THE PHYSIOLOGICAL COST INDEX (PCI) AND WALKING PERFORMANCE OF DIFFERENT WALKING AIDS IN STROKE SURVIVORS

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Abstract

Objective: Walking aids are widely prescribed for supporting ambulation in stroke patients. Many factors must be considered to decide which walking aid will be prescribed, including the energy cost and the walking performance produced by using the walking aids. This research aimed to investigate the differences between the Physiological Cost Index (PCI), the Timed Up and Go (TUG) Test, and walking speed in stroke patients according to the type of walking aid used. **Methods:** A total of 26 patients with subacute stroke were sampled in a consecutive sampling at Malang Saiful Anwar General Hospital's PM&R outpatient clinic. Each patient completed walking with four different walking aids: a fixed walker, a rollator, a quad cane, and a single-point cane, resting between tests until the patient's heart rate returned to its resting level. We measure the PCI using heart rate and walking speed during a 10-meter walk test (10MWT) and mobility performance during the Timed Up and Go (TUG) Test. **Results:** The PCI was lower with the single-point cane ($p<0.001$), and the walking speed and mobility performance were higher with the single-point cane ($p<0.001$) than with any other walking aid. **Conclusion:** Our research revealed that a single-point cane requires less energy and permits more excellent performance for stroke patients who can already walk with a walking aid.

Keywords: Stroke, Walking Aid, Physiological Cost Index, Walking Performance.

1. INTRODUCTION

The ability to ambulate is a critical function for carrying out daily activities. However, ambulation disorders are also the most common sequelae of stroke. Thus, the impact on daily activities and the quality of life of post-stroke patients is enormous (Danielsson et al., 2012; Winstein et al., 2016). The pathophysiology of ambulation disorders in stroke patients can be influenced by various factors, including muscle weakness, loss of voluntary movement, asymmetrical patterns of posture, balance disturbances and instability, spasticity, sensory disturbances, and visual disturbances that occur as manifestations of stroke (Beyaert et al., 2015). Although stroke reduces ambulation function, as many as 50%-85% of stroke survivors can ambulate independently, both with and without walking aids, 6 months after the stroke (Danielsson et al., 2012; MEDICA, 2018; Park et al., 2017; van Bloemendaal et al., 2012).

The use of ambulation aids to improve gait patterns and balance as well as the efficiency and safety of ambulation is supported by class I recommendations and level B evidence. Research shows that more than 50% of post-stroke patients need walking aids (a cane, walker, rollator, or wheelchair) to help improve their ambulation function (Jutai et al., 2007; Winstein et al., 2016). Tyson and Polese showed in their research that the use of walkers can improve the functional ability of ambulation in post-stroke patients. In this research, it was also stated that post-stroke patients felt their confidence and sense of security when walking increased if they walked using an ambulation aid (Polese et al., 2012; Tyson & Rogerson, 2009; Winstein et al., 2016).

In line with the above research, previous research from Laufer has also stated that the use of walking aids can reduce postural sway and improve walking stability and performance (Laufer, 2002; Winstein et al., 2016).

In post-stroke patients, energy requirements when walking will increase due to limb weakness and other functional disorders. The severity of functional impairment and the level of disability can also affect the efficiency and safety of the ambulation process (Polese et al., 2017). Oxygen consumption and the energy cost of walking (ECW) have been used extensively in the literature to investigate the efficacy of interventions performed for It has been widely reported previously that a reliable measurement method for measuring energy requirements is air exchange (in this case, oxygen) analysis. However, this method is relatively difficult to do in some conditions and depends on the availability of instruments (which are relatively expensive) and other resources (da Cunha-Filho et al., 2003; Delussu et al., 2014; Eng et al., 2004). Another method that can be used to measure energy needs is the Physiological Cost Index (PCI) proposed by MacGregor. This PCI theory is based on the submaximal effort, where there is a correlation between heart rate and oxygen volume (VO2). The Physiological Cost Index (PCI) has also been used to measure energy requirements when working on several conditions, including stroke, lower limb amputation with the use of prostheses, multiple sclerosis, cerebral palsy, spinal cord injury, and in the elderly (Arazpour et al., 2016; Cetin et al., 2010; Du Plessis et al., 2019; Narimani et al., 2016; Sadeh & Sharifatpour, 2020).

There are many methods that can be used to measure walking performance in post-stroke patients, including the 6-minute walk test, the 10-meter comfortable walk test, the 10-meter fast walk test, and many others. Achievements measured include walking distance, walking speed, and the functional ambulation of the patient. 4 The Timed Up and Go (TUG) test is also used to measure the functional ability of ambulation. Research states that the TUG Test is a valid, reliable, and easy method of measuring ambulation/walking performance.[20,21,22]

2. MATERIALS AND METHODS

For this cross-sectional research, the participants were recruited consecutively from the Department of Physical Medicine and Rehabilitation at Malang Saiful Anwar General Hospital. This research was conducted from October 2021 to March 2022. This research was approved by the ethical committee of Malang Saiful Anwar General Hospital under Ethic Approval No. 400/153/K.3/302/2021. Each participant was given all the information they needed to consent to participate in the research, and they all gave their consent for the research's data and, if necessary, images or videos, to be published.

2.1 Participants

Inclusion criteria for the patients were: age 21–60 years, infarct or hemorrhagic stroke in the subacute phase with walking disturbance, using a walking aid for daily activities, being able to walk at least 10 meters at a parallel bar, being able to use the walking aid tested, being cooperative, not having cognitive impairment (Moca-INA $\geq$ 26), being pain-free (VAS $\leq$ 2), and giving consent to participate in this research. Exclusion criteria were: comorbidities or disabilities other than stroke affecting walking capability; an unstable condition (new symptoms related to the disease, SBP > 160mmHg, DBP > 100mmHg, resting HR > 120x/m, SpO2 < 95%, RR > 24x/m, Borg scale $\geq$ 13).

