COMPARISON BETWEEN APPLICATION FOR SIX MINUTE WALK TEST AND CONVENTIONAL SIX MINUTE WALK TEST IN PEOPLE WITH CORONARY HEART DISEASE, CHRONIC KIDNEY DISEASE, CHRONIC OBSTRUCTIVE PULMONARY DISEASE AND STROKE

BY

MISS KULPRIYA WECHKAMA SPIVEY

A THESIS SUBMITTED IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF MASTER OF SCIENCE (PHYSICAL THERAPY)

GRADUATED PROGRAM

FACULTY OF ALLIED HEALTH SCIENCES

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was approved as thesis fulfillment of the requirements for
the degree of Master of Science (Physical Therapy)

on November 8, 2024

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Academic Year	2024

ABSTRACT

6-minute walk test (6MWT) is a widely use sub-maximal test for asseesing functional capacity. Nowadays, medical technology plays a significant role for evaluation of health status. There was a the developed device for 6MWT has been experimentally used in healthy populations, their application in clinical populations remains limited. Patients with coronary artery disease (CAD), chronic kidney disease (CKD), chronic obstructive pulmonary disease (COPD), and stroke typically exhibit reduced functional capacity and frequently undergo 6MWT for functional assessment. Therefore, the aim of this study was to investigate the accuracy between mobile application and standard device used for testing patients in these 4 groups. Methods: One-hundred males and females, aged 40-80 years, diagnosed with CAD, CKD, COPD, or stroke, were enrolled in the study. Participants were asked to wear a mobile application device on the wrist of their dominant hand, or on the non-affected hand in the case of stroke patients, while performing the standard 6MWT protocol. Upon completion of the walk, the total walking distances were recorded and compared between the mobile application and the conventional 6MWT. Results: There were no statistically significant difference in between 6MWD from mobile application and conventional 6MWD in CAD (Mean difference = 12.60 ± 9.28 meters, 4.09 ± 2.92 %, p = 0.187), CKD (Mean difference = 8.39 ± 8.46 meters, 2.81 ± 13.34 %, p = 0.331) and COPD group (Mean difference = 2.07 ± 7.98 meters, 0.62 ± 1.06 %, p = 0.798). In contrast, there were statistically significant difference between total 6MWD from mobile application and conventional 6MWD (mean difference = 15.29 ± 4.95 meter, 5.29 ± 10.84 %, p = 0.003) and in stroke group (mean difference = 38.10 ± 12.30 meters, 17.63 ±11.85 %, p = 0.005). Moreover, to determine the generalizability of the medical device, the Maximum Permissible Error (MPE), set at 5%, was considered. Based on this criterion, the mobile application could be considered applicable for use in populations with CAD, CKD, and COPD, as the observed error falls within the acceptable range. Conclusion: The innovative wearable sensor prototype with a mobile application, demonstrates potential as an effective tool for evaluating physical performance in patients with CAD, CKD, and COPD. However, discrepancies were observed in the stroke group, suggesting the need for further validation and refinement of the technology in clinical settings.

Keywords: six-minute walk test, mobile application, coronary heart disease, chronic kidney disease, chronic obstruction pulmonary, stroke

ACKNOWLEDGEMENTS

First and foremost, this thesis would not have been possible without the guidance and support of my research advisor. Words cannot fully express my gratitude, but I am incredibly thankful to Associate Professor Dr. Kornanong Yuenyongchaiwat for their invaluable advice, unwavering support, and patience throughout my master's degree journey. It has been a privilege to work under their compassionate mentorship.

I would also like to extend my heartfelt thanks to the chairperson of my thesis committee, Associate Professor Dr. Wattana Jalayondeja, and committee member Associate Professor Dr. Kedsara Rakpongsiri, for their insightful suggestions and constructive feedback. I take full responsibility for any shortcomings in this work.

My sincere appreciation goes to all the nurses and staff at the Physical Therapy Center of the Faculty of Allied Health Sciences, the Physical Therapy Department, the Hemodialysis Center, and the Outpatient Department of Thammasat University Hospital. Their willingness to assist, provide facilities, and coordinate with participants made this research possible. I am also grateful to all my participants, whose names must remain confidential, but whose cooperation and openness were crucial to completing this thesis.

Lastly, I want to express my deep gratitude to my family and closest friends for their unwavering encouragement and support during challenging times. Their belief in me has helped create lasting memories that I will cherish forever. Thank you all for being part of this journey.

Kulpriya Wechkama Spivey

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CHAPTER 1
INTRODUCTION

1.1 Background

Walking tests encompass a group of performance-based assessments aimed at measuring an individual's walking capabilities, typically conducted over various time intervals such as 2 minutes, 6 minutes, and 12 minutes(1). Furthermore, walking tests are technically simple and a widely used method of fitness testing in medicine, physical therapy as well as rehabilitation. The distance of a 6-minute walk test (6MWT) less than 350 meters is associated with well-documented thresholds for increased mortality(2) in chronic obstructive pulmonary disease, chronic heart failure and pulmonary arterial hypertension(3). Desaturation during a 6MWT is an important prognostic indicator for patients with interstitial lung disease(4). Therefore, walking tests are meaningfully important in terms of being a part of understanding a personal current status, evaluation and follow-up of treatment in various patient groups, such as patients within the elderly group and those with heart disease, lung disease, neurological disease, nutritional deficiencies, impaired cognitive function, as well as a general group to conduct a preliminary assessment of physical fitness(5).

However, there are several problems while performing the walking test, such as carrying devices before, during and after the test (i.e., form or worksheets on a clipboard for recording, stopwatch to record the laps, mechanical lap counter, the Borg scale chart, cones to mark the turnaround points)(6). Consequently, these issues might affect results of the test because of discrepancy between accessing and measuring the walking tests.

Notwithstanding, the walking tests are straightforward and easy to perform, though it involves costs and some practical limitations. To start with, it requires a dedicated corridor in a hospital with a length no shorter than 15 meters(7). It also requires a therapist to observe the test and to note down the measurements on worksheets. Patients should go to the hospital clinic or rehabilitation center for walking testing. Additionally, there are associated costs, such as transportation expenses for patients to reach the testing facility. These limitations can lead to infrequent testing, even when it may be medically advisable. For example, pulmonary hypertension patients are often recommended to undergo the 6MWT every 3 to 6 months[8], despite guidelines suggesting more frequent at least monthly for a year[9, 10].

Application development for walking tests could help therapists be more comfortable and have greater accessibility through the use of a smart mobile phone device. This is connected system between the mobile phone application and the smart band device prototype, used to measure walking distance.

Although some commercial products are designed walking test software and incorporate a 3D accelerometer into a belt buckle to record accelerations close to the body's center of mass[11]. Even though these products are specifically for medical use and require the purchase of, and familiarization with using, specialized commercial equipment and software. Therefore, these products might not be practical for using as well as assessing in the field or in a general hospital setting.

Study of Mekritthikrai N. has led to the creation and development of a prototype wearable walking sensor device for monitoring 6-minute walking test. This device seamlessly integrates with a mobile application, offering an easily accessible and user-friendly prototype solution. The study was conducted to compare the distance measurements obtained from the 6-minute walking signal measurement device, which collaborates with a mobile application, with the results of a standardized 6MWT in a group of healthy individuals across various age groups. The findings indicated that the measured distances have no statistically significant differences[12]. This indicates that the prototype wearable walking sensor device of 6 minute walk can be used for assess walking distance when compared to a standard 6MWT. However, the developed device has been experimentally used within the healthy population group, but it has not yet been applied in clinical settings.

Typically, the 6MWT serves as a standardized assessment tool used to evaluate overall pulmonary and respiratory function, cardiovascular health, monitor symptoms, and predict disease outcomes in various patient groups such as chronic obstructive pulmonary disease (COPD), post-lung transplant patients, heart failure patients, open-heart surgery patients, peripheral artery disease patients, neurological patients, and elderly[13].

Therefore, patients with coronary artery disease, chronic kidney disease, chronic obstructive pulmonary disease, and cerebrovascular disease are a significant burden in low- and middle-income countries. These diseases have a negative impact on the resilience of the cardiorespiratory systems, resulting in a diminished ability to walk, poor functional capacity and ultimately affecting the quality of life of the patient, which proves to be a significant contributor to mortality, morbidity, and disability. There are many studies that assess functional capacity using the 6MWT in these 4 groups. In recent years, the 6MWT has emerged as a widely accepted and utilized tool for evaluating functional capacity and for measuring therapeutic interventions in these patients. While being simple to perform, it's also economical. It's particularly useful in the fact that it reflects the activity of daily living. And it strongly correlates with peak oxygen uptake, which is acquired through a cardiopulmonary exercise test. Furthermore, the results of the 6-minute walking distance may vary across different population groups due to several factors, including step length and walking speed, which are not consistent among various groups.

Coronary artery disease (CAD), predominantly caused by the accumulation of plaque in the thickening vessel walls, leads to narrowing and obstruction of blood flow through the arteries. This diminished blood supply to the heart necessitates increased effort from the heart to pump blood, resulting in symptoms such as chest pain (angina), fatigue, or shortness of breath during various activities. These symptoms often limit or reduce a patient's ability to engage in certain activities. In study of Joshi S. et al., the gait analysis of cardiovascular disease patients using wearable sensors revealed that, during a 10-meter walking test, individuals with cardiovascular diseases exhibited shorter stride lengths and lower walking frequencies compared to healthy individuals(14). Additionally, Lenasi et al. conducted a study involving 67 stable CAD patients and found that, during a 6MWT, all participants covered an average distance of 473±91 meters. When categorized based on their functional capacity using the New York Heart Association (NYHA) classification, those with NYHA class III walked an average of 385±100 meters, NYHA class II covered an average of 494±28 meters, and NYHA Class I walked an average of 587±31 meters (15). In 2022, Yuenyongchaiwat K. et al. conducted a study involving 64 patients who had undergone open heart surgery in

Thailand, all participants covered an average distance of 328.16±126.64 meters in the 6MWT[16].

Patients with chronic kidney disease (CKD) and hemodialysis patients have kidney dysfunction which results in the accumulation of waste products, electrolyte imbalances, and fluid retention and edema, leading to symptoms like fatigue, weakness, diminished ability to control posture and balance[17]. This reduction in physical function extends to activities like walking. In 2019, Study of Tran J. et al., it was found that individuals with CKD have shorter stride lengths compared to those without CKD[18]. In 2014, Study of Kono et al. assessed the 6-minute walking distance (6MWD) in 43 CKD patients undergoing hemodialysis and found that the average 6MWD covered was 410±118.2 meters. Factors influencing the 6MWD in these patients included muscle strength, iron deficiency anemia, and pre-existing CAD[19]. In 2020, Yuenyongchaiwat K. et al. found that among the 100 patients had a mean 6MWD of 373.04±107.80 meters. Consequently, patients with a longer duration (>5years) of hemodialysis exhibited a decrease in distance covered during the 6MWT[20].

Patients with chronic obstructive pulmonary disease (COPD) have direct lung-related pathologies that reduce respiratory efficiency, leading to symptoms such as breathlessness and reduced exercise tolerance during various activities. Study of Liu WY. et al. in 2017, observed gait patterns in COPD patients while performing a 6MWT on treadmill in a laboratory setting, the results showed that variability of stride length consistently rose after walking speed had been correctly adjusted and the found that was both a shorter step length and stride length compared to healthy people. The COPD patients covered an average distance of 493.5±79.7 meters, while the healthy individuals walked an average distance of 689.3±64.3 meters[21].

Patients with cerebrovascular disease have brain-related pathologies that result in muscle weakness, requiring increased energy expenditure for activities. This leads to faster onset of fatigue and reduced activity levels. In a study by Chang HC. et al, an Inertial Measurement System was used to analyze the gait of patients with stroke and Parkinson's disease. The results showed that stroke patients had shorter stride length, lower stride frequency and needed more time to complete the 10 meter walk test when compare to the healthy group when walking at self-selected speeds[22]. In 2009, a study conducted by Sibley KM. et al. found that 24 community-dwelling individuals with stroke had an average 6MWD of 283.3 ± 136.8 meters. Consequently, these findings suggest that post-stroke walking performance declines due to both cardiorespiratory and muscular fatigue mechanisms[23]. In 2017, Fulk GD. et al. conducted a study involving 441 post-stroke patients. The results showed that the average 6MWD covered was 201.0 ± 106.1 meters[24]. Another study by Pramodhyakul N. et al. involved 174 patients with cerebrovascular disease. These patients had an average 6MWD of 126.19±92.33 meters. However, patients with cerebrovascular disease who achieved a minimum 6MWD of 193.50±50 meters were capable of walking in the community[25].

Therefore, it is necessary to assess the health status of these patients extensively to develop treatment plans and improve their quality of life. The 6MWT serves as a valuable tool to predict disease progression, monitor outcomes, and evaluate patients' abilities. This assessment aids in designing appropriate treatment strategies for each individual, ultimately enhancing their well-being.

The purpose of this study will be to develop a prototype of waking tests using a smart band device to record distance and explore the accuracy between mobile applications and standard devices used for testing patients with coronary heart disease, chronic kidney disease, chronic obstruction pulmonary disease and stroke patients. This application is intended for the purpose of monitoring and assessing the capabilities of patients within each respective group.

1.2 Research question of the study

Is there any correlation between mobile application with the smart band device prototype and standard 6-minute walk test in coronary heart disease, chronic kidney disease, chronic obstructive pulmonary disease and stroke patients

1.3 Objective of the study

To explore the correlation of distance and time between the mobile application with the smart band device prototype and standard 6-minute walk test in coronary heart disease, chronic kidney disease, chronic obstruction pulmonary disease and stroke patients.

