilitation training. Analyzing the reasons for the above results, compared with traditional rehabilitation assessment and treatment, wearable devices can more accurately evaluate and record patients' physiological and motor parameters through sensors, and provide real-time presentation and feedback, enabling patients and therapists to quickly and intuitively capture patients' physiological and motor conditions, thus enabling more targeted and safer rehabilitation training.

Consistent with previous research findings, the study conducted by Marion et al showed that without changing the initial activity time and activity dose, for every increase in activity frequency, the probability of patients achieving good outcomes at 3 months after stroke increased by 13%, and the probability of achieving a 50 meter walk without assistance increased by 66%.[36] The first activity time and frequency remain unchanged, and increasing the activity dose by 5 minutes per day reduces the likelihood of patients achieving good outcomes. This may be related to the fact that high-dose activities can exacerbate the degree of cerebral ischemia and hypoxia, leading to a reduced possibility of ischemic penumbra recovery, suggesting that low-dose and high-frequency early rehabilitation activities are more conducive to limb function recovery after stroke.

Cognition of Medical Personnel Towards Early Rehabilitation Activities

In clinical practice, most healthcare professionals believe that the risk of motor function, cognitive impairment, and depression in stroke patients is closely related to their time out of bed.[37,38] They support early activity in stroke patients and hold a positive attitude towards the outcome of early rehabilitation activities. However, they are concerned about early activity in hemorrhagic stroke patients. Our team conducted a random survey of domestic neurology medical personnel, and the results showed that their professional knowledge of stroke rehabilitation is relatively lacking, and their understanding of early rehabilitation activities is insufficient. They cannot timely obtain new developments and technologies related to stroke rehabilitation, which is influenced by various factors such as specialized working hours, hospital level, and receiving training on early rehabilitation activities. In addition, the clinical implementation of early rehabilitation activities for stroke is not ideal. According to the National Rehabilitation Medicine Professional Medical Service and Quality Safety Report, only 18.90% of stroke patients underwent early rehabilitation activities within 24–48 hours of admission.[39] The early rehabilitation activity rate for patients with acute cerebral infarction is relatively high, but only 39.50%.[39,40] Therefore, it is necessary to strengthen the training of stroke rehabilitation knowledge and skills for medical personnel, increase their attention to early rehabilitation activities, and promote the widespread application of early rehabilitation activities in stroke patients.

Given this situation, the portable plantar pressure testing technology equipped in AIoT stroke walking wearable devices uses flexible pressure sensors embedded in shoes (pads) to provide real-time feedback on plantar pressure distribution, and continuously captures plantar pressure during training, providing timely feedback to medical staff for targeted rehabilitation training. Therefore, based on the above analysis, the observation group patients were able to achieve better walking and lower limb function after treatment, which has a positive effect on their rehabilitation.

This study also inevitably has the following limitations.Firstly, this study is essentially retrospective, and although PSM was performed based on patient and tumor characteristics, there may be selection bias to reduce bias. The results obtained should be further validated in prospective studies. Secondly, the use of AIoT based walking wearable devices in the rehabilitation training of patients with IS is still in the exploratory stage, so a large sample and multi-center research queue is still needed to confirm the universality of this auxiliary exercise strategy in the future. Finally, our study included a single center sample and the follow-up time was relatively short. Therefore, long-term follow-up is still needed for these patients to more comprehensively evaluate the advantages and disadvantages of AIoT stroke walking wearable devices in patients with IS.

Conclusion

In conclusion, our study has demonstrated that a stroke walking wearable devices based on AIoT technology can effectively improve walking condition, lower limb muscle tone, lower limb function, and joint mobility to a certain extent, as well as the prognosis of patients with IS. Additionally, we have also identified AIoT and other clinical factors as independent predictive factors for the 90-day readmission of patients with IS, suggesting that AIoT technology could play a critical role in tailoring treatment plans to better meet the individual needs of patients, potentially enhancing therapeutic outcomes and personalizing care strategies.

Data Sharing Statement

The datasets analyzed during the current study are available from the corresponding author on reasonable request.

Ethical Statement

Ethical approval was obtained from the Ethics Committee of the Longgang District Central Hospital of Shenzhen. This retrospective study did not contain any identifiable human images and was an anonymous data collection that waived patients' written informed consent. The study was conducted in compliance with the Declaration of Helsinki, and all patient data were anonymized and handled with strict confidentiality to protect patient privacy.

Author Contributions

All authors made a significant contribution to the work reported, whether that is in the conception, study design, execution, acquisition of data, analysis and interpretation, or in all these areas; took part in drafting, revising or critically reviewing the article; gave final approval of the version to be published; have agreed on the journal to which the article has been submitted; and agree to be accountable for all aspects of the work.

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Disclosure

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