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2.2 Equipment

Materials used were a fixed walker, a rollator, a quadripod cane, and a single-point cane; a HR monitor (*Polar H10 heart rate sensor chest strap* (*Polar Electro*)); a timing sensor system (*Speed Tech Wireless Laser Timer (Speed Tech)*); a stopwatch; and a chair with an armrest.

Figure 1: Fixed walker

Figure 2: Rollator

Figure 3: Quadripod Cane

Figure 4: Single-point Cane

2.3 Procedure

Before the research began, patients had the chance to test out various walking aids for a short while in front of the researcher until they felt comfortable using them to confirm their proper use and customize the height for each patient.

We conducted the measures in the following manner:

- Evaluation of the resting heart rate with the subject seated in a chair with a heart rate monitor
- The TUG test measurement using a fixed walker
- Recuperating until the subject is able to return to their resting heart rate
- The 10MWT was measured with a fixed walker at comfort speed; measurements were taken once the comfort speed was reached: walking time and maximal heart rate during the test.
- Recuperating until the subject is able to return to their resting heart rate
- The TUG test and 10MWT were measured consecutively for rollator, quadripod cane, single-point cane, and without any walking aid, with rests in between to allow heart rate to return to resting levels.

The PCI uses the following formula to calculate the number of extra heartbeats required per meter walked:[12]

$$\text{PCI (beats/m)} = \frac{\text{Walking heart rate (beats/min)} - \text{Resting heart rate (beats/min)}}{\text{Walking speed (m/min)}}$$

Figure 5: The Patient Performs the Walking Test with Various Walking Aids

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2.4 Statistical Analysis

The data obtained is in the form of walking performance, as measured by the TUG Test and walking speed, as well as the Physiological Cost Index (PCI). Descriptive data is presented as means and standard deviations, whereas categorical data is presented as percentages. The data will be analyzed using the SPSS 26 program with a 95% confidence level ($\alpha<0.05$) and 80% power. We analyzed group differences with the Friedman test due to heterogeneity. The Wilcoxon signed-rank test was used for within-group comparisons within the walking aid. The data is also compared with the minimal detectable change (MDC) and minimal clinically important difference (MCID) constants for each running performance variable and PCI.

3. RESULTS

There were a total of 117 stroke patients in the Medical Rehabilitation Installation at Malang Saiful Anwar General Hospital during the period October 2021 to March 2022. There were 26 subjects who fulfilled the inclusion criteria, while 91 others did not meet the requirements. All 26 subjects who met the requirements successfully followed the procedures, and there was no dropout. No unexpected events, either falls or injuries, occurred during the implementation of this research. All subjects were then included in the analysis for research results.

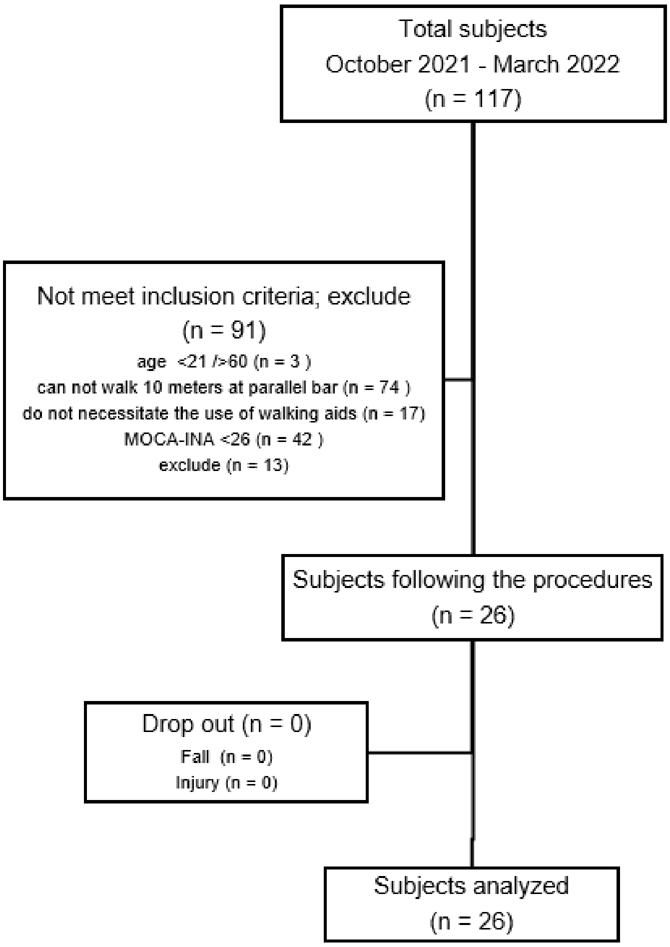

Figure 6: Research Flowchart

Table 1: Subjects Baseline Characteristics

Characteristics	Results (n = 26)
Age	49,35 ± 9,73
Gender	
Male	15 (57,7%)
Female	11 (42,3%)
Stroke type	
Non-bleeding	16 (61,5%)
bleeding	10 (38,5%)
Paretic side	
Right	13 (50%)
Left	13 (50%)
Onset (days)	43,46 ± 20,28
Systolic blood pressure (mmHg)	130 ± 10
Diastolic blood pressure (mmHg)	80 ± 10
Resting heart rate (beae/minute)	79,54 ± 7,17
Respiratory rate (breath/minute)	20 ± 4
Oxygen saturation (%)	98 ± 2
Spasticity (MAS)	
1	17 (65,4%)
2	9 (34,6%)
FMA UE	23 ± 2,45
FMA LE	28,62 ± 1,30
7-items BBS	10,81 ± 1,41
Borg scale	9 ± 2