1.4 Research hypothesis

Accuracy of walking distance between the mobile application with prototype of smart bands device and the standard walking test will be found in 4 groups

1.5 Conceptual framework

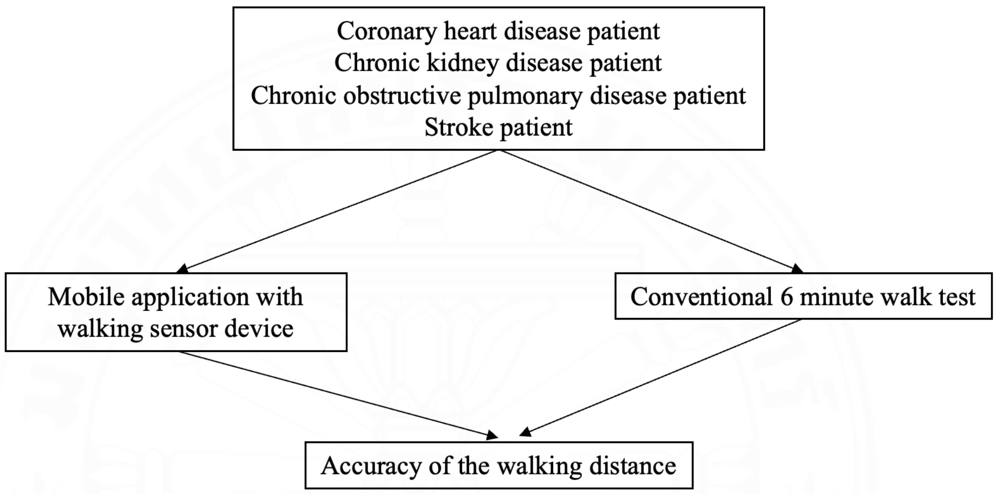


Figure 1.1 Conceptual framework

1.6 Research scope

The study will explore the correlation of walking distance between the mobile application with the smart band device prototype and an conventional 6 minute walk test in coronary heart disease, chronic kidney disease, chronic obstruction pulmonary disease, and stroke patients.

1.7 Advantage of the study

1. Development of a walking sensor device prototype and it's application for practical use in clinical and medical research
2. Standardize measurement tools of walking tests
3. An alternative that provides telemedicine to help assess and monitor disease progression.

CHAPTER 2
REVIEW OF LITERATURE

Literature review regarding development of walking test application, normal walking in humans, kinematics, kinetics of a normal walking cycle and function of the lower extremity muscles while walking normally will be issued in this chapter. Functional capacity will be defined and expanded in the six-minute walk test. Additionally, the utilization of this test in the context of various diseases will be explored. The literature review will be presented as follows:

2.1 Human walking or human gait

Walking or gait (also known as ambulation) and mobility are not the same thing(26). Walking refers to the movement activities that use both legs of the human body. Walking is the movement of both legs forward center of gravity. Mobility is the ability to move easily in any environment without restrictions; whereas a movement is defined as only a requirement for moving arms and or legs from one place to another. Therefore, equilibrium and locomotion are two important components of walking(26). Equilibrium is the ability to upright and maintain balance; whereas locomotion is the ability to initiate and maintain the rhythm of the movement of the stride. To cover the body in upright position, the body relies on the working of the core muscles that are upright in the plane of the sacral base(27). There are natural curves of the spine that correspond to the center of gravity, whether static or dynamic balance, including weight bearing and good posture. In addition, the body does not use only the vertebra or spine but also there are other elements that enhance the posture, such as the anterior vertebrae, anterior and posterior longitudinal ligaments, facets joint, and spinal muscles, to maintain the body balance(26). Balance control is interconnected systems of the body, namely sensory inputs, motor outputs, and cognitive systems. A central nervous system operates as a balance control center using sensory information from vison, somatosensory, somatosensory and proprioceptive that work in harmony with each other to create the functions of the bones and muscles used in posture(27). When the spine moves out of a balanced position, there are three-dimensional movements of the spine causing flexion, lateral bending. flexion, and rotation of the muscles spine, and as the center of mass (COM) moves, reaction forces stimulate the body's joints to work, especially the lower extremity.

In general, each of these walking cycles is composed of two phases: the single-support phase and the double-support phase. During the single-support phase, one leg is on the ground and the other leg is experiencing a swinging motion. The double-support phase starts once the swinging leg meets the ground and ends when the support leg leaves the ground. The adoption of the concept that fundamentally locomotion is the translation of the center of gravity through space along a pathway requiring the least expenditure of energy supplies the necessary unifying principle which permits of qualitative analysis in terms of the essential determinants of gait.[(28)] The principle proposed by Saunders et al. suggests that efficient locomotion, including preferred walking speed is inherently geared towards minimizing energy expenditure. Walking, as a motor skill, is acquired through repetition, and it is intended to be efficiency, automation, and goal-directed movement[(29)]. Therefore, they were explained the six factors for the gait cycle (pelvic rotation, pelvic obliquity, stance knee flexion, foot and ankle mechanisms, and tibiofemoral angle) that have become key to understanding normal human locomotion. Furthermore, human walking is characterized by a repetitive sequence of limb motion whereby an ipsilateral lower limb alternately provides support for the contralateral lower limb as the body advances forward[(30)]. Besides, the optimal human walking results in the forward translation of the body, using bipedal support, with maximal symmetry, stability, and energy efficiency[(31)].

2.1.1 Gait Cycle

Walking is a highly coordinated cyclical series of movements. Several developed nomenclatures describe the limb movements. Terminology in gait is defined for understanding functional tasks of the whole limb and in providing a framework for explaining the contributions of the musculoskeletal system at individual joints[(32)]. The gait cycle could be defined as a period of time between any two nominally identical events in the gait process[(29)]. Generally, these two nominally identical events correspond to the instant where one foot strikes the ground and ends when the same foot strikes again the ground (called initial contact). During the gait cycle, lower limb considered an alternate stance phase (foot in contact with the ground) and swing phase (foot without ground contact). A gait cycle is thus divided in a period of stance phase (about 60% of the cycle) and in a period of swing phase (about 40% of the cycle) of the lower limbs, right and left (Figure 2.1). It is possible to make a sub-division according to the stance and swing phase of the two lower limbs. When both members are in stance phase, this is a double support and when one of the two members is in stance phase while the other is in swing phase, this is a single support.

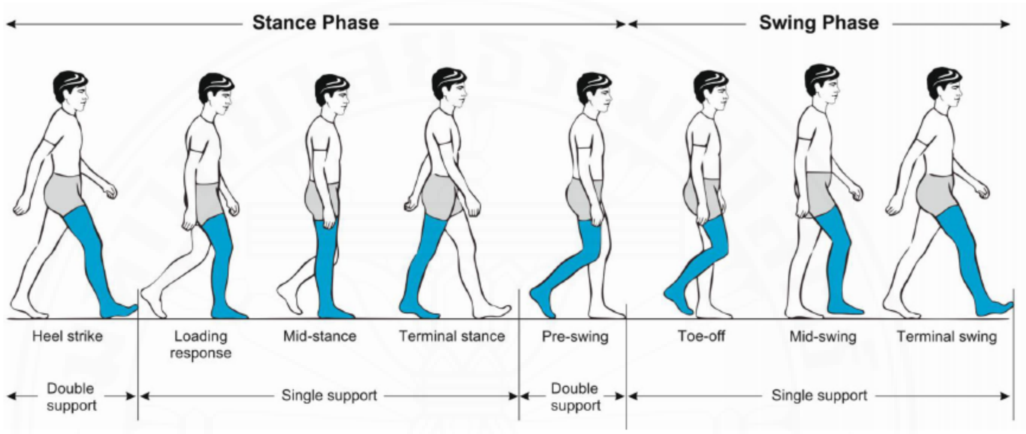


Figure 2.1 Phases of the normal gait cycle[33]

2.1.2 Gait cycle timing

The timings of initial contact and toe off for both feet during a little more than one gait cycle. (Fig. 2.2) Right initial contact occurs while the left foot is still on the ground and there is a period of double support between initial contact on the right and toe off on the left. During the swing phase on the left side, only the right foot is on the ground, giving a period of right single support, which ends with initial contact by the left foot. There is then another period of double support, until toe off on the right side. Left single support corresponds to the right swing phase and the cycle ends with the next initial contact on the right[34].

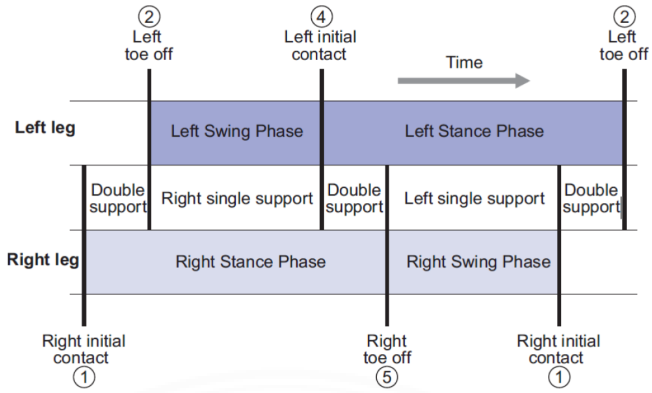


Figure 2.2 Timing of single and double support during one gait cycle(34).

2.1.3 Stance phase

Stance phase (Figure 2.3) represents the portion of the gait cycle during which the reference limb is in contact with the ground. During normal walking, this portion accounts for approximately the first 60% of the gait cycle. The second division, swing phase, occurs when the reference limb is not in contact with the ground. During normal walking, this portion accounts for approximately the latter 40% of the gait cycle. Stance phase time and swing phase time are common temporal measures of the respective length of each phase of the gait cycle(35).

The start and end of each phase are marked by discrete events. By convention, the starting point of the gait cycle (0% of the gait cycle) occurs at the point in time when the foot first contacts the ground. The heel typically makes contact first in normal walking. Traditional methods describing the gait cycle refer to this event as heel strike. However, first contact with the surface may not occur with the heel, especially in pathologic gait. As such, the term initial contact is recommended, because it offers greater flexibility and accuracy in defining the start of the gait cycle. The end of stance phase and start of swing phase are marked in the gait cycle by toe-off as the foot leaves contact with the ground. The initial contact for the same limb concludes swing, ends the current gait cycle (100% of gait), and is the start of the following cycle. In summary stance phase is the moment the feet touch the ground. This accounts for 60 percent of a walking cycle, which is subdivided into four phases, respectively, of the time when both feet touch the ground.

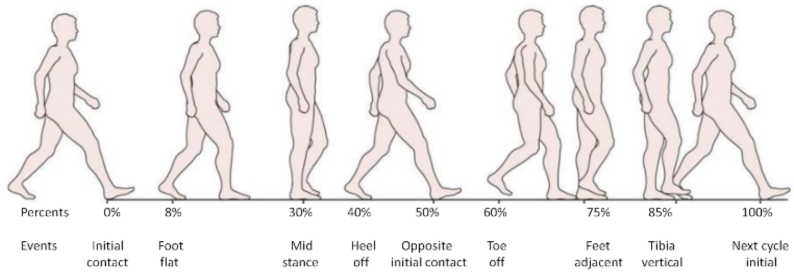
1. Initial contact[35] is the point at which the foot comes in contact with the ground and serves as the starting point of stance phase and the overall gait cycle. Initial contact is an instant in time (0% of gait) rather than a true phase or function of stance. Loading response (0%–10% of gait) starts at initial contact and lasts until the contralateral foot leaves the ground. Loading response is a period of double limb support during which the impact of initial contact is absorbed and weight is transferred rapidly onto the leading limb. Double limb support reflects any time during the gait cycle in which both limbs remain in contact with the ground. During normal gait, this period accounts for 20% of the total gait cycle, 10% at the beginning of the stance phase and 10% at the end of stance phase.
2. Midstance[35] (10%–30% of gait) starts when the contralateral foot leaves the ground and lasts until the ipsilateral heel leaves the ground. During midstance the body weight moves forward, typically aligned over the foot in contact with the ground. Midstance also accounts for the start of single limb support in that only one limb is in contact with the ground while the contralateral limb is in swing phase.
3. Terminal stance[35] (30%–50% of gait) begins when the ipsilateral heel leaves the ground and ends at the time of the contralateral foot initial contact with the ground. During terminal stance, the body weight continues its forward progress such that normally the heel rises as weight moves over the forefoot. Terminal stance is the second half of single limb support and accounts for a total of 40% of the total gait cycle when combined with the portion from midstance.
4. Preswing[35] (50%–60% of gait) is the final phase of stance and lasts from the time of contralateral foot initial contact with the ground until the ipsilateral foot leaves the ground (toe-off). Preswing includes the second portion of double limb support in which the now trailing limb is rapidly unloaded in preparation for advancement during swing phase.

2.1.4 Swing phase

Swing phase (Figure 2.3) is the moment the feet lift off the ground. accounted for 40 percent of one walking cycle. Swing phase is said to be the function of the body's systems. It consists of these things in order to make a normal walk. For example, the legs must be able to support the structural weight of the body without subsidence and able to maintain balance when one foot touches the ground; whereas another leg swing to the right position to continue to carry the weight and provide sufficiently to move the legs and body forward.

1. Initial swing[35] (60%–73% of gait) is the first phase of swing and encompasses the time from when the foot leaves the ground to ipsilateral foot alignment with the contralateral ankle. During initial swing the foot lifts off the ground and the limb begins its forward advancement. A critical task of initial swing is positioning the foot such that it clears the ground and any obstacles as it advances.
2. Midswing[35] (73%–87% of gait) is the time from ankle and foot alignment until when the swing leg tibia becomes vertical. During midswing the advancement of the limb continues.
3. Terminal swing[35] (87%–100% of gait) is the final portion of swing phase from the time the tibia reaches a vertical position until initial contact of the swing foot with the ground. During terminal swing, the limb completes its forward advancement. Normally, a period of limb deceleration occurs leading up to the initial contact.

Walking is also a natural evolution; people learn to walk with the central and peripheral neuroadaptations per walk. Human walking is started in early child at aged 12 months and aged 10 years for controlling own walking pattern[29].



Periods	Loadding response	Mid stance	Terminal stance		Pre swing	Initial swing	Mid swing	Terminal swing
Tasks	Initial double limb support	Initial single limb support			Second double limb support	Second single limb support		
Phase	Stance phase					Swing phase		
Per				Push off				
Cycle	One cycle							

Figure 2.3 Represents a normal gait cycle[36]

A walking cycle can be described as a continuous operation of eight steps[37]. From 0% heel-to-floor contact to the next heel contact at 100% of the lap, Stage 0 is the start of double-limb support during the first 10% of the cycle, Stage 1 is the mid-stance, which appears from 10% to approximately 30% of the following stance. Ten percentage of the following stance is the terminal-stance, the propulsion phase or toe-off occurs after the foot is flat for 40% of the gait, this step pushes the body forward and prepares it for the swing phase. Approximately 60% of the stride single-limb support takes place on the foot as; opposite side is foot flat. The second double-limb support occurs from the opposite limb at 50% until the toe is out of the area 60% of the cycle, then the second single-limb support completes the cycle. The next step is to swing fast at approximately between 60% and 75% of the cycle, mid-swing at approximately from 75% to 85% of the cycle, and late swing at approximately from 85% to 100% of the cycle[37].

2.1.5 Kinematics

Kinematic measures describe joint motions as rotations around the principal axis of the body. This chapter primarily focuses on kinematics in the sagittal plane. Figure 2.4 provides a description of the motion (kinematics) that occurs at the hip, knee, and ankle during normal human gait in the sagittal plane.