MAS = Modified Asworth Scale; FMA = Fugl-Meyer Assessment; UE: Upper Extremity; LE: Lower Extremity; BBS = Berg Balance Score

The subjects in this research had a mean age of 49.35 years, were 57.7% male, had 61.5% non-hemorrhagic strokes, 50% right-sided weakness, and had been hospitalized for an average of 43.46 days. They had a blood pressure of 130/80 mmHg, a resting pulse rate of 79.54 beats per minute, a respiratory rate of 20 breaths per minute with an oxygen saturation of 98%, MAS 1 spasticity of 65.4%, an FMA/AGA score of 23 points and an AGB/AGA score of 28.62 points, a BBS score of 10.81 points, and a Borg scale of 9 (Table 1).

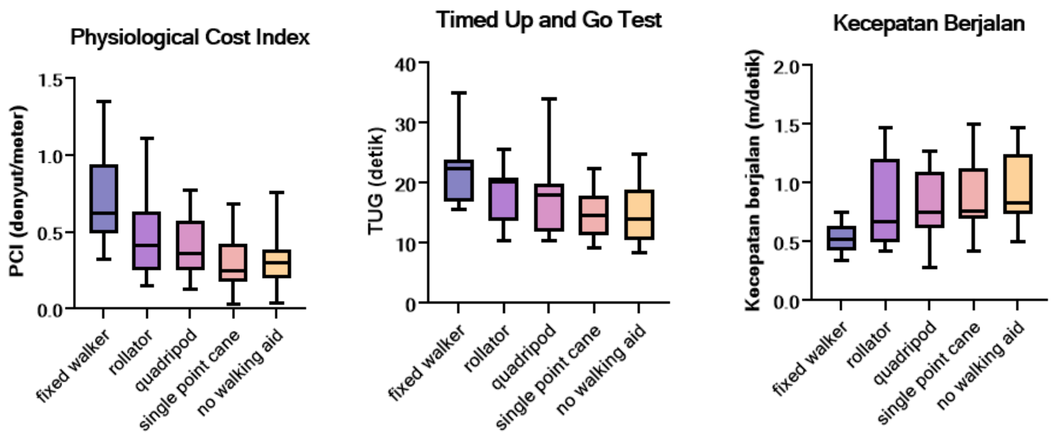

Figure 7: Physiological Cost Index (PCI) and Walking Performance within Walking Aids

Table 2: Comparison of Physiological Cost Index (PCI) and Walking Performance within Walking Aids

Walking Performance	Walking Aids	N	Mean ± SD	P
TUG (second)	Fixed Walker	26	21,76 ± 4,45	<0,001*
	Rollator	26	18,02 ± 4,33	
	Quadripod cane	26	17,16 ± 5,45	
	Single-point cane	26	14,66 ± 3,63	
	Without walking aid	26	15,11 ± 4,66	
10MWT (m/second)	Fixed Walker	26	0,54 ± 0,14	<0,001*
	Rollator	26	0,82 ± 0,35	
	Quadripod cane	26	0,82 ± 0,28	
	Single-point cane	26	0,90 ± 0,31	
	Without walking aid	26	0,94 ± 0,29	
PCI (beat/meter)	Fixed Walker	26	0,707 ± 0,285	<0,001*
	Rollator	26	0,450 ± 0,244	
	Quadripod cane	26	0,406 ± 0,203	
	Single-point cane	26	0,304 ± 0,164	
	Without walking aid	26	0,313 ± 0,180	

Friedman Test
TUG = Timed Up and Go Test; 10MWT = 10 Meters Walking Test; PCI = Physiological Cost Index

The slowest average TUG value was in a fixed walker (21.76 seconds), then increasing sequentially in a rollator (18.02 seconds), quadripod (17.16 seconds), and reaching the fastest value on a single-point cane (14.66 seconds), but slower without a walking aid (15.11 seconds). The average value of walking speed as assessed by the 10MWT is the slowest with a fixed walker (0.54 meters/second), then it increases faster with the same results in rollators and quadripods (0.82 meters/second), single-point canes (0.90 m/s), and the fastest without walking aids (0.94 m/s). The highest mean PCI value was in the use of a fixed walker (0.707 beats/meter), then decreased sequentially in the use of a rollator (0.450 beats/meter), quadripod (0.406 beats/meter), and became the lowest in the use of a single-point cane (0.304 beats/meter), but increased even more without the use of a walking aid (0.313 beats/meter) (Figure 7).

The results of the Friedman test analysis between walking performance and PCI with the walking aids used showed significant results (p<0.001), which means that in each parameter assessed, there were at least 2 types of walking aids that had significantly different walking parameters (Table 2). In order to find out which pair of walking aids differed significantly in each walking parameter studied, a post hoc test was used.

Table 3: The Physiological Cost Index and Walking Performance in Walking Aids: A Posthoc Comparison

Walking Aids	p		
	TUG (second)	10MWT (m/second)	PCI (beat/meter)
Fixed Walker vs Rollator	<0,001*	<0,001*	<0,001*
Fixed Walker vs Quadripod cane	<0,001*	<0,001*	<0,001*
Fixed Walker vs Single-point cane	<0,001*	<0,001*	<0,001*
Fixed Walker vs Without walking aid	<0,001*	<0,001*	<0,001*
Rollator vs Quadripod cane	0,013*	0,534	0,023*
Rollator vs Single-point cane	<0,001*	0,096	<0,001*
Rollator vs Without walking aid	<0,001*	0,003*	<0,001*
Quadripod cane vs Single-point cane	<0,001*	0,002*	<0,001*

Quadripod cane vs Without walking aid	<0,001*	<0,001*	0,003*
Single-point cane vs Without walking aid	0,191	0,014*	0,829
Wilcoxon Signed Ranks Test			
TUG = *Timed Up and Go Test*; 10MWT = *10 Meters Walking Test*; PCI = *Physiological Cost Index* * p<0,05			

In the TUG parameter, all types of walking aids had significant differences (p<0.05), except between single-point canes and without walking aids (14.66 seconds vs. 15.11 seconds; p=0.191). In the 10MWT parameter, there was a significant difference between types of walkers with p<0.05, except between rollators and quadripod walkers (0.82 m/s vs. 0.82 m/s; p=0.534) and rollators with single-point canes (0.82 m/s vs. 0.90 m/s; p=0.096). The PCI parameters showed that there was a significant difference in the comparison of all types of walking aids (p<0.05), except between a single-point cane and no walking aids (0.304 beats/meter vs. 0.313 beats/meter; p<0.829) (Table 3).

Table 4: Physiological Cost Index and Walking Performance within Walking Aids: Minimal Detectable Change and Minimal Clinically Significant Difference

Walking Aids	**MDC & MCID**		
	TUG (second)	**10MWT** (m/second)	**PCI** (beat/meter)
MDC	**2,08**	**0,04**	**0,52**
MCID	**3,4**	**0,14**	**0,76**
Fixed Walker vs Rollator	3,74[a,b]	0,28[a,b]	0,257
Fixed Walker vs Quadripod cane	4,60[a,b]	0,28[a,b]	0,301
Fixed Walker vs Single-point cane	7,10[a,b]	0,36[a,b]	0,403
Fixed Walker vs Without walking aid	6,65[a,b]	0,40[a,b]	0,394
Rollator vs Quadripod cane	0,86	0,00	0,004
Rollator vs Single-point cane	3,36[a]	0,08[a]	0,146
Rollator vs Without walking aid	2,91[a]	0,12[a]	0,137
Quadripod cane vs Single-point cane	2,50[a]	0,08[a]	0,102
Quadripod cane vs Without walking aid	2,05	0,12[a]	0,093
Single-point cane vs Without walking aid	0,45	0,04[a]	0,009
MDC = *Minimal Detectable Change*; MCID = *Minimal Clinically Important Difference*; TUG = *Timed Up and Go Test*; 10MWT = *10 Meters Walking Test*; PCI = *Physiological Cost Index*			
[a] = meet MDC; [b] = meet MCID			

The MDC value of the TUG test is 2.08 seconds, while the MCID value for the TUG test is 3.4 seconds.[23] In comparisons between walking aids used in stroke patients with hemiparese, all of them met the MDC value of the TUG test (> 2.08 seconds), except for the comparison between rollators and quadripods (0.86 seconds), quadripods without walkers (2.05 seconds), and single-point canes without a walker (0.45 seconds). Those that meet the MCID value of the TUG test are the comparisons of fixed walkers with rollators (3.74 seconds), quadripod canes (4.60 seconds), single-point canes (7.10 seconds), and without walking aids (6.65 seconds). The MDC value of 10MWT in stroke patients is 0.04 meters/second, while the MCID value is 0.14 meters/second.[24] In comparison between walkers used in stroke patients with hemiparesis, all of them met the MDC value of 10MWT (>0.04 meters/second), except for the comparison between the rollator and quadripod cane (0.00 meters/second). Those that meet the MCID value of 10MWT are the comparisons of fixed walkers with rollators (0.28 meters/second), quadripod canes (0.28 meters/second), single-point canes (0.36 meters/second), and without walking aids (0.40 meters/second). The MDC value for PCI is 0.52 beats/meter, while the MCID value for PCI is 0.76

beats/meter.[12] In comparisons of walking aids used in stroke patients with hemiparesis, all did not meet PCI's MDC or MCID values.

4. DISCUSSION

4.1 Physiological Cost Index

Oxygen consumption and the energy cost of walking (ECW) have been used extensively in the literature to investigate the efficacy of interventions to improve walking ability. One method that can be used to measure energy needs is PCI, as proposed by MacGregor. This method is done by measuring the total heart rate during activity minus the heart rate at rest, then dividing it by walking speed. The PCI theory is based on the fact that there is a correlation between heart rate and oxygen volume (VO2) at submaximal effort, with units of beats per meter. Several studies have been conducted to test the validity of this PCI method, which showed that PCI is a valid measuring tool for measuring energy requirements when walking (ECW).[12] In post-stroke patients, the Physiological Cost Index (PCI) has also been used as a measurement method.[12] Fredrickson[25] has conducted research on the use of PCI in measuring the ability to walk in post-stroke patients, and the results stated that PCI can be used to represent energy requirements when walking in post-stroke patients. Jaiyesimi[26] also concluded that PCI is a measurement tool that is easy to use, valid, and can be recommended for measuring energy requirements and evaluating functional abilities.

According to Jeong[27], the energy required for stroke patients to walk using a walking aid was lowest when a single-point cane was used, followed by a quadripod cane and a hemi-walker ($p<0.01$). Kim's[28] research discovered that walking with a walking aid and climbing stairs as high as 7 cm ($p<0.005$) can reduce PCI in stroke patients. Deltombe[29] discovered no significant difference in PCI in stroke patients who walked with a rolling cane walker versus a quadripod cane.