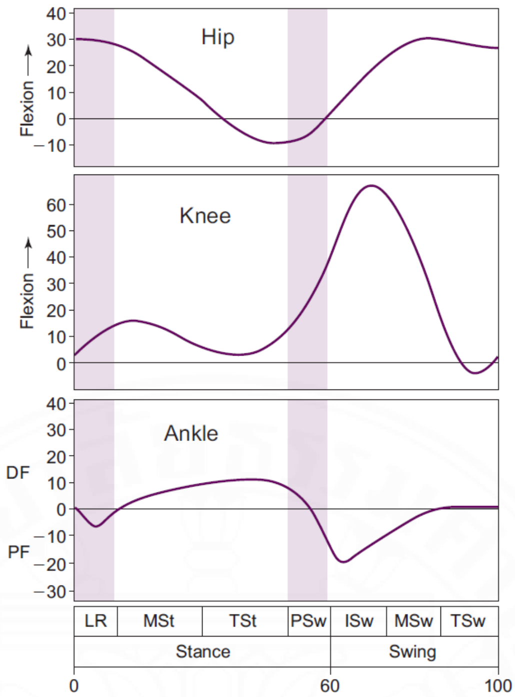


Figure 2.4 Typical motion pattern of the limb during a gait cycle for the hip (top), knee (middle), and ankle (bottom). DF, Dorsiflexion; ISw, initial swing; LR, loading response; MSt, midstance;MSw, midswing; PF, plantar flexion; PSw, preswing; TSw, terminal swing; TSt, terminal stance. 0, Onset of gait cycle; 60, end of stance; 100, end of gait cycle[35].

2.1.6 Kinetics

To analysis of walking motion, the assessments of the forces that occur across the hip, knee, and ankle joints during gait should be included. These kinetic forces represent the sum total of gravity acting on the body mass, counterforces from contact with the ground, muscular effort generated in the limbs, and resultant forces from the potential and kinetic energy from the body in motion. Because these forces are created when the limb is in contact with the ground during the stance phase of the gait cycle.

The ground reaction force (GRF) is an important force in walking. Indeed, the point of application of this force found underneath the contacting foot and it is direct opposite to the body weight. Thus, the GRF influences the movement of the entire body during the gait and the analysis of the shape of the GRF can be derived on the whole-body motion. During the stance phase of the normal gait, the GRF has a typical pattern with a double bump corresponding to two maxima surpassing body weight with an intermediate minimum inferior at the body weight. This specific pattern is often modeled in the literature as an inverted pendulum moving over a rigid supporting leg(38).

Thus, the generation of the ground force begins at the instant where the foot contacts the ground i.e., at the IC of the gait cycle. At this specific instant, the body weight is transferred very quickly on one leg. Consequently, the impact force is followed by a loading response. During this short period, the whole foot is in contact with the ground and the vertical GRF increases to attain the first maximum peak force (F1 on Figure 2.5). After this first peak, the vertical force diminishes corresponding at the mid stance phase (F2 on the Figure 2.5). Indeed, during this phase, the opposite foot is in the mid swing phase, therefore the whole-body weight is supported by the stance limb. The foot and the leg provide a stable platform to able the movement of the body, like an inverted pendulum. When the heel lifts away from the ground, the GRF starts increasing once again. This ascending second peak (F3 on the Figure 2.5) of the GRF corresponds to the second double support. Finally, the GRF pattern starts descending to zero with the pre-swing phase and drops to zero when the foot leaves the ground (Figure 2.5).

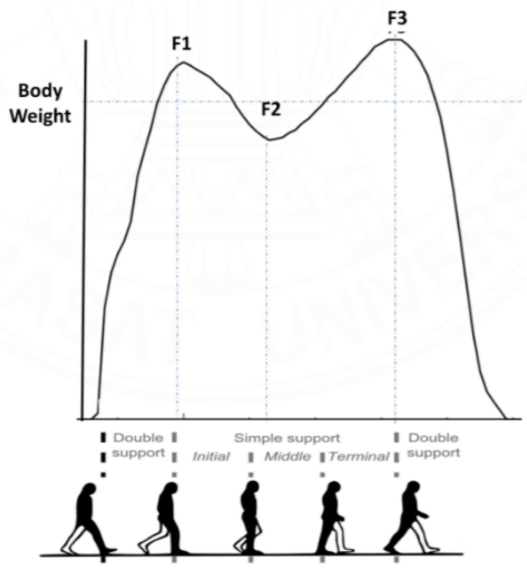


Figure 2.5 Example of the vertical ground reaction force recorded during the stance phase of the normal gait cycle(39).

Ankle: The ground reaction force is initially located posterior to the ankle at initial contact, creating a plantarflexion moment. During the loading response, the plantarflexion moment continues at the ankle, and ankle dorsiflexors resist this torque to prevent foot drop. During midstance, the GRF moves anteriorly, so a strong dorsiflexion moment at the ankle is produced in terminal stance. This dorsiflexion moment is opposed by the ankle plantar flexors to limit forward progression of the tibia. In preswing, a dorsiflexion moment remains at the ankle. Thus, ankle plantarflexion motion is created by concentric contraction of the ankle plantar flexors, and this helps to propel the stance limb forward.

Knee: At initial contact, the GRF is normally located anterior to the knee, but the GRF quickly moves posterior to the knee during the loading response. A flexion moment is the result, and knee extensors counter this moment to keep the knee from collapsing. The knee flexion moment remains in place until terminal stance, at that time the GRF moves back anterior to the knee. At the end of preswing, before the foot leaves the ground, the GRF moves posterior to the knee. Therefore, this produces a knee flexion moment and helps initiate a period of rapid knee flexion in preparation for the swing phase of gait.

Hip: The GRF is initially anterior to the hip joint center. As such, a flexion moment is presented at the hip at initial contact and during the loading response. During midstance which the tibia moves to forward rotation, the hip moves anterior to the GRF, creating an extension moment. The extension torque across the hip remains in place throughout the remainder of stance phase and activation of the hip flexors is required to overcome in late stance to initiate hip flexion.

2.1.7 Muscle activities of the lower limbs during the normal gait

The human gait pattern is normally motion and shows continuous movements. It is a natural as well as repetitive movement controlled by muscles. Thus, the muscles are the motors of the gait and accomplish a specific role during the gait cycle. During muscles are actively contracted under neural control, an electric signal that can be recorded by electromyography is created(35).

During stance phase, hip motion transitions from flexion at heel strike and progresses to extension by heel rise. The hip extensor muscles are responsible for limb deceleration at terminal swing (eccentric contraction) and for restraint of forward momentum as the limb is loaded at heel strike. The primary hip extensors are the gluteus maximus muscle and the 3 hamstring muscles (i.e., semimembranosis, biceps femoris, and semitendinosis). The role of the hip abductors (i.e., gluteus medius and minimus, tensor fasciae latae) is to counter the contralateral pelvic drop during the cyclic intervals of non–weight bearing throughout ipsilateral stance. In addition, the primary hip flexors are the iliopsoas and rectus femoris muscles, both of which contract concentrically at early swing. Although there are 14 specific muscles providing stability at the knee during the gait cycle, the quadriceps complex (i.e., vastus medialis longus and oblique, vastus intermedius, and vastus lateralis) is the dominant muscle group for knee extension. Stance stability is also largely reliant on the soleus muscle to control the forward motion of the tibia, iliotibial band tension, and the actions of the rectus femoris, upper portion of the gluteus maximus, and hamstring muscles. Limb deceleration during terminal swing is largely influenced by the balance between the eccentric contraction of the hamstring muscles and the concentric contraction of the quadriceps muscles. The tibialis anterior muscle is the primary ankle dorsiflexor, contracting eccentrically during stance phase (heel strike to foot flat) and concentrically during swing phase. Lastly, the gastroc-soleus complex is the primary ankle plantar flexor, concentrically contracting during terminal stance. Figure 2.6 presents the pattern of lower muscle activation during the normal human gait cycle[31].

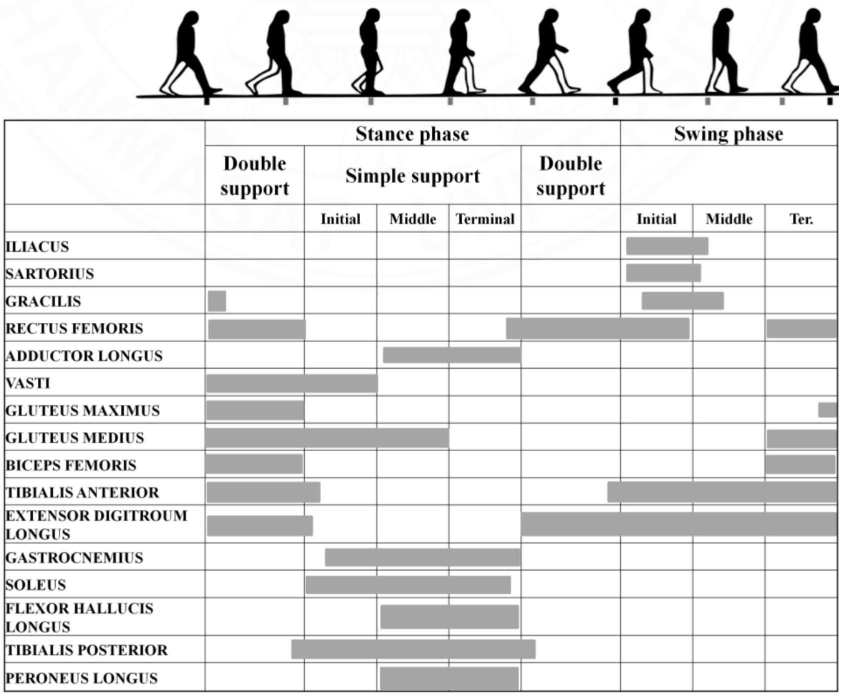


Figure 2.6 Pattern of muscle activation of lower limb muscles in normal gait[39].

Table 2.1 Summary table of the functions of the lower extremity muscles during normal walking [40]

Hip

	Kinematic Motion	**Kinetic motion**	
Phase	**Hip**	**External Forces**	**Internal Forces**
Heel strike	20° to 40° of hip flexion moving toward extension; slight adduction and lateral rotation	Reaction force in front of joint; flexion moment moving toward extension; forward pelvic rotation	Gluteus maximus and hamstrings work in eccentrically to resist flexion moment; erector spinae working eccentrically to resist forward bend
Foot flat	Hip moving into extension, adduction, medial rotation	Flexion moment	Gluteus maximus and hamstrings contracting concentrically to bring hip into extension; erector spinae resisting trunk flexion
Midstance	Moving through neutral	Reaction force posterior to hip joint; extension moment	Iliopsoas working eccentrically to

	position; pelvis rotating posteriorly		resist extension; gluteus medius contracting in reverse action to stabilize opposite pelvis; iliopsoas activity continuing
Heel off	10° to 15° extension of hip abduction, lateral rotation	Extension moment decreasing after double-limb support begins	
Toe off	Moving toward 10° extension, abduction, lateral rotation	Decrease of extension moment	Adductor magnus working eccentrically to control or stabilize pelvis; iliopsoas activity continuing

Knee and Tibia

Phase	Kinematic Motion		Kinetic motion	
	Knee	**Tibia**	**External Forces**	**Internal Forces**

Heel strike	In full extension before heel contact; flexing as heel strikes floor	Slight lateral rotation	Rapidly increasing reaction forces behind knee joint causing flexion moment	Quadriceps femoris contracting eccentrically to control rapid knee flexion and to prevent buckling
Foot flat	In 20° flexion moving toward extension	Medial rotation	Flexion moment	After foot is flat, quadriceps femoris activity becoming concentric to bring femur over tibia
Midstance	In 15° flexion moving toward extension	Neutral	Maximum flexion moment	Quadriceps femoris activity decreasing; gastrocnemius working eccentrically to control excessive knee extension
Heel off	In 4° flexion moving toward extension	Lateral rotation	Reaction forces moving anterior to joint;	Gastrocnemius beginning to work concentrically to start knee flexion

			extension moment	
Toe off	Moving from near full extension to 40° flexion	Lateral rotation	Reaction forces moving posterior to joint as knee flexes; flexion moment	Quadriceps femoris contracting eccentrically

Foot and Ankle [41]

	Kinematic Motion		Kinetic motion	
Phase	**Foot**	**Ankle**	**External Forces**	**Internal Forces**
Heel strike	Supination (rigid) at heel contact	Moving into plantar flexion	Reaction forces behind joint axis; plantar flexion moment at heel strike	Dorsiflexors (tibialis anterior, extensor digitorum longus, and extensor hallucis longus) contracting eccentrically to slow plantar flexion

Foot flat	Pronation, adapting to support surface	Plantar flexion to dorsiflexion over a fixed foot	Maximum plantar flexion moment; reaction forces beginning to shift anterior, producing a dorsiflexion moment	Dorsiflexion activity decreasing; tibialis posterior, flexor hallucis longus, and flexor digitorum longus working eccentrically to control pronation
Midstance	Neutral	3° of dorsiflexion	Slight dorsiflexion moment	Plantar flexor muscles (gastrocsoleus and peroneal muscles), activated to control dorsiflexion of the tibia and fibula over a fixed foot, contracting eccentrically

Heel off	Supination as foot becomes rigid for push-off	15° dorsiflexion toward plantar flexion	Maximal dorsiflexion moment	Plantar flexor muscles beginning to contract concentrically to prepare for push-off
Toe off	Supination	20° plantar flexion	Dorsiflexion moment	Plantar flexor muscles at peak activity but becoming inactive as foot leaves ground

2.2 Functional capacity

Functional capacity is the ability to perform activities of daily living that require sustained aerobic metabolism as well as ability of an individual to perform aerobic work as defined by the maximal oxygen uptake ($\dot{V}O_{2max}$), that is, the product of cardiac output and arteriovenous oxygen ($a{-}\dot{V}O_2$) difference at physical exhaustion[(42)].

Assessment of functional capacity can be dissected into subjective assessment and oobjective assessment. Subjective assessment for example, New York Heart Association (NYHA) is often used to describe the functional capacity of adults with congenital heart disease (ACHD)[(43)]. NYHA (Figure 2.7) can be used for cardiopulmonary exercise testing and 6-minute walking test, also can be an indicator of mortality risk and complaints of chest pain, dyspnea, and fatigue, [(44)].