Holder[30] and Aiyejusunle[31] mention that energy requirements when walking increased with the use of a heavier and more complex walking aid (walkers compared to canes), whereas without the use of a walking aid the energy requirements were the lowest. This is in accordance with the results of this research, except for those without a walking aid who have a higher PCI compared to the use of a single-point cane. Increased PCI with the use of a more complex walking aid can be caused by the weight and complexity of their use, which increase the metabolic rate and cardiopulmonary response and can result in increased fatigue. Meanwhile, without a walking aid, the muscle weakness that occurs in stroke patients also contributes to an increase in metabolic rate and cardiopulmonary response and can further trigger fatigue. Thus, that in this research, the PCI results obtained were higher than PCI on a single-point cane.[30,31]

4.2 Timed Up and Go Test

The Timed Up and Go Test (TUG test) is a method used to measure the functional ability of ambulation, one of which is walking performance. This test can be performed on elderly patients, patients with chronic diseases, patients with a high risk of falling, and also stroke patients. This test also correlates closely with the 10-meter walk test. This test has also proven to be valid for both children, adolescents, adults, and the elderly.[32] A systematic review stated that the TUG test is a sensitive, valid, and reliable indicator for measuring walking performance in post-stroke patients.[33] Ng and Hui-

Chan[20], Pollock[21], and Chan[22] also both stated that the Timed Up and Go Test (TUG Test) is a valid, reliable, and easy method of measuring ambulation/walking performance.

The Timed Up and Go Test (TUG Test) is also a simple test to determine the dynamic balance status when running. The lower the TUG test value, the lower the risk of falling that might occur in stroke patients with walking disorders. Bower[34] demonstrated that using a walking aid while walking can improve dynamic balance in stroke patients ($p<0.005$). This research states that the results of the TUG test within 14 seconds significantly reduce the risk of falling. By increasing the dynamic balance when running, the running performance will also increase, whether assessed by the TUG test, 10MWT, or 6MWT.[34,35] Although it has not been able to increase TUG test results by 14 seconds to reduce the risk of falling, the trend of TUG test values in this research shows that walking speed is getting better in stroke patients who walk with the use of walking aids.

Elmamoun[36] showed that the use of a walker can improve gait patterns, reduce postural sway, increase stability, and provide weight support. Fixed walkers are more stable but are said to not improve walking performance too much because they are stiff, while rollators improve walking performance more because they don't need to be lifted, but stability is inferior even though they are equipped with a handbrake.[36]

4.3 Walking Speed

The 10-meter walking test (10MWT) is a method that can be used to measure walking performance in post-stroke patients. According to Peters[38], the recommended short-distance walking performance test is the 10-meter walk test. Dalgas[40] stated that both long (6-minute walk test) and short (10-meter walk test) walking performance tests can be used to measure the walking performance of post-stroke patients. The research stated that the 10-meter walk test is good for assessing lower limb strength performance and walking speed, while the 6-minute walk test is good for assessing aerobic capacity and walking distance. Cheng[41] also stated that the 10-meter walk test is valid and comparable to the 6-minute walk test in measuring walking performance in post-stroke patients.

The results of this research are in accordance with research from Aiyejusunle and Hardi, which states that walking speed when using a cane is faster than using a tripod and walker ($p<0.001$). [31,42] According to Jeong[27], the best walking speed of a stroke patient occurred with the use of a single-point cane, as opposed to a quadripod and a hemi-walker ($p<0.01$). The use of a walker results in a slower walking speed, possibly because the walker requires the use of both hands to lift it and then take a step forward, step by step. Whereas the use of a single-point cane, apart from being simpler and used with one hand, is also lighter. Thus, that it is easier to use and results in a faster walking speed. The use of a tripod produces a slower walking speed than a single-point cane because a tripod has more legs, which makes a tripod heavier and more complex in its use.[27,31]

The increase in walking speed as assessed by the 10MWT was also influenced by the improvement in dynamic balance when walking as assessed by the TUG test, thus improving walking performance in stroke patients with gait disorders.[34,35] According to the Kim[28] research, using walking aids can increase walking speed in stroke patients when walking and climbing stairs up to 7 cm high (p 0.005). Deltombe[29] who studied walking speed in stroke patients, showed that walking speed also increased with the rolling cane walker compared to the quadripod cane ($p<0.001$).

4.3 Walking Aids in Stroke Patients

The results of this research indicate that the use of a single-point cane in stroke patients provides the best walking performance compared to other walking aids, as indicated by the fastest TUG test value (14.66 seconds) and the fastest 10MWT value (0.90 m/ seconds), as well as the lowest energy requirement when walking (0.304 beats/meter). For this reason, the prescription of single-point canes is recommended for post-stroke patients to improve their walking ability. However, the selection of a walking aid must still be based on the functional ambulation capabilities of each patient.