Class I (mild)	No limitation on physical activity. Ordinary physical activity does not cause undue fatigue, palpitation, or dyspnoea (shortness of breath)
Class II (mild)	Slight limitation of physical activity. Comfortable at rest, but ordinary physical activity results in fatigue, palpitation, or dyspnoea
Class III (moderate)	Marked limitation of physical activity. Comfortable at rest, but less than ordinary activity causes fatigue, palpitation, or dyspnoea
Class IV (severe)	Unable to carry out any physical activity without discomfort. Symptoms of cardiac insufficiency at rest. If any physical activity is undertaken, discomfort is increased

Figure 2.7 The New York Heart Association Classes[45]

2.2.1 Maximal exercise testing

Maximal exercise test is performed with progressively increasing workloads up to limiting fatigue and/or dyspnea caused by exhaustion. Maximal exercise test can assess by maximum oxygen consumption test that highly reproducible, and considered a "gold standard" for functional capacity assessment in athletes and pathology individuals[46]. This parameter expresses the functional health of the cardiovascular, pulmonary, and skeletal muscle systems[47]. In addition, it provides important prognostic information that is useful for identifying potential of patients cardiac transplantation[47]. VO_2 max test also provides objective data, which is helpful in formulating appropriate exercise prescription. For instance, ventilatory expired gas techniques during exercise testing or cardiopulmonary exercise testing (CPET) also known as gold standard of maximal exercise testing which perform by using bicycle or treadmill. (Figure 2.8)

2.2.1.1 Cardiopulmonary exercise testing

CPET provides assessment of the integrative exercise responses involving the pulmonary, cardiovascular, hematopoietic, neuropsychological, and skeletal muscle systems, which are not adequately reflected through the measurement of individual organ system function.[48] This non-invasive, dynamic physiological overview permits the evaluation of both submaximal and peak exercise responses, providing the doctor with relevant information for clinical decision making[48]. CPET is increasingly being used in a wide spectrum of clinical applications for the evaluation of undiagnosed exercise intolerance and for the objective determination of functional capacity and impairment. There are several limitations to assessing maximal performance with a $\dot{V}O_2$max test[49]. Unless an individual is able to attain a $\dot{V}O_2$max without fatiguing first or being limited by musculoskeletal impairments or other problems, the results of the test are invalid. In addition, higher levels of motivation are required by the individual, and maximal tests require additional monitoring equipment (e.g., electrocardiograph machine), gas analyzer equipment, time-consuming characteristic and trained staff and are labor intensive[49].

Figure 2.8 Cardiopulmonary exercise testing (CPET)

(Ref: https://www.thecardiologyadvisor.com/home/topics/heart-failure/cardiopulmonary-exercise-testing-useful-to-predict-cv-death-risk-in-hf-with-midrange-ejection-fraction/)

2.2.1.2 Modified Bruce treadmill test

Bruce Treadmill Test[50] is a maximal test that was designed to diagnose coronary heart disease. There has risen to the use of the Modified Bruce treadmill test compared with the original test, which starts at 1.7 mph at a grade of 10%, the modified test has a zero stage (1.7 mph at 0% grade) and a one-half-stage (1.7 mph at 5% grade) (Figure 2.9). Predictive equations for estimating $\dot{V}O2$max have been developed and can be used with the original and modified tests. Bruce et al[50] developed the first predictive equations, which are population-specific for active and sedentary adults with and without cardiac conditions. Individuals must be correctly classified to determine which equation is appropriate. Foster et al[51] later developed a regression equation applicable to all men based on a sample of 230 men of various ages with a variety of clinical conditions (symptomatic angina, n=14; post myocardial revascularization surgery, n=36; outpatient cardiac rehabilitation surgery, n=63; preventative medicine program, n=90, and athletes, n=27) and activity levels.

Stage	*Speed (km h^{-1})*	*Incline (%)*	*Duration (min)*	*Duration total (min)*
0	2.7	0	3	3
0.5	2.7	5	3	6
1	2.7	10	3	9
2	4	12	3	12
3	5.4	14	3	15
4	6.7	15	3	18
5	8	15	3	21
6	8.8	15	3	24
7	9.6	15	3	27

Figure 2.9 Modified Bruce treadmill test protocol[(52)]

Reliability and validity: Bruce et al[(50)] reported Pearson product moment correlation coefficients (r) between predicted $\dot{V}$O2max and measured $\dot{V}$O2max of 0.94 for without cardiac conditions (n=292), 0.93 for women without cardiac conditions (n=509), and 0.87 for men with cardiac disease (n=153). Foster et al[(51)] compared predicted $\dot{V}$O2max and measured $\dot{V}$O2max for the general equation and the population-specific equations introduced by Bruce et al.[(50)] The average predicted error was −0.6 mL·kg−1·min−1 for the general equation versus −2.0 mL·kg−1·min−1 for the population-specific equations. The correlation between measured $\dot{V}$O2max and predicted $\dot{V}$O2max for the general equation was high (r=0.96), with a multiple correlation coefficient (R) of 0.98 and a standard error of the estimate (SEE) of 3.5 mL·kg−1·min−1.30

2.2.1.3 Astrand and Ryhming cycle ergometer test

The Astrand and Ryhming (A-R) cycle ergometer test, which is used to predict $\dot{V}$O2max by use of a cycle ergometer, is based on the linear relationship between $\dot{V}$O2 and Heart rate.[(53)] Astrand and Ryhming[(53)]noted that, in subjects aged 18 to 30 years, the men had an average HR of 128 bpm at 50% of $\dot{V}$O2max and an average HR of 154 bpm at 70% of $\dot{V}$O2max, and the women had an average HR of 138 bpm at 50% of $\dot{V}$O2max and an average HR of 164 bpm at 70% of $\dot{V}$O2max. A nomogram was developed by Astrand and Ryhming(53) to estimate $\dot{V}$O2max (Figure2.10), and later an age-correction factor was incorporated to account for the decrease in HRmax with age (Figure2.11) Modification of the A-R nomogram were proposed by Legge and Banister(54) and by Hartung and colleagues(55) to improve the accuracy of the equation. A revision to the A-R nomogram was also proposed by Siconolfi et al.(56)

Reliability and validity: Astrand (53) reported a correlation of 0.71 between the measured $\dot{V}$O2max and the estimated $\dot{V}$O2max in the original A-R Cycle Ergometer Test and a correlation of 0.78 between the measured $\dot{V}$O2max and the A-R Cycle Ergometer Test using the age-correction factor. Teraslinna et al(57) reported a correlation of 0.69 between the original A-R Cycle Ergometer Test and the measured $\dot{V}$O2max and a correlation of 0.92 using the age-correction factor in a sample of 31 sedentary men.

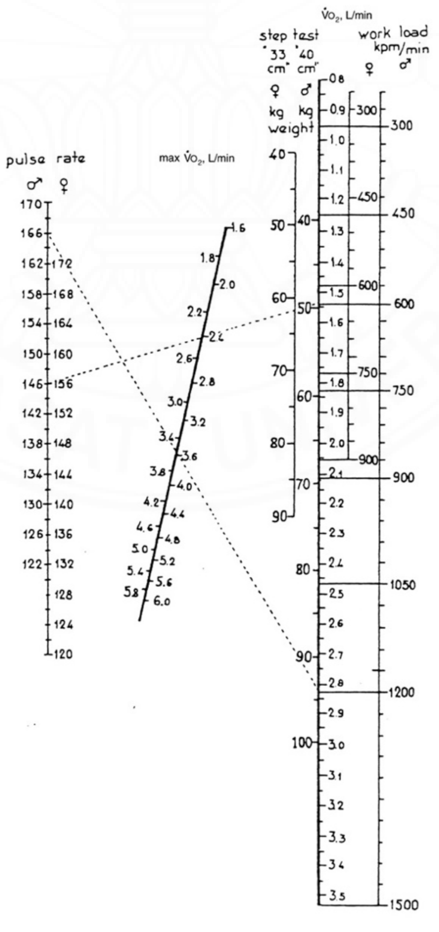


Figure 2.10 The Astrand and Ryhming nomogram(53)

Age (y)	Factor	Maximal Heart Rate (bpm)	Factor
15	1.10	210	1.12
25	1.00	200	1.00
35	0.87	190	0.93
40	0.83	180	0.83
45	0.78	170	0.75
50	0.75	160	0.69
55	0.71	150	0.64
60	0.68		
65	0.65		

Figure 2.11 Astrand and Ryhming Cycle Ergometer Test: correction factor for age-predicted maximal heart rate(57)

2.2.2 Submaximal exercise tests

Submaximal exercise tests can be used to predict $\dot{V}O_2max$, to make diagnoses and assess functional limitations, to assess the outcome of interventions such as exercise programs, to measure the effects of pharmacological agents, and to examine the effect of recovery strategies on exercise performance(49). The most popular clinical exercise tests in order of increasing complexity are stair climbing, 6MWT, shuttle-walk test, detection of exercise-induced asthma, a cardiac stress test (e.g., Bruce protocol) and cardiopulmonary exercise test(58, 59, 60). For subject functional capacity in traditionally assessing can be done by asking the patient questions such as “How many flights of stairs have you climbed? or how many blocks can you walk?” However, patients differ in their recall and may report their responses being inflated, in which their true functional exercise capacity is underestimated(42, 61). For objective measurements, it is often better than self-reports. In the early 1960s Balke developed a simple test to assess the body's ability to function by measuring the distance traveled over a specified period of time, then a 12-minute field.(62) The performance test was developed to assess the level of physical fitness of healthy individuals. The gait test is also adapted to assess impairments in patients with chronic bronchitis.

Early detection of impaired functional capacity in older adults with cardiovascular disease is highly important for clinical management and treatment decisions. For an assessment tool that can be used conveniently, quickly and safely in clinical practice to screen for reduced physical performance in patients, one of these is the 6-min walk distance or 6-minute walk test.

2.2.2.1 Modified shuttle walking test

The modified shuttle walking test (MSWT) was modified from the 20-Meter Shuttle Test (subjects run between 2 lines spaced 20 m. apart at a pace set by signals on a pre-recorded cassette tape) to provide a standardized progressive test for obtaining a symptom-limited maximum performance in individuals with chronic airway obstruction[63]. The individual walks up and down a 10-m course at incremental speeds of 0.17 m/s each minute dictated by a prerecorded audio signal on a cassette deck[63] (Figure 2.12).

Level	Speed (m/s)	Speed (mph)	No. of Shuttles
1	0.50	1.12	3
2	0.67	1.50	4
3	0.84	1.88	5
4	1.01	2.26	6
5	1.18	2.64	7
6	1.35	3.02	8
7	1.52	3.40	9
8	1.69	3.78	10
9	1.86	4.16	11
10	2.03	4.54	12
11	2.20	4.92	13
12	2.37	5.30	14

Figure 2.12 Modified shuttle walking test[63]

The measurements obtained with this test were replicable in a sample of 10 individuals after one practice trial.[63] The mean difference between trials 2 and 3 was −2.0 m (95% confidence interval of −21.9 to 17.9 m). The validity of measurements obtained with the test, which was established by comparing the distance completed during the MSWT with the distance completed during the 6-minute walk test (6-MWT), was moderate (Spearman's rho =0.68)[63].

2.2.2.2 Six-Minute Walk Test

A six-minute walk distance (6MWD)[6, 13] is often used to assess the functional capacity of a broad population. Several studies have shown the ability to predict outcomes in patients. cardiovascular disease(CVD), such as heart failure angina and those undergoing heart surgery.[64] However, measuring 6MWD requires a long corridor, which is not always possible assess in smaller clinical practice or at-home assessments, where gait speed is an outcome through a physical function, Gait speed measures the time required to walk short distances at a comfortable pace. This is another test commonly used to screen for bodily functions. It also showed walking speed to predict morbidity and mortality in various populations, including elderly patients with CVD. But in a study by Kentaro Kamiya et al, 2018, Gait speed and 6MWD were both prognostics and the mortality hazard are similar[65].

The 6-minute walk test (6MWT) is a submaximal exercise test involving measurements of walking distance over 6 minutes and it can demonstrate the function of the multiple cardiopulmonary and musculoskeletal systems involved.[6] The 6MWT test subjects can provide information on functional capacity, response to therapy and prognosis for a wide range of chronic heart and lung conditions.[66] The main strength of the 6 MWT stems from the idea that the assessment should be simple, quick to understand, low cost, easy to set standards and accepted by test participants. There is a lot of research that uses the 6MWT assessment, not just an assessment in patients with lung and heart disease. It is also assessment for elderly, children, arthritis, including fibromyalgia and systemic sclerosis.[6, 67] The 6MWT is a simple, practical, clinical test and can be used in research. 6MWT requires a 30 meter long hallway without requiring any exercise equipment or advanced training for assessors.[6]. The test measures the distance for 6 minutes that individual can perform. It evaluates the global and integrated responses of all the systems involved during exercise, including the pulmonary and cardiovascular systems, systemic circulation, peripheral circulation, blood, neuromuscular units, and muscle metabolism[6, 68]. The 6MWT, has shown similar reproducibility and accuracy when compared to the shuttle walk test, an incremental form of exercise testing.[68] Patients with chronic heart failure showed well-preserved functional capacity according to the distance walked in both tests (six-minute walk test 491±94 m versus incremental shuttle walk test 422±119 m; $P<0.001$).[69] The 6MWT can reflect a better level of functional fitness for daily physical activity because at the time of the test, participant is able to stop walking if he/she experiences excessive tiredness the assessment can be continued until six minutes are complete.

Reliability

Test-Retest Reliability

According to an Alzheimer's disease study done by Ries et al. in 2009(70), based on 51 participants performing the 6MWT, with an average age of 80.71±8.77, the ICC result ranged from 0.982 - 0.987. Of the 51 participants, 20 had mild to moderate AD, while 31 having moderately severe to severe AD.

A geriatrics 6MWT study carried out on 86 participants by Harada et al. in 1999(71), produced results of test-retest reliability (r = 0.95) with the average age being 75, while in 2002, Steffen et al(72), produced similar results of test-retest reliability (ICC = 0.95) using 96 participants with an average age of 73.

As for the osteoarthritis 6MWT study, it was conducted by Kennedy et al. in 2005(73). Involving 150 participants with an average age of 63.7±10.7, the test-retest reliability results were ICC = 0.94.

In the chronic stroke category, Eng et al. oversaw the 6MWT study in 2004(74), featuring 12 community-dwelling individuals who had all suffered from a stroke with moderate motor deficits. The average time since stroke onset being 3.5±2.0 years, while the average age was 62.5±8.6. The results are as follows: test-retest reliability (ICC = 0.99) and test-retest reliability for VO2 (ICC = 0.99). And it would seem as though the study results acheived by Flansbjer et al. in 2005(75), proved to be identical with the same ICC of 0.99.

The study of 6MWT in acute stroke patients conducted by Fulk et al. in 2008(76), consisted of 35 acute stroke patients were enrolled in inpatient rehabilitation after stroke, with an average age of 67.4±13.8. Average time since stroke onset was 34.5 ±17.7 days. The results are as follows: test-retest reliability for all participants (ICC = 0.862), test-retest reliability for those who require physical assistance to walk (ICC = 0.97), test-retest reliability for those who can walk without assistance (ICC = 0.80), and test-retest for those require an assistive device to walk (ICC = 0.914).

The study of 6MWT in chronic stroke patients conducted by Wevers et al. in 2011[77], was completed with 27 participants, where the average age was 60.7±10.9. In fact, there were two separate studies, with both 6MWT being conducted outdoors, resulting in ICC = 0.96 for GPS and 0.98 for measuring wheel.

Interrater/Intrarater Reliability

In a 1997 Alzheimer's disease study by Tappen et al[78], consisting of 33 participants with an average age of 84.7±3.94, interrater reliability (ICC = 0.97-0.99) was found to be very high while intrarater reliability (ICC = 0.76-0.9) was quite strong.

A study on stroke was conducted in 2005 by Kosak & Smith[79], with 18 participants, having an average age of 77±11 and an average time since stroke onset of 28±34 days. These participants were enrolled in inpatient rehabilitation and at the time of admission, the average FIM score was 68±17. The levels of both interrater reliability (ICC = 0.78) and intrarater reliability (ICC = 0.74) were of comparable levels and relatively high.

Validity

A study by Szekely et al. in 1997[80], shown the criterion validity in COPD involving 47 participants with an average age of 60.5±7.5 who were undergoing volume reduction surgery. Testing was done to show their inability to walk > 200m before the operation, as well as a test determining their resting PCO2 > 45, which were the best predictors of unacceptable postoperative outcome and mortality (specificity: 84%, sensitivity: 82%). Adequate correlation with length of hospital stay: pre-surgical 6MWT (R = 0.32) and post-surgical 6MWT (R = 0.40).

In 1999, Harada et al[81], studied 86 eldery adults who were without any significant disease. Of these 86 participants, 35 were recruited from retirement homes and 57 from community centers, with the average age being 75±6. The study resulted in adequate concurrent validity based on chair stands (r = 0.67), standing balance (r = 0.52), and gait speed (r = -0.73).

In 2005, Flansbjer et al[82], studied in stroke patients with the results that chronic stroke has a excellent concurrent validity with TUG (r = -0.89), 10-meter comfortable gait speed (r = 0.84), 10-meter fast gait speed (r = 0.94), stair climbing (r = -0.82), and stair descent (r = -0.80).

In 1999, Harada et al[71], studied the construct validity of physical performance test in geriatrics, there were adequate correlation with chair stands (r = 0.67), tandem balance (r = 0.52), and gait speed (r = -0.73) and adequate correlation with SF 36 physical function subscale (r = 0.55) and general health perceptions subscale (r = 0.39)

Indications [6, 62]

The six-minute walk test measures response to medical treatment in patients with moderate to severe cardiac or pulmonary disease. It is also used to measure a patient's functional status, a predictor of morbidity and mortality.

Contraindications[6, 83]

Contraindications for 6MWT include the following: unstable angina during the previous month and myocardial infarction during the previous month. Related contraindications include resting heart rate greater than 120 bpm, systolic blood pressure greater than 180 mmHg, and diastolic blood pressure greater than 100 mmHg. Patients with any of these findings should be referred to the physician ordering or supervising the test for individual clinical assessment and a decision about the conduct of the test. The results from a resting electrocardiogram done during the previous 6 months should also be reviewed before testing. Stable exertional angina is not an absolute contraindication for a 6MWT, but patients with these symptoms should perform the test after using their antiangina medication, and rescue nitrate medication should be readily available. Patients with the risk factors mentioned above may be at increased risk for arrhythmias or cardiovascular collapse during testing.[84, 85]

Absolute contraindications[86]

a. Recent infarction (3-5 days)

b. Unstable angina

c. Uncontrolled arrhythmias causing symptoms or hemodynamic compromise

d. Syncope and acute endocarditis, myocarditis, or pericarditis

f. Severe or symptomatic aortic stenosis

g. Uncontrolled heart failure

h. Recent pulmonary embolism or pulmonary infarction

i. Lower limb thrombosis

j. Suspected dissecting aneurysm

k. Uncontrolled asthma

l. Pulmonary edema

m. Severe respiratory insufficiency

n. Acute non-cardiopulmonary disease that may affect ability to exercise or aggravated by exercise (infection, thyrotoxicosis, kidney failure)

o. Mental disorder that creates an inability to cooperate

Relative contraindications[6]

a. Left coronary artery stenosis

b. Moderate valve stenosis

c. Systolic untreated resting arterial hypertension> 200 mmHg or diastolic> 120 mmHg

d. Tachyarrhythmias or bradyarrhythmias and high-grade AV block

f. Hypertrophic cardiomyopathy

g. Advanced or complicated pregnancy

h. Electrolyte abnormalities

i. Orthopedic inability to walk

j. SpO2 at rest <85% (if applicable, it can be done with supplemental oxygen and specify flow. This cut-off point is arbitrary and can be modified according to the altitude above the sea level)

k. Resting heart rate> 120 beats per minute

Safety issues[6, 83]

1. Testing should be performed in a location where an emergency can be referred as quickly as appropriate. The appropriate location of a crash cart should be determined by the physician supervising the facility.

2. Supplies that must be available include oxygen, sublingual nitroglycerine, aspirin, and albuterol (metered dose inhaler or nebulizer). A telephone or other means should be in place to enable a call for help.

3. The technician should be certified in cardiopulmonary resuscitation with a minimum of Basic Life Support by an American Health Association–approved cardiopulmonary resuscitation course.

4. Assessors or physicians are not required to be present during all tests. The physician ordering the test or a supervising laboratory physician may decide whether physician attendance at a specific test is required.

5. If a patient is on chronic oxygen therapy, oxygen should be given at their standard rate or as directed by a physician or a protocol.

Reasons for immediately stopping a 6MWT include the following: chest pain, intolerable dyspnea, leg cramps, staggering, diaphoresis, and pale or ashen appearance.

Assessors should be trained to recognize these issues and to respond appropriately. If a test is stopped for any of these reasons, the patient should sit or lie supine as appropriate depending on the severity or the event and the technician's assessment of the severity of the event and the risk of syncope. The following should be obtained based on the judgment of the technician: blood pressure, pulse rate, oxygen saturation, and a physician evaluation. Oxygen should be administered as appropriate.

Technical considerations[6]

Hallway or corridor: the corridor must be indoors, with a flat surface, which is wide enough to allow free roaming of patients requiring assistive gait devices. The walking course must be 30 meters in length. A 100-ft hallway is, therefore, required. The length of the corridor should be marked every 3 meters. The turnaround points should be marked with a cone (such as an orange traffic cone). Two traffic cones should be placed: one at 0.5 m and another 29.5 m from the start line. On the floor or the wall, visible marks should be made every 3 meters so that the measurement of the distance traveled by the patient is as accurate as possible. In case of limited space corridor. The walkway should be at least 15 meters (50 feet) long to avoid having to make frequent turns or turns because the length of the path affects 6MWD. The distance between walking on the treadmill was 6 minutes less than walk on the ground so cannot use treadmill to performed 6MWT. [87]

Required equipment

- At least one chair, positioned at one end of the walking course
- A validated scale to measure dyspnea (Modified breathlessness scale) and subjective fatigue
- Sphygmomanometer for blood pressure measurement
- Pulse oximeter
- Stopwatch
- Pre-measured marks along the track or corridor
- Access to oxygen and telephone in case of an emergency
- An emergency plans
- Portable supplemental oxygen if required by patient to perform exercise test
- Clipboard with reporting sheet and pen

Preparation of the patient

Before the 6MWT, when scheduling the test must be provided the following indications to the patient:

1. On the day of the test, you must come with comfortable clothes and light.
2. Appropriate shoes for exercising.
3. Remove the nail polish, if it is the case.
4. If the subject uses devices to assist the march e.g., cane, prosthesis, walker. This should be noted on the data collection for subsequent testing are carried out under the same conditions and can be compared.
5. Having eaten a light meal.
6. Do not stop the usual medications.
7. Do not perform vigorous exercise in the previous two hours to the test.

The day of the test and upon arrival of the patient should be:

1. Verify the study application duly completed, with the correct folio number, date and time.
2. Receive and introduce yourself to the patient; confirm that your data are correct (name and date of birth).

3. If the patient speaks a dialect, he or she should an interpreter must accompany you to explain the procedure.
4. Explain the purpose of the test to the patient. The phrase that simple recommended is the following: “The walk of 6 minutes is a test that consists of walking as quickly as possible over a period 6 minutes in a flat corridor.”
5. Verify that there are no contraindications to perform the test.
6. Inform the medical staff of the laboratory if the patient presents one or more contraindications to the test is performed.
7. In case the patient uses supplemental oxygen on an outpatient basis, the test should be performed with the usual oxygen supply, with the constant flow. If the purpose is to compare the distance traveled between two tests, the same device must be used for the administration of oxygen and the same flow. On any of the cases must be recorded in the data collection.
8. In case it is required to increase the flow of oxygen during the test should be recorded on the sheet work.
9. Report the type of management device supplemental oxygen; for example, liquid oxygen fixed or portable concentrate, and if the flow is continuous or at demand.

6 MWT Procedure

1. Measure and weigh the patient in a standardized way and record it on the worksheet.
2. Calculate and record the expected maximum heart rate with the formula (220-age of patient).
3. Measure blood pressure and record baseline values.
4. Ask the patient to remain in a sitting position for at least 15 minutes before the test.
5. Put on the pulse oximeter and record SpO2 and the resting heart rate and record the values basal
6. Verify that the lap counter is at zero and the timer set for six minutes.

7. Explain to the patient what the Borg Scale consists of, and record the baseline value. (Figure2.13)

Borg CR10 Scale	
0	Nothing at all
0.5	Extremely weak (just noticeable)
1	Very weak
2	Weak (light)
3	Moderate
4	Somewhat strong
5	Strong (heavy)
6	
7	Very strong
8	
9	
10	Extremely strong (almost max)
•	Maximal

Figure 2.13 The Borg Scale[88]

8. Read verbatim the instructions to the patient; show by written to those patients with impaired hearing
9. Read verbatim to the patient: The object of this test is to walk as far as possible for 6 minutes. You will walk back and forth in this hallway. Six minutes is a long time to walk, so you will be exerting yourself. You will probably get out of breath or become exhausted. You are permitted to slow down, to stop, and to rest as necessary. You may lean against the wall while resting, but resume walking as soon as you are able. You will be walking back and forth around the cones. You should pivot briskly around the cones and continue back the other way without hesitation. Now I'm going to show you. Please watch the way I turn without hesitation."

a. Demonstrate by walking one lap yourself. Walk and pivot around a cone briskly.

b. "Are you ready to do that? I am going to use this counter to keep track of the number of laps you complete. I will click it each time you turn around at this starting line. Remember that the object is to walk as far as possible for 6 minutes, but don't run or jog. Start now, or whenever you are ready."

Test start

1. Place the patient on the start line and indicate "Start".
2. Start the stopwatch as soon as the patient start walking.
3. Observe the patient carefully.
4. Do not walk with or behind the patient.
5. Record oxygen saturation and frequency on the sheet heart rate every turn.
6. Use a uniform tone of voice when saying the following stimulation phrases:
   a. After the first minute, tell the patient the following (in even tones): "You are doing well. You have 5 minutes to go."
   b. When the timer shows 4 minutes remaining, tell the patient the following: "Keep up the good work. You have 4 minutes to go."
   c. When the timer shows 3 minutes remaining, tell the patient the following: "You are doing well. You are halfway done."
   d. When the timer shows 2 minutes remaining, tell the patient the following: "Keep up the good work. You have only 2 minutes left."
   e. When the timer shows only 1 minute remaining, tell the patient: "You are doing well. You have only 1 minute to go."

   Do not use other words of encouragement (body language to speed up).
7. If the patient stops walking during the test and needs a rest, say this: "You can lean against the wall if you would like; then continue walking whenever you feel able." Do not stop the timer. If the patient stops before the 6 minutes are up and refuses to continue (or you decide that they should not continue), wheel the chair over for the patient to sit on, discontinue the walk, and note on the worksheet the distance, the time stopped, and the reason for stopping prematurely.
8. When the timer is 15 seconds from completion, say this: "In a moment I'm going to tell you to stop. When I do, just stop right where you are and I will come to you."

9. When the timer rings (or buzzes), say this: “Stop!” Walk over to the patient. Consider taking the chair if they look exhausted. Mark the spot where they stopped by placing a bean bag or a piece of tape on the floor.
    a. Post-test: Record the post walk Borg dyspnea and fatigue levels and ask this: “What, if anything, kept you from walking farther?”
    b. If using a pulse oximeter, measure SpO_2 and pulse rate from the oximeter and then remove the sensor.
    c. Record the number of laps from the counter (or tick marks on the worksheet).
    d. Record the additional distance covered (the number of meters in the final partial lap) using the markers on the wall as distance guides. Calculate the total distance walked, rounding to the nearest meter, and record it on the worksheet.
    e. Congratulate the patient on good effort and offer a drink of water.
10. Calculate the achieved percentage of the maximum heart rate for the patient.
11. Place the patient in a sitting position for 30 minutes and then repeat the test with the same methodology.
12. It is recommended that the test be done in duplicate 30 minutes apart. It is up to the criteria of the medical director of the laboratory if in some cases it is only done once.
13. Generate the report of the results.

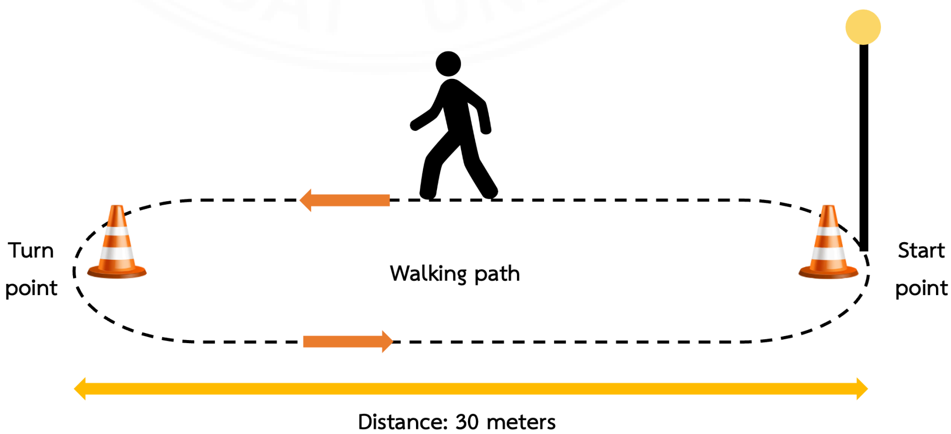


Figure 2.14 Walking path of 6MWT[89]

Results report

The final report of the 6MWT should include:

1. Patient information: name, age, weight and height.
2. Full name of the technician who performed the test.
3. Diagnosis or indication of the test.
4. The results of the measured variables should be included; before, during and after 6MWT (vital signs, Borg scale, oxygen saturation).
5. In case the patient has presented symptoms that they forced the stoppage of the test should be mentioned in the report.
6. The number of meters walked If do more than are made tests the test with the highest number of meters traveled is usually reported.
7. Optionally you can enter: to. Percentage (%) of the predicted meters walked, and in that case specify the equation of reference used.
8. SpO2 droop during the test. It has been proposed recently as an indicator of severity and as an index to predict mortality in patients with interstitial diseases. This SpO2 droop it often does not occur at the end of the 6MWT.