Walker has a specific design that can be adjusted to the needs of its users, including being foldable and height adjustable. A walker is useful for people who have poor coordination and balance; it can be used to reduce weight bearing on both legs; it is useful for the elderly and those who are obese; it is useful for long-distance ambulation; it is useful for people who have low endurance; and it can be used for endurance training. The use of a walker is to improve mobility, stability, and the ability to sit, stand, and walk. Meanwhile, the disadvantages of using a walker include being difficult to use in crowds or less roomy environmental conditions, difficult to use on stairs, and difficult to use on rough and uneven terrain.[43,44,45]

The rollator also has design specifications that can be adjusted to the needs of its users, including folding, adjustable height, brakes, and adjustable seats. The benefits of using a rollator include the ability to reduce weight bearing on both legs, use in the elderly, with obesity, for long-distance ambulation, with low endurance, and for endurance training. The use of a rollator, besides being able to prevent the risk of falling, can also improve mobility, including the ability to sit, stand, and walk. Meanwhile, the disadvantages of using a rollator include being difficult to use in crowded or less roomy environmental conditions, difficult to use on stairs, and difficult to use on rough and uneven terrain.[43,44,45]

A cane has design specifications that can be adjusted to the needs of its users: that it can be folded, can be adjusted in height, and can have one, three, or four legs. The cane is also able to support balance problems and muscle weakness and can improve the processes of transfer and mobilization, thereby increasing the user's safety, independence, and self-confidence. The advantages of using a cane include being relatively inexpensive, functioning well on various surfaces, including stairs, and being used more for support than for weight bearing. While its weakness is that it cannot be used as a weight-bearing aid and is difficult to use for users who have poor balance or are afraid of falling.[43,44,45]

In post-stroke patients, energy requirements when walking will increase due to limb weakness and other functional disorders. The severity of functional impairment and the level of disability can also affect the efficiency and safety of the ambulation process. According to Buurke[46], stroke patients with hemiparesis have increased muscle activity in the erector spinae, gluteus maximus, gluteus medius, vastus lateralis, and tibialis anterior muscles, especially when walking. Increased activity of these muscles will certainly increase energy requirements. The use of walking aids has been shown to reduce the activity of the erector spinae, vastus lateralis, and tibialis anterior muscles as measured using surface electromyography (SEMG).[11,46]

The use of walking aids can improve the walking performance of post-stroke patients. Elmamoun[36] shows that the use of a cane can improve gait patterns, reduce postural sway, increase stability, and provide weight support. The use of a quadripod can reduce postural sway more than a single-point cane, but the two do not differ in terms of balance or stability. Walkers can help patients who have poor balance and have difficulty standing or walking. Besides improving their walking patterns, walkers can also improve their posture. The fixed walker is more stable but does not really improve walking performance because it is stiff, while the rollator improves walking performance more because it does not need to be lifted, but the stability is inferior even though it is equipped with a handbrake.[36] Ademoyegun[47] also states that the use of a cane can reduce postural sway and improve stability and walking performance. Hardi[42] stated that the use of walking aids (walkers and canes) improved walking performance when compared to not using a walking aid. In this research, gait analysis was carried out, which showed that the use of a cane increased speed and stride length (stride), decreased cadence, and decreased stride variability, while the use of a walker increased walking speed and stride length and reduced the base of support. It was stated that walking speed and step variability when using a cane were better than when using a walker. In this research, a single-point cane outperformed a fixed walker, a rollator, and a quadripod. However, in a comparison of single-point canes without the use of a walking aid, while they showed better results for walking performance and PCI, they were not statistically significantly different, indicating that a single-point cane was not better than not using a walker in this research. This could be because the patient can already walk and performed well on the TUG and 10-meter walk tests without using a walking aid.

5. RESEARCH LIMITATION

Several factors can influence the results of this research. The first is the complexity of using different walking aids, which makes it possible for research subjects to experience difficulty adapting to their use. Second, the research subjects had used one particular walker for daily ambulation. Thus, they were more used to using it. Third, the subjects in this research could walk as far as 10 meters without using a walking aid. Thus, their ambulation abilities were relatively good. Fourth, initial data on gait speed, balance, and gait patterns in research subjects have also yet to be considered for their influence on research results. For further research, to make the results more convincing, other comparisons are needed to assess walking performance, for example, walking pattern analysis, and other comparisons to assess energy requirements when walking, for instance, by using a walking test or training test that can be converted into specific and valid energy requirement units. Furthermore, initial data on the walking speed and balance of research subjects also need to be considered for their influence on research results.

6. CONCLUSIONS

According to this research, walking with a single-point cane is associated with lower energy costs and higher walking performance than a fixed walker, rollator, and quadripod cane. Walking aids significantly reduced energy expenditure and improved walking performance in stroke patients with ambulation problems. Our analysis revealed that a single-point cane requires less energy and permits more excellent performance for stroke patients who can already walk with a walking aid.

References

1) Danielsson, A., Willén, C. and Sunnerhagen, K.S., 2012. *Physical activity, ambulation, and motor impairment late after stroke*. *Stroke research and treatment*, *2012*.

2) Winstein, C.J., Stein, J., Arena, R., Bates, B., Cherney, L.R., Cramer, S.C., Deruyter, F., Eng, J.J., Fisher, B., Harvey, R.L. and Lang, C.E., 2016. *Guidelines for adult stroke rehabilitation and recovery: a guideline for healthcare professionals from the American Heart Association/American Stroke Association*. *Stroke*, *47*(6), pp.e98-e169.

3) Beyaert, C., Vasa, R. and Frykberg, G.E., 2015. Gait post-stroke: pathophysiology and rehabilitation strategies. *Neurophysiologie Clinique/Clinical Neurophysiology*, *45*(4-5), pp.335-355.

4) van Bloemendaal, M., van de Water, A.T. and van de Port, I.G., 2012. Walking tests for stroke survivors: a systematic review of their measurement properties. *Disability and rehabilitation*, *34*(26), pp.2207-2221.

5) Park, H.J., Oh, D.W., Choi, J.D., Kim, J.M., Kim, S.Y., Cha, Y.J. and Jeon, S.J., 2017. *Action observation training of community ambulation for improving walking ability of patients with post-stroke hemiparesis: a randomized controlled pilot trial*. *Clinical rehabilitation*, *31*(8), pp.1078-1086.