Example of prediction equations of 6-minute walk distance in healthy adults[90].

Study	**Reference equations**	**Age range (years)**	**Number of patients**	R^2
Enright P, et al[91].	M: 7.57 × Height(cm)–5.02 × Age– 1.76 × Weight(kg)– 309 F: 2.11 × Height(cm)– 2.29 × Weight(kg)– 5.78 × Age + 667	>40	290	M: 0.42 F: 0.38
Troosters T, et al [92].	218 + [5.14×Height(cm)–5.32 × Age]– 1.8 × Weight(kg) + 51.31 × Sex, Sex: F = 0, M = 1	50–85	53	0.66

Gibbons W, et al[93].	794.1–2.99 × Age + 74.7 × Sex, Sex: F = 0, M = 1	20–80	79	0.41
Enright P, et al [94].	M: 539 + 6.1 × Height(cm)–0.46 × Weight(kg)–5.8 × Age F: 493 + 2.2 × Height(cm)–0.93 × Weight(kg)–5.3 × Age	≥68	752	M: 0.20 F: 0.20
Chetta A, et al[95].	479.78 + 1.25 × Height(cm)–2.82 × Age + 39.07 × Sex, Sex: F = 0, M = 1	20–50	102	0.42
Camarri B, et al[96].	182.86 + 4.12 × Height(cm)–1.75 × Age–1.15 × Weight(kg) + 34.04 × Gender, Sex: F = 0, M = 1	55–75	70	0.36
Poh H, et al[97].	5.50 × (HRmax/HRmax Predicted) + 6.94 × Height(cm)–4.49 × Age–3.51 × Weight(kg)–473.27	45–85	35	0.78
Masmoudi K, et al[98].	299.8–4.34 × Age + 3.43 × Height(cm)–1.46 × Weight(kg) + 62.5 × Sex, Sex: F = 0, M = 1	40–80	155	0.60
Alameri H, et al[99].	2.81 × Height(cm) + 0.79 × Age–28.5	16–50	298	0.25
Ben Saad H, et al[100].	560.50–5.14 × Age–2.23 × Weight(kg) + 2.72 × Height(cm) + 160 × Sex, Sex: F = 0, M = 1	≥40	229	0.77
Iwama A, et al[101].	622.46–1.85 × Age + 61.50 × Sex, Sex: F = 0, M = 1	13–84	134	0.30

Casanova C, et al[102].	361– 4 × Age + 2× Height(cm) – 1.5 × Weight(kg) + 3 × (HRmax/HRmax predicted) –30 (if Female)	40–80	440	0.38
Dourado VZ, et al[103].	299.30–2.73 × Age – 2.16 × Weight(kg) + 361.73 × Height + 56.39 × Sex, Sex: F = 0, M = 1	≥40	90	0.55
Soaresa MR, et al[104].	511 + [0.0066 × Height(cm)^2] – 0.068 × (Age^2× 0.03 –BMI^2)	20–80	132	0.55
Britto RR, et al[105].	890.46–6.11 × Age + 0.035 × Age^2 + 48.87 × Sex −4.87 × BMI, Sex: F = 0, M = 1	≥18	617	0.46
Duncan MJ, et al[106].	M: 290.6 × [Height (cm) × 0.525] × [Weight(kg) –0.317] × e$^{-0.009 \times Age}$ F: 260.3 × [Height (cm) × 0.525] × [Weight(kg) –0.317] × e$^{-0.009 \times Age}$	50–85	246	0.53
Oliveira MJ, et al[107].	787.2–2.0 × Age –4.4 × BMI + 58.4 × Sex, Sex: F = 0, M = 1	18–70	158	0.3

Annotation: BMI, body mass index; F, female; HR, heart rate; M, male; R^2, a measure of the variance explained by the model/equation

Factor about 6-minute walk distance

Factors associated with shorter 6-minute walk distance:[83] shorter height (shorter legs), old age, higher body weight, female gender, impaired cognition, shorter walking corridor (more turns), chronic obstructive pulmonary disease, asthma, cystic fibrosis, interstitial lung disease angina, myocardial infarction, congestive heart failure, stroke, transient ischemic attack, peripheral vascular disease, ankle-arm index arthritis; ankle, knee, or hip injuries; muscle wasting. Factors associated with longer 6-minute walk distance:[83] taller height (longer legs), male gender, high motivation patient has previously performed the test, medication for a disabling disease taken just before the test and oxygen supplementation.

Related research for 6MWT

Goldman MD, et al, 2008[108] assess the characteristics of the 6-min walk test in multiple sclerosis (MS) subjects of varied disability, and healthy controls. For the method: Forty MS expanded disability status scale [(EDSS) 0-6.5] and 20 control subjects were recruited from a MS outpatient clinic. Subjects completed survey material and three 6MWT with 1-hr interval rest in a single study visit. The results were no practice effect or fatigability with repeat 6MWT with a one-hr rest period between test sessions. The 6MWT had excellent intra (ICC) = 0.95 and inter-rater (ICC = 0.91) reliability. MS subjects demonstrated reduced 6MWT distance and speed compared with controls ($P < 0.0001$). Within the MS population 6MW distance was significantly reduced with increasing disability ($P = 0.05$). thus, the 6MWT is a feasible, reproducible, and reliable measure in MS.

Casey AF, et al, 2012 [109] evaluated the reliability of the 6-minute walk test (6MWT) in individuals with Down syndrome and explore factors affecting walking distance. There were four repeated walk tests in the span of 2 weeks including 2 practice walks. All tests were carried out in a 40-meter corridor at a university sport complex. Participants consisted of adolescents and young adults with Down syndrome (N=55) aged 11 to 26 years. Participants were instructed to walk as far as possible for the duration of 6 minutes. Distance walked, heart rate, blood pressure, and perceived exertion were measured across 4 tests (t1, t2, t3, and t4). They found that the walking distances for t1, t2, t3, and t4 averaged 395, 428, 433, and 436 meters, respectively. The 6-minute walk distance (6MWD) during t1 and t2 was significantly different from that during t3 and t4 ($t(54)=-6.475$, $P<.001$). Repeated analysis of variance showed no significant difference between the distance walked in t3 and t4 (433±64m vs 436±68m) ($F(1,54)=2.439$, $P=.124$). Body mass index as well as levels of intellectual disability and physical activity all affected the distance walked to different degrees.

Vancampfort D, et al, 2012[110] determined whether the 6MWT is associated with the global assessment of functioning (GAF) score in patients with schizophrenia. A total of 68 male and 25 female in-patients with schizophrenia (34.6 ± 9.7 years; body mass index = 24.9 ± 4.4) performed a 6MWT and were assessed with the GAF scale and the Psychosis Evaluation tool for Common use by Caregivers (PECC). The mean distance walked on the 6MWT was 587.3 ± 98.4 m, while the mean GAF score was 52.0 ± 10.4. The Pearson's correlation coefficient between the 6MWT and the GAF score was 0.59 ($P < 0.001$), indicating a moderate association between both measures. The 6MWT was also significantly related to negative ($r = -0.45$, $P < 0.001$), depressive ($r = -0.48$, $P < 0.001$) and cognitive (r=, P) symptoms and with body mass index (r = -0.31, $P < 0.005$), smoking behavior ($r = -0.36$, $P < 0.001$)) and dose of antipsychotic medication ($r = -0.38$, $P < 0.001$). As a result, clinicians in in-patient settings should consider incorporating the 6MWT into their test battery to measure the functional consequences of schizophrenia and its treatment.

Ekman MJ, et al, 2013[111] evaluated exercise capacity and related co-morbidities in obese patients. They evaluated by the 6-minute walk test before and after a 7.3 (6.1-8.2) month weight reduction program. The 251 subjects, 41.9 (33.6-51.6) years old completed the test at baseline (BMI 40.6 [36.9-44.6] kg/m^2) and 129 (51.4%) repeated the test after intervention (BMI 35.6 [31.2-38.5] kg/m^2). The six-minute walking distance at baseline (535 [480-580] m) and at follow up (599 [522-640] m) correlated to several cardiovascular risk markers.

Mänttäri A, et al, 2018[112] develop a prediction model for $\dot{V}O_2max$ based on 6MWT results among healthy adults. 75 participants (39 men, 36 women) and age in 19- to 75-year-old were equipped with portable gas analyzer and heart rate monitor. Participants performed 6MWT on a 15-mindoor track and maximal graded exercise test (GXT) on a treadmill. Participant's mean walking distance was 652 ± 74 m. Their mean VO2 max in GXT and O2 uptake at the end of the 6MWT were 34·4 ± 7·6 ml kg-1 min-1 and 27·2 ± 6·5 ml kg-1 min-1, respectively. For men, the best predictors for VO2 max were walking distance, age, BMI, heart rate at the end of 6MWT and height, and for women, walking distance, age and weight. The predictors explained 82% and 79% of men's and women's measured VO2 max with the standard error of estimate of 3·6 ml kg-1 min-1 and 3·5 ml kg-1 min-1, respectively.

Nolen-Doerr E, et al, 2018[113] study investigated the correlation between the 6MWT and graded exercise testing (GXT) in an effort to validate the 6MWT as a quality tool for assessing exercise capacity in adults with type 2 diabetes (T2DM). The

18 patient was scheduled for the baseline assessment visit, which included completion of the 6MWT. Prior to starting the 6MWT, two parameters needed to be met for safe participation. These included an appropriate blood pressure <160/90 and blood glucose range between 80mg/dL and 300mg/dL. The study was a secondary data analysis of Program ACTIVE II, a randomized controlled trial designed to assess the effectiveness of two behavioral interventions on depression and glycemic outcomes in adults with T2DM. The correlation of 6MWT and predicted VO2 max using GXT was examined in a subsample of participants at the time of study enrollment and at post-intervention. PVO2M showed a significant correlation with 6MWT distance both at baseline ($r=0.57$, $p=0.014$) and post-intervention ($r = 0.66$, $p = 0.037$). The regression analysis of baseline data revealed that 6MWT distance alone explained 45% ($F = 13.03$, $p = .0024$) of the variability in PVO2M. When combined with the SF-12 physical health component score (PCS), 6MWT explained 66% ($F = 13.62$, $p < .001$) of the variance in PVO2M. After adjusting for PCS, 6MWT distance explained an additional 30% variability in and predicted VO2 max.

Nakashima H, et al, 2020[114] studied about relationship between 6MWT distance and forced vital capacity (FVC) and the major curve among children with congenital scoliosis with rib anomalies. 20 children with congenital scoliosis before outpatient surgical treatment. The authors recorded 6MWT distance in meters, FVC as a percentage of predicted normal value using arm span for height (FVC%), and Cobb angle. The 6MWT uses a standardized protocol and measures distance traveled in 6 minutes on a flat surface. The authors then determined the correlation between these measures using linear regression analysis. They find the Cobb angle of the major curvature was 55.4 ± 20.5 degrees. The type of vertebral anomaly was mixed in 17 cases, formation failure in 2 cases, and segmentation failure in 1 case. The range of rib anomalies was 3.4 ± 3.9 levels; 15 and 5 patients, respectively, had unilateral and bilateral rib anomalies. FVC and FVC% were 0.7±0.2 L and 60% ± 19%, respectively. The ratio of forced expiratory volume at 1 second to FVC (FEV1/FVC), which indicates obstructive lung disease, was normal at 93%±7%. The 6MWT distance was 386.3±59.4 m, which was ≤10% of the predicted distance for normal children. No child was able to walk the normal distance on the basis of published norms. 6MWT distance was significantly correlated with arm span (=0.46, P=0.04) and major curve (P =-0.61, P=0.004), but not with FVC% (p =0.17, P=0.49). The conclusion: the 6MWT distance is a feasible measure of function and is substantially reduced before surgery in children with thoracic congenital scoliosis with rib anomalies. The 6MWT distance was significantly correlated with a major curve but not with FVC%. 6MWT distance is not affected by moderate lung function impairment.

Regan E, et al, 2020[(115)] determined the association between the six-minute walk test and fall risk in persons with stroke with a mean age of 66 ± 12years and median stroke chronicity of 60.9 months (range 6.0-272.1). The six-minute walk test was evaluated using logistic regression. The best fit model was used in Receiver Operating Characteristic analysis. Likelihood ratios and post-test probabilities were calculated. Lower six-minute walk test distance was associated with increased fall risk in logistic regression (p = .002). The area under the curve for the univariate six-minute walk test model (best fit) was 0.701 (p = .006). The cutoff for increased fall risk was six-minute walk test <331.65 m. The post-test probability of fall risk increased to 74.3% from a pre-test probability of 59.1%. As a consequence, using the six-minute walk test cutoff to screen fall risk in community exercise programs may enhance safety for persons with stroke without additional testing required.

Vitacca M, et al, 2020[(116)] study presents a cluster analysis performed on the data of 1,228 patients with obstructive sleep apnea (OSA). Severity of exercise limitation was defined on the basis of 6MWD. Sixty-one percent showed exercise limitation (29.2% and 31.9% mild and severe exercise limitation, respectively). About 60% and 40% of patients were included in cluster 1 (CL1) and 2 (CL2), respectively. CL1 included younger patients with high prevalence of apneas, desaturations, and hypertension with better exercise tolerance. CL2 included older patients, all with chronic obstructive pulmonary disease (COPD), high prevalence of chronic respiratory failure (CRF), fewer apneas but severe mean desaturation, daytime hypoxemia, more severe exercise limitation, and exercise-induced desaturations. Only CRF and COPD significantly (P < .001) correlated with 6MWD < 85% of predicted value. 6MWD correlated positively with apnea-hypopnea index, oxygen desaturation index, nocturnal pulse oxygen saturation (SpO_2), resting arterial oxygen tension, mean SpO_2 on exercise, and negatively with age, body mass index, time spent during night with SpO_2 < 90%, mean nocturnal desaturation, arterial carbon dioxide tension, and number of comorbidities. Patients without severe comorbidities had higher exercise capacity than those with severe comorbidities, ($P < 0.001$). Exercise limitation was significantly worse in OSA severity class I when compared to other classes ($P < 0.001$).