6) Pournajaf S., Goffredo M., Agosti M., Massucci M., Ferro S., Franceschini M., 2018. *Community ambulation of stroke survivors at 6 months follow-up: an observational research on socio-demographic and sub-acute clinical indicators. European journal of physical and rehabilitation medicine*.

7) Jutai, J., Coulson, S., Teasell, R., Bayley, M., Garland, J., Mayo, N. and Wood-Dauphinee, S., 2007. Mobility assistive device utilization in a prospective research of patients with first-ever stroke. *Archives of physical medicine and rehabilitation*, *88*(10), pp.1268-1275.

8) Tyson, S.F. and Rogerson, L., 2009. *Assistive walking devices in nonambulant patients undergoing rehabilitation after stroke: the effects on functional mobility, walking impairments, and patients' opinion*. *Archives of physical medicine and rehabilitation*, *90*(3), pp.475-479.

9) Polese, J.C., Teixeira-Salmela, L.F., Nascimento, L.R., Faria, C.D.M., Kirkwood, R.N., Laurentino, G.C. and Ada, L., 2012. The effects of walking sticks on gait kinematics and kinetics with chronic stroke survivors. *Clinical biomechanics*, *27*(2), pp.131-137.

10) Laufer, Y., 2002. Effects of one-point and four-point canes on balance and weight distribution in patients with hemiparesis. *Clinical rehabilitation*, *16*(2), pp.141-148.

11) Polese, J.C., Ribeiro-Samora, G.A., Lana, R.C., Rodrigues-De-Paula, F.V. and Teixeira-Salmela, L.F., 2017. *Energy expenditure and cost of walking and stair climbing in individuals with chronic stroke*. *Brazilian journal of physical therapy*, *21*(3), pp.192-198.

12) Delussu, A.S., Morone, G., Iosa, M., Bragoni, M., Paolucci, S. and Traballesi, M., 2014. Concurrent validity of Physiological Cost Index in walking over ground and during robotic training in subacute stroke patients. *BioMed research international*, *2014*.

13) Protas, E.J., 2003. Reliability of measures of gait performance and oxygen consumption with stroke survivors. *Journal of rehabilitation research and development*, *40*(1), pp.19-26.

14) Eng, J.J., Dawson, A.S. and Chu, K.S., 2004. Submaximal exercise in persons with stroke: test-retest reliability and concurrent validity with maximal oxygen consumption. *Archives of physical medicine and rehabilitation*, *85*(1), pp.113-118.

15) Cetin E., Muzembo, J., Pardessus, V., Puisieux, F. and Thevenon, A., 2010. Impact of different types of walking aids on the physiological energy cost during gait for elderly individuals with several pathologies and dependent on a technical aid for walking. *Annals of physical and rehabilitation medicine*, *53*(6-7), pp.399-405.

16) Arazpour, M., Samadian, M., Bahramizadeh, M., Ahmadi Bani, M., Gharib, M., Hosseini, S.A., Hutchins, S.W. and Mardani, M.A., 2016. The effect of trunk extension on physiological cost index in spinal cord injury patients when using the advanced reciprocating gait orthosis: A pilot research. *Prosthetics and orthotics international*, *40*(6), pp.696-702.

17) Narimani, M., Bani Talebi, E., SHokri, B. and Soheili, B., 2016. The Effect of 12 Weeks Individualized Combined Exercise Rehabilitation Training on Physiological Cost Index (PCI) and Walking Speed in Patients with Multiple Sclerosis at all Levels of Physical Disability. *Armaghane danesh*, *21*(8), pp.787-803.

18) Du Plessis, N., Buys, T.L. and De Bruyn, J.T., 2019. Effect of hippotherapy on physiological cost index and walking speed of adolescents with diplegia. *British Journal of Occupational Therapy*, *82*(10), pp.639-645.

19) Sadeh, M.R. and Sharifatpour, R., 2020. The Effect of Eight Weeks of Aerobic Exercise on Balance Function and Physiological Cost Index in Multiple Sclerosis Patients. *Journal of Community Health Research*.

20) Ng, S.S. and Hui-Chan, C.W., 2005. The timed up & go test: its reliability and association with lower-limb impairments and locomotor capacities in people with chronic stroke. *Archives of physical medicine and rehabilitation*, *86*(8), pp.1641-1647.

21) Pollock, C., Eng, J. and Garland, S., 2011. Clinical measurement of walking balance in people post stroke: a systematic review. *Clinical rehabilitation*, *25*(8), pp.693-708.

22) Chan, P.P., Tou, J.I.S., Mimi, M.T. and Ng, S.S., 2017. Reliability and validity of the timed up and go test with a motor task in people with chronic stroke. *Archives of physical medicine and rehabilitation*, *98*(11), pp.2213-2220.

23) Donoghue, O.A., Savva, G.M., Börsch-Supan, A. and Kenny, R.A., 2019. Reliability, measurement error and minimum detectable change in mobility measures: a cohort research of community-dwelling adults aged 50 years and over in Ireland. *BMJ open*, *9*(11), p.e030475.

24) Cayco, C.S., Gorgon, E.J.R. and Lazaro, R.T., 2017. Effects of proprioceptive neuromuscular facilitation on balance, strength, and mobility of an older adult with chronic stroke: A case report. *Journal of bodywork and movement therapies*, *21*(4), pp.767-774.

25) Fredrickson, E., Ruff, R.L. and Daly, J.J., 2007. Physiological Cost Index as a proxy measure for the oxygen cost of gait in stroke patients. *Neurorehabilitation and Neural Repair*, *21*(5), pp.429-434.