Vásquez-Gómez J, et al, 2021[117] developed reference values and a predictive model of cardiorespiratory fitness in 741 Chilean adolescents in both genders with an average age of 15.7 years. Participants were assessed a basic anthropometry, performance in the 6MWT, and in Course Navette was measured. Percentiles were determined for the 6MWT, for the $\dot{V}O_2max$, and an equation was developed to estimate it. The 50th percentile values for males and females in the 6MWT and in the $\dot{V}O_2max$ of Course Navette were, respectively, from 607 to 690 and from 630 to 641 m, and from 43.9 to 45 and from 37.5 to 31.5 $mlO_2 \cdot kg \cdot min^{-1}$, for the range of 13 to 17 years.

Conclusion of the 6MWT

The 6MWT is a useful functional capacity measurement targeted at people with least moderately and severe impairment.[118]. Currently, The 6-minute walking test (6MWT) has emerged as a widely accepted and utilized tool for evaluation of preoperative and postoperative functional capacity and for measuring therapeutic interventions in various disease populations, including coronary artery disease, chronic kidney disease, chronic obstructive pulmonary disease, and cerebrovascular disease, due to the increasing prevalence of these conditions annually and significant burden in low and middle income countries, which is significant contributor to mortality, morbidity, and disability. The presence of these diseases has a negative impact on the resilience of the cardiorespiratory systems, resulting in a diminished ability to walk, ultimately affecting the quality of life of the patient.

2.3 Diseases

2.3.1 Coronary heart disease / Coronary artery disease

Coronary artery disease is a common and significant cardiovascular disorder that plays a major role in global mortality. 10 years ago, There are increasing number of patients with coronary artery disease in Thailand[119]. Coronary artery disease is the result of accumulation of plaque in the thickening vessel walls, leads to narrowing and obstruction of blood flow through the arteries. It originates from a prolonged inflammatory sequence, spanning from the initial emergence of fatty streaks to the eventual development of fibrous atheromas. This cascade is triggered by endothelial dysfunction, often catalyzed by various factors. These inciting elements encompass shear stress, oxidative harm provoked by free radicals, genetic mutations, persistent infections, and elevated levels of cholesterol. These triggers are frequently associated with uncontrolled hypertension, diabetes, tobacco usage, and specific genetic predispositions[(120)].

The presentation of coronary artery disease symptoms can differ widely, spanning from asymptomatic cases to distinctive clinical scenarios such as stable angina, fatigue, shortness of breath, acute coronary syndrome (encompassing unstable angina, NSTEMI, and STEMI), and in certain instances, even sudden cardiac death. In cases of stable angina, the chest pain is often felt at the center of the chest and described as squeezing, accompanied by a sense of tightness or anxiety. This discomfort may spread to other areas like the arms, neck, jaw, back, or upper abdomen. These symptoms tend to worsen during physical or emotional exertion due to the body's increased need for oxygen, but they ease during rest when less oxygen is required [(121, 122)].

The primary effect of Coronary Artery Disease (CAD) is the reduced blood flow to the heart muscle. During physical activities, the heart requires more oxygen and nutrients to meet the increased demand. With narrowed or blocked coronary arteries, the heart may not receive an adequate supply of blood which may result in decreased cardiac output and the heart cannot pump enough oxygen-rich blood to meet the demands of the body, leading to symptoms such as chest pain (angina), shortness of breath (dyspnea), easily fatigued and limiting physical performance. These symptoms often limit or reduce a patient's ability to engage in certain activities or heavy workloads[(120)]. Furthermore, recent studies have shown that physical performance of individuals with coronary artery disease (CAD) such as skeletal muscle strength, encompassing parameters of grip strength, leg strength, and walking speed has been observed to decline to approximately 70% when compared to individuals without CAD. This decrease in physical performance has been closely related to increased mortality rates and cardiovascular events[(123)]. Moreover, severe CAD increases the risk of acute cardiovascular events, such as heart attacks (myocardial infarctions) and lifethreatening arrhythmias. These events can occur during physical exertion and have a significant impact on physical performance.

Evaluating the performance of coronary heart disease patients are helpful to monitor the effectiveness of treatment, manage risk factors, and make informed medical decisions. There are several functional assessment tools are available to evaluate physical performance and daily activity levels of individuals with coronary heart disease, including the Cardiopulmonary exercise test (CPET), the 6-minute walk test (6MWT), and the 10-meter walk test. These exercise tolerance tests play a vital role in monitoring a patient's capacity to participate in physical activities and everyday tasks. Therefore, Among these assessments, the 6-minute walk test stands out as an especially convenient and safe option for these patients.[122]

Coronary artery disease with 6MWT

Coronary artery disease, predominantly caused by the accumulation of plaque in the thickening vessel walls, leads to narrowing and obstruction of blood flow through the arteries. This diminished blood supply to the heart necessitates increased effort from the heart to pump blood, resulting in symptoms such as chest pain (angina), fatigue, or shortness of breath during various activities. These symptoms often limit or reduce a patient's ability to engage in certain activities. The 6-Minute Walk Test (6MWT) is often used as a measure of functional capacity and endurance, particularly in individuals with cardiovascular conditions like Coronary Artery Disease (CAD).[6] 6MWT are benefits for CAD patients in ways; consists of assessment of Exercise Tolerance, monitoring Disease Progression, effectiveness of Treatment, risk Stratification, prescribe exercise program or treatment. It's important to note that while the 6MWT is a useful tool, it's not a definitive diagnostic test for CAD but more focused on functional capacity and can be a complementary tool in managing CAD and evaluating its impact on an individual's daily life.

In 2012, Study of Beatty AL, et al[124], the research underscores the remarkable prognostic value of the 6-minute walk test (6MWT) in patients with stable coronary disease. Notably, individuals covering shorter distances (≤419 m) displayed a fourfold higher event rate in contrast to those achieving longer distances (≥544 m) during an eight-year follow-up period. These observations further contribute to the existing body of literature affirming the strong associations between 6MWT distance and subsequent cardiopulmonary morbidity and mortality. This study accentuates the clinical relevance of the 6MWT as an effective predictive tool that aids risk assessment, informs patient management strategies and provide valuable information about a person's exercise tolerance and cardiovascular fitness.

Study of Joshi S, et al[14], the gait analysis of cardiovascular disease patients using wearable sensors revealed that, during a 10-meter walking test, individuals with cardiovascular diseases exhibited shorter stride lengths and lower walking frequencies compared to healthy individuals.

Study of Lenasi, et al [15], conducted a study involving 67 stable coronary artery disease patients and found that, during a 6-minute walking test, male participants covered an average distance of 451±122 meters, while female participants covered an average distance of 485±69 meters. When categorized based on their functional capacity using the New York Heart Association (NYHA) classification, those with NYHA class III walked an average of 385±100 meters, NYHA class II covered an average of 494±28 meters, and NYHA Class I walked an average of 587±31 meters.

In 2020, Yuenyongchaiwat K, et al[16], conducted a study examining the relationship between functional capacity (FC) and the psychological health of preoperative cardiac surgery patients. FC was evaluated using the 6-Minute Walk Test (6MWT) and Inspiratory Muscle Strength (IMS). The study included 64 patients who had undergone Open Heart Surgery.The findings shown that the mean anxiety score was 4.55 ± 4.06, the depression score was 3.38 ± 3.35, and the mean 6MWD was 328.16 ± 126.64 meters. These results indicated that the patients exhibited high anxiety scores and lower IMS and FC. In addition, depression and anxiety were correlated with IMS and FC.

2.3.2 Chronic kidney disease

Chronic kidney disease (CKD) is a global health problem and presents a significant burden, particularly in low- and middle-income countries, which is significant contributor to mortality, morbidity, and disability from non-communicable diseases (NCD)[125]. Thailand is classified as an upper-middle-income country, There are 11.6 million (17.5%) people currently have CKD, 5.7 million (8.6%) have advanced

CKD (stages 3–5), and over 0.1 million require dialysis. Annually, more than 20,000 individuals suffering from End-Stage Kidney Disease (ESKD) require medical care through either hemodialysis (HD) 1002 per million population or peritoneal dialysis (PD) 390 per million population[126]. Chronic kidney disease is defined as abnormalities of kidney structure, or function, present for more than 3 months, with implication for health. Obesity and diabetes mellites are risk factors that causing CKD and other NCDs. CKD are slow progression and typically progresses without noticeable symptoms in its early stages. Hemodialysis patients with low physical activity, there is an increased risk of comorbidities, protein energy wasting, sarcopenia, decreased physical function, decreased aerobic capacity, sedentary lifestyle, and post-dialysis fatigue. As CKD advances, distinct indicators emerge, including swelling in the ankles, persistent fatigue, challenges with concentration, reduced appetite, presence of blood and foamy appearance in the urine.[127] Patients with CKD have a reduced exercise capacity, poor health fitness, impaired physical functioning. Furthermore, The reduced physical function is associated with increased mortality and poor quality of life in CKD patients.[128]

Kidney function can test by using Serum creatinine, Glomerular filtration rate (GFR) and Albumin to creatinine ratio (ACR); [127]

- Serum creatinine test is a blood testing to measures the level of creatinine in the blood, which is a waste product generated by muscle metabolism. Elevated creatinine levels can indicate impaired kidney function.
- Glomerular filtration rate (GFR) is calculated using serum creatinine levels, age, gender, and other factors. It estimates how well the kidneys are filtering waste from the blood. A GFR below 60 mL/min/1.73 m^2 for three months or more indicates CKD.
- Albumin to creatinine ratio (ACR) urine test involves measuring the ratio of albumin (a protein) to creatinine in a urine sample. An elevated ACR suggests kidney damage.

Stages of chronic kidney disease (CKD) can identify by using glomerular filtration rate (GRF) in blood and urine testing.[127]

Stage	Description	GRF level
Normal kidney function	Healthy kidney	90 ml/min
Stage 1	Kidney damage with normal or High GRF	≥90 ml/min
Stage 2	Kidney damage and mild decrease in GRF	60-89 ml/min
Stage 3	Moderate decrease in GRF	30-59 ml/min
Stage 4	Severe decrease in GRF	15-29 ml/min
Stage 5 (ESKD)	Established kidney function (Kidney failure)	<15 ml/min or on dialysis

Table 2.2 Stages of chronic kidney disease (Modified from KDIGO 2012 Clinical Practice Guideline for the Evaluation and Management of Chronic Kidney Disease)(127)

Patients with CKD have a reduced exercise capacity, poor health fitness, impaired physical functioning. Furthermore, The reduced physical function is associated with increased mortality in CKD patients.(128) Patients with end-stage renal disease undergoing dialysis have reduced muscle strength and physical function, which significantly decreased capacity to perform activities in daily living and less ability to engage in entertainment, social, or exercise, resulting in a lower quality of life compared to healthy population(129). These patients often experience a notable decrease in their walking speed, approximately 60% of the norm for their age group. This reduced walking ability, characterized by slower walking speeds, has been linked to adverse clinical outcomes. Additionally, cardiac disease, a history of fractures, diminished leg strength, and compromised standing balance were all found to be independent factors contributing to slower walking speeds among ambulatory hemodialysis patients(130).

Chronic kidney disease with 6MWT

The 6-minute walk test (6MWT) holds extensive applicability within the field of Nephrology, finding utility across diverse studies encompassing various stages of the disease. Moreover, it serves as a valuable instrument for assessing functional capacity across different treatment modalities, such as hemodialysis, peritoneal dialysis, and kidney transplantation[131]. Kidney dysfunction in hemodialysis patients results in the accumulation of waste products, electrolyte imbalances, and fluid retention, leading to symptoms like fatigue, weakness, diminished ability to control posture and balance. This reduction in physical function extends to activities like walking[17].

In 2023, study of Andrade, et al[132], a group of 26 patients undergoing hemodialysis (HD) participated. The study employed both a cardiopulmonary exercise test (CPET) and a 6-minute walk test (6MWT) to evaluate their cardiorespiratory fitness. The CPET involved a cycle ergometry with incremental 5/10 watts load per minute to directly measure the peak oxygen consumption (VO2peak), while the 6MWT took place in a 30-meter corridor to indirectly estimate VO2peak. Notably, both tests were conducted on a midweek non-dialysis day. The results demonstrated that the direct mean VO2peak obtained through CPET was 15.91 ± 5.26 (ml/kg/min), while the indirect mean VO2peak obtained through 6MWT was 14.89 ± 4.21 (ml/kg/min). An important finding was the strong positive correlation between the VO2peak values from both tests ($r = 0.734$; $p < 0.001$). The 6-minute walk test (6MWT) proves to be a dependable method for approximating peak oxygen consumption (VO2peak) in patients undergoing hemodialysis (HD).

In a prospective study by George C, et al (2012)[133], researchers investigated the effects of a 6-month regular walking program on 40 predialysis patients categorized with GFR levels of G4-G5 (GFR below 30 ml/min/1.73 m^2). Among the participants, 20 engaged in the exercise program, while the other 20 continued with their usual physical activity for comparison. Over the course of the study, 18 out of 20 participants who completed the exercise regimen consistently experienced sustained improvements from the 1-month mark to the 6-month duration. These improvements encompassed enhanced exercise tolerance (requiring less effort for the same level of activity), weight loss, better cardiovascular reactivity, averted escalation of blood pressure medication, and advancements in both health-related quality of life and uremic symptom scores, as evaluated through questionnaires.

In 2019, study of Tran J. et al. found that individuals with CKD have shorter stride lengths compared to those without CKD[18].

In 2014, Study of Kono et al. assessed the 6-minute walking distance in 43 CKD patients undergoing hemodialysis and found that the average distance covered was 410±118.2 meters. Factors influencing the 6-minute walking distance in these patients included muscle strength, iron deficiency anemia, and pre-existing coronary artery disease[19].

In 2017, study of Garcia RSA, et al [134], shown that the average 6 minute walk distance of 102 patients with end-stage renal disease undergoing dialysis was 438.65 ± 121.64 meters. Moreover, Functional capacity evaluated by the 6-minute walk test was significantly associated with educational level, hemoglobin, peripheral muscle strength, and depression.