26) Jaiyesimi, A.O. and Fashakin, O.G., 2007. Reliability of physiological cost index measurements. *African journal of medicine and medical sciences*, *36*(3), pp.229-234.

27) Jeong, Y.G., Jeong, Y.J., Myong, J.P. and Koo, J.W., 2015. Which type of cane is the most efficient, based on oxygen consumption and balance capacity, in chronic stroke patients?. *Gait & posture*, *41*(2), pp.493-498.

28) Kim, W.H., 2006. The effect of walking aid on chronic hemiplegic gait. *Physical Therapy Korea*, *13*(3), pp.67-74.

29) Deltombe, T., Leeuwerck, M., Jamart, J., Frederick, A. and Dellicour, G., 2020. Gait improvement in adults with hemiparesis using a rolling cane: A cross-over trial. *Journal of rehabilitation medicine*, *52*(7), pp.1-5.

30) Holder, C.G., Haskvitz, E.M. and Weltman, A., 1993. The effects of assistive devices on the oxygen cost, cardiovascular stress, and perception of nonweight-bearing ambulation. *Journal of Orthopaedic & Sports Physical Therapy*, *18*(4), pp.537-542.

31) Aiyejusunle, C.B., Akodu, A.K. and Giwa, O.J., 2018. Effects of Walking with Aids on Walking Speed and Selected Cardiovascular Parameters in Apparently Healthy Elderly Individuals. *Middle East Journal of Rehabilitation and Health*, *5*(1).

32) Kear, B.M., Guck, T.P. and McGaha, A.L., 2017. Timed Up and Go (TUG) test: normative reference values for ages 20 to 59 years and relationships with physical and mental health risk factors. *Journal of primary care & community health*, *8*(1), pp.9-13.

33) Hafsteinsdóttir, T.B., Rensink, M. and Schuurmans, M., 2014. Clinimetric properties of the Timed Up and Go Test for patients with stroke: a systematic review. *Topics in Stroke Rehabilitation*, *21*(3), pp.197-210.

34) Bower, K., Thilarajah, S., Pua, Y.H., Williams, G., Tan, D., Mentiplay, B., Denehy, L. and Clark, R., 2019. Dynamic balance and instrumented gait variables are independent predictors of falls following stroke. *Journal of neuroengineering and rehabilitation*, *16*(1), pp.1-9.

35) Azharuddin, M. and Zia, N.U., 2021. Correlation between sit-to-stand ability, dynamic balance, gait speed, and quality of life in stroke population: a non-randomized pilot research. *Bulletin of Faculty of Physical Therapy*, *26*(1), pp.1-6.

36) Elmamoun, M. and Mulley, G., 2007. Walking sticks and frames for patients with neurological disorders. *Practical neurology*, *7*(1), pp.24-31.

37) Rahman, M. and Alagappan, T.R., 2019. The test–retest reliability of 10 meter walk test in healthy young adults-A Cross sectional research. *IOSR Journal of Sport and Physical Education*

38) Bushnell, C., Bettger, J.P., Cockroft, K.M., Cramer, S.C., Edelen, M.O., Hanley, D., Katzan, I.L., Mattke, S., Nilsen, D.M., Piquado, T. and Skidmore, E.R., 2015. Chronic stroke outcome measures for motor function intervention trials: expert panel recommendations. *Circulation: Cardiovascular Quality and Outcomes*, *8*(6_suppl_3), pp.S163-S169.

39) Peters, D.M., Fritz, S.L. and Krotish, D.E., 2013. Assessing the reliability and validity of a shorter walk test compared with the 10-Meter Walk Test for measurements of gait speed in healthy, older adults. *Journal of geriatric physical therapy*, *36*(1), pp.24-30.

40) Dalgas, U., Severinsen, K. and Overgaard, K., 2012. Relations between 6 minute walking distance and 10 meter walking speed in patients with multiple sclerosis and stroke. *Archives of physical medicine and rehabilitation*, *93*(7), pp.1167-1172.

41) Cheng, D.K., Nelson, M., Brooks, D. and Salbach, N.M., 2020. Validation of stroke-specific protocols for the 10-meter walk test and 6-minute walk test conducted using 15-meter and 30-meter walkways. *Topics in stroke rehabilitation*, *27*(4), pp.251-261.

42) Härdi, I., Bridenbaugh, S.A., Gschwind, Y.J. and Kressig, R.W., 2014. The effect of three different types of walking aids on spatio-temporal gait parameters in community-dwelling older adults. *Aging clinical and experimental research*, *26*(2), pp.221-228.

43) Mansouri, N. and Goher, K., 2016. Walking aids for older adults: review of end-user needs.

44) Dreeben-Irimia, O., 2010. *Introduction to physical therapy for physical therapist assistants*. Jones & Bartlett Publishers.

45) Odebiyi, D.O. and Adeagbo, C.A., 2020. Ambulatory Devices: Assessment and Prescription. In *Prosthesis*. IntechOpen.

46) Buurke, J.H., Hermens, H.J., Erren-Wolters, C.V. and Nene, A.V., 2005. The effect of walking aids on muscle activation patterns during walking in stroke patients. *Gait & posture*, *22*(2), pp.164-170.

47) Ademoyegun, A.B., Mbada, C.E., Ibitoye, A.G., Malomo, O.E., Fatai, W.A. and Ojo, T.A., 2020. Influence of clinical characteristics of stroke survivors on their walking capacity. *Sports Medicine Journal/Medicina Sportivâ*, *26*(2).