In 2020, Yuenyongchaiwat K, et al[20], conducted a study examining the impact of dialysis duration on cardio-respiratory dysfunction and breathlessness in 100 chronic renal failure patients, with a mean age of 51.54 ± 11.19 years. The study employed the 6-Minute Walk Test (6MWT) to assess functional capacity. The results showed that among the 100 patients, those with a duration of hemodialysis (HD) of less than 5 years (50 patients) had a mean 6MWD of 386.14 ± 122.29 meters, while those with a duration of HD greater than 5 years (50 patients) had a mean 6MWD of 359.94 ± 90.39 meters. Consequently, patients with a longer duration of hemodialysis exhibited a decrease in distance covered during the 6MWT.

2.3.3 Chronic obstructive pulmonary disease

The world health organization (WHO) reported that Chronic obstructive pulmonary disease (COPD) ranks as the third major global cause of mortality, resulting in 3.23 million deaths in 2019. A significant proportion of COPD-related deaths (nearly 90%) among individuals under 70 years occur in low to middle-income countries (LMIC). On a global scale, COPD stands as the seventh principal contributor to poor health, quantified by disability-adjusted life years. While tobacco smoking is the primary factor behind over 70% of COPD cases in high-income nations, in LMIC, around 30-40% of cases can be attributed to smoking, with household air pollution emerging as a substantial risk factor.[135]

Chronic obstructive pulmonary disease (COPD) is an umbrella term for emphysema and chronic bronchitis. Emphysema primarily involves damage to the alveoli within the lungs, whereas chronic bronchitis centers around inflammation and irritation of the airways that connect to the lungs. COPD is a prevalent lung condition characterized by airflow limitations caused by airway narrowing and obstruction, loss of elastic recoil or both, These are resulting in lung damage and phlegm accumulation, leading to symptoms like cough, breathing challenges, wheezing, dyspnea and fatigue. These symptoms are contributing factors to physical performance. Smoking and air pollution are major triggers of COPD, increasing the risk of associated health issues These includes lung infections, lung cancer, heart problems, weak muscles and brittle bones, depression and anxiety. Although COPD isn't curable, symptom management and improvement are possible through smoking cessation, reduced exposure to air pollution, vaccination for infection prevention, medications, oxygen therapy, and pulmonary rehabilitation.

The progression of chronic obstructive pulmonary disease (COPD) and the decline in lung function lead to increased alveolar hypoxia, which elevates the risk of hypoxemia. The primary contributor to hypoxemia is a ventilation/perfusion mismatch resulting from the ongoing obstruction of airways and the destruction of the pulmonary capillary bed due to emphysema, Patients will be more fatigue and dyspnea during activity and that lead to reduced quality of life, decreased lung function, decreased functional exercise capacity, decrease physical activity level and skeletal muscle weakness [(136)].

In 2011, study of Kapella MC, et al[(137)], studied in 88 COPD patients followed annually for 3 years, found significant declined in functional performance ($P = 0.001$), spirometry ($P<0.0001$), diffusion capacity ($P<.0001$) and muscle strength ($P<0.0001$). The declined of functional performance indicates that increasing sedentary lifestyle, increasing risk of cardiovascular disease and development of frailty.

Chronic obstructive pulmonary disease with 6MWT

Patients with chronic obstructive pulmonary disease (COPD) have direct lung-related pathologies that airflow limitations and reduce respiratory efficiency. This leading to symptoms such as dyspnea, fatigue, and reduced exercise tolerance during various activities. The 6 minute walk test is increasingly use for complement the evaluation and assess the functional status of patients with COPD.[(138)]

In 2004, The study of Pinto-Plata VM, et al[139], they measured 6MWD, age, body mass index, FEV1, and comorbidities in 198 patients with severe COPD and followed for 2 yrs, the results showed that among individuals with COPD, those who did not survive (42%) exhibited a more significant decline in the 6-minute walk distance (6MWD) compared to survivors (−40 versus −22 m per year). Interestingly, both groups showed a similar decline in forced expiratory volume in 1 second (FEV1) (118 versus 102 mL per year). Importantly, the 6MWD emerged as an independent predictor of survival even after adjusting for age, body mass index, FEV1, and comorbidities. In severe chronic obstructive pulmonary disease, the 6-min walk distance predicts mortality better than other traditional markers of disease severity.

In 2017, Liu WY, et al[21], compare gait patterns during the GRAIL-based 6-minute walk test (6MWT) while performing a 6-minute walking test on treadmill in a laboratory setting between COPD patients and healthy elderly individuals. Results showed that COPD patients exhibited significant differences in gait characteristics, including increased temporal gait features, reduced stride and step lengths, variability of stride length consistently rose after walking speed had been correctly adjusted, highlighting potential implications for rehabilitation strategies. The COPD patients covered an average distance of 493.5±79.7 meters, while the healthy individuals walked an average distance of 689.3±64.3 meters.

In 2021, Charususin N, et al[140], conducted a study investigating the beneficial effects of water-based exercise training on exercise capacity in COPD patients. Exercise capacity was assessed using the 6-Minute Walk Test (6MWT). The study involved seven COPD patients in the water-based exercise group, with a mean age of 66 ± 8.1 years. Baseline measurements indicated a 6-Minute Walk Distance (6MWD) of 335.0 ± 107.2 meters. After the 8-week training program, the 6MWD improved to 360.6 ± 103.2 meters.

2.3.4 Stroke patient

World stroke organization (WSO) reported that between 1990 and 2019, the incidence of strokes has risen by 70%, resulting in a 43% increase in stroke-related fatalities, a 102% increase in stroke prevalence, and a 143% rise in Disability Adjusted Life Years (DALY). the majority of the worldwide stroke burden, accounting for 86%

of stroke-related deaths and 89% of Disability Adjusted Life Years (DALYs), is occur in lower and lower-middle-income countries.[141]

Stroke represents a significant healthcare challenge in Thailand, emerging as the primary cause of both mortality and long-term disability. Currently, there is a comprehensive study underway to examine the incidence of stroke in a substantial cohort. The estimated prevalence of stroke among adults aged 45 and above is 1.88%. Stroke tends to affect men more frequently, with the average age of onset being 65 years. In the Thai population, ischemic stroke remains the predominant type, accounting for the majority of stroke cases and showing a higher proportion than hemorrhagic stroke. Major risk factors for stroke in this population include hypertension, diabetes, dyslipidemia, metabolic syndrome, and atrial fibrillation. Patients with cerebrovascular disease have brain-related pathologies that result in muscle weakness, requiring increased energy expenditure for activities. This leads to faster onset of fatigue, poor cardiovascular endurance and reduced activity levels[142].

In a study by Chang HC, et al, an Inertial Measurement System was used to analyze the gait of patients with cerebrovascular disease and Parkinson's disease. The results showed that patients with cerebrovascular disease had shorter stride length, lower stride frequency, slower stride velocity, lower stride cadence, longer stance time, longer swing time, and needed more time to walk compare with the healthy group when walking at self-selected speeds on 10 meter walk test[22].

Stroke patient with 6MWT

The 6-Minute Walk Test (6MWT) has become a commonly employed tool in stroke research. The distances covered by stroke patients during this test serve as a clear indicator of their significantly impaired walking abilities.

In 2002, study of Pohl PS, et al[143], explored the impact of stroke-related physical impairments on the performance of the 6-Minute Walk Test among 72 post-stroke patients. The mean age of these participants was 72.1 ± 10.2 years, and the average time elapsed since their stroke was 73.3 ± 26.8 days. The study revealed that the average distance covered during the 6-minute walk test was 215.8 ± 91.6 meters. Furthermore, it was observed that the performance of stroke survivors in the 6-minute walk test is notably influenced by motor impairments in the affected lower limb and issues related to balance.

In 2009, Sibley KM, et al[23], investigated gait dysfunction and fatigue in post-stroke individuals during the 6-Minute Walk Test (6MWT). They studied 24 community-dwelling individuals who had been independently ambulating for more than three months after their stroke. The findings revealed that the mean total distance walked was 283.3 ± 136.8 meters. Notably, participants walked 6.4 ± 18.1 meters less in the second two minutes compared to the initial two minutes, with a further 5.4 ± 17.1 meters less in the final two minutes. This indicated a significant decline in walking distance during the final two minutes compared to the first two minutes, suggesting a notable change in gait speed over the course of the 6MWT. Consequently, these findings suggest that post-stroke walking performance declines due to both cardiorespiratory and muscular fatigue mechanisms.

In 2017, study of Fulk GD, et al[24], involving 441 post-stroke patients revealed valuable insights. The average 6-Minute Walk Distance (6MWD) for all participants was 201.0 ± 106.1 meters. Among these individuals, 190 were categorized as household ambulators, taking 100–2499 steps per day, covering an average distance of 135.1 ± 85.4 meters. Additionally, 134 participants, classified as the most limited community ambulators with 2500–4999 steps per day, achieved an average distance of 225.2 ± 94.3 meters. Furthermore, 63 individuals, the least limited community ambulators with 5000–7499 steps per day, attained an average distance of 251.0 ± 79.6 meters. 54 participants considered unlimited community ambulators with ≥7500 steps per day, achieved an average distance of 312.2 ± 70 meters. Moreover, walking endurance, as assessed through the 6 MWT, emerged as the most influential single predictor of community-based walking activity. 6-minute walk distance of at least 205 meters distinguished between individuals who primarily walked at home and those engaged in community ambulation, while a 6 minute walk distance of at least 288 meters differentiated between individuals with limited versus unrestricted community ambulation.

In a study of Pramodhyakul N. et al. involved 174 patients with cerebrovascular disease, including 137 with ischemic stroke and 37 with hemorrhagic stroke. These patients had an average 6-minute walking distance of 126.19±92.33 meters. However, patients with cerebrovascular disease who achieved a minimum 6-minute walking distance of 193.50±50 meters were capable of walking in the community[25].

2.4 Walking test application

Mobile application is a software application designed to run on mobile devices such as smartphones and tablet computers. It is a result of recent technological innovations. Mobile applications have appeared because of the convergence of media, information technology, Internet and advanced technologies. In addition, for many years, mobile telecommunications have been under investigation by mobile device manufactures, mobile service providers, application developers, and many researchers in the sphere of information technology (IT) and information systems (IS) [144].

Application programming interfaces (APIs)[145]

An API is a particular set of rules and specifications that a software program follows in order to access and make use of the services and resources provided by another software program or hardware that also implements that API. In essence, APIs allow software programs and hardware, or different software programs, to communicate with each other. In the smart mobile device environment, APIs are important as they allow app developers to integrate "cloud" web services directly in their apps. This allows app developers to offload computationally challenging or data intensive tasks to cloud computers, in order not to impact the storage, performance or battery of a smart mobile device. Due to the technical limitations of smart mobile devices compared to PCs, cloud services and related APIs have a particularly important role in the smart mobile environment.

Android operating system[146]

Based on the Linux kernel, Google developed an operating system for mobiles. They called it Android. The Android operating system is primarily designed for smartphone devices which implement a touch screen input interface. Not only that, it has also been developed for many devices such as smart watches (Android Wear), tablet computers and cars (Android Auto). Android is known for its OS touch inputs that correspond to real-world actions such as swiping, tapping, pinching and reverse pinching. Among several mobile operating systems, Android is the most popular operating system, which is competing with IOS for Apple devices and Windows Phones.[147] A developer survey conducted in 2017 found that 64.8% of mobile developers use Android as their preferred platform.[147] Android phones typically come with several built-in applications and also support third-party programs. Developers can create programs for Android using the free Android software developer kit (SDK). Android programs are written in Java and run through a Java virtual machine JVM that is optimized for mobile devices. The "Dalvik" JVM was used through Android 4.4 and was replaced by Android Runtime or "ART" in Android 5.0. Users can download and install Android apps from Google Play and other locations.

6MWT application

A 6MWT smartphone application is designed for conducting walking tests to measure the maximum distance walked in 6 minutes. Smartphones also come equipped with various additional sensors, including gyroscopes, GPS, and accelerometers, which can be enhance the accuracy of 6MWT results. These walking test applications, along with the utilization of supplementary sensors, have been recognized as valuable assessment tools for walking tests in healthcare and medical settings. They have also become commercial products available in many countries, such as the USA, but are not yet found in Thailand.[148]

In 2014, Juen J, et al[149], developed a smartphone application called "GaitTrack software", This application monitors walking patterns by using a accelerometers embedded in smartphones to record spatiotemporal motion, eliminating the need for external sensors. To evaluate the accuracy of the GaitTrack software on smartphones in comparison to medical pedometers for step counting, a pilot study involving 30 patients with chronic lung conditions was conducted in Chicago, USA. The results revealed that the GaitTrack software on smartphones demonstrated a remarkably low error rate of 0.94%. In contrast, the Omron pedometer exhibited a higher error rate of 5.20%, while the ActiGraph accelerometer had an even higher error rate of 11.08%. These findings emphasize that phone sensors, when appropriately employed and processed during walk tests, are not only comparable to but can even surpass the accuracy of commercial medical pedometers in reliably counting steps. This underscores the potential of smartphones as effective tools for health monitoring and activity tracking in various healthcare and wellness applications.

In 2018, study by Ata R, et al(150), developed the VascTrac iPhone app for monitoring peripheral artery disease via a digital 6-Minute Walk Test (6MWT). They evaluated the accuracy of iPhone's built-in distance and step-counting algorithms during the 6MWT using 114 participants with peripheral artery disease. The results showed that the iPhone CMPedometer step algorithm underestimated steps by approximately 7.2% with a mean percent difference of 5.7% compared to the ActiGraph GT9X Activity Monitor. On the other hand, the iPhone CMPedometer distance algorithm overestimated distance by around 43% due to an overestimation in stride length.

In 2020, study by Salvi D, et al(151), a mobile app was developed for patients to self-administer the 6-Minute Walk Test (6MWT), augmented by pulse oximeters. Two algorithms, one using GPS for outdoors and another using inertial sensors for indoors, estimated walk distances. Results showed small differences from reference values, below clinical significance. A discussion group with patients and clinicians confirmed the app's usability, with patients expressing interest in long-term use. This technology has potential to improve 6MWT convenience and accuracy in various settings.

In 2021, study by Mak J, et al(152), the reliability of a home-based 6-Minute Walk Test (6MWT) using smartphones was assessed in patients with cardiovascular disease. They provided patients with iPhones and Apple Watches loaded with a research app and conducted both supervised in-clinic and at-home 6MWTs over six months. The study found high reliability (0.99) between in-clinic measurements and slightly lower reliability (0.74) for at-home measurements. These findings suggest that while in-clinic measurements were consistent, further refinement may be needed for at-home assessments. This research contributes to the exploration of smartphone-based assessments in healthcare for cardiovascular patients, highlighting potential benefits and areas for improvement.

2.5 Related research

In 2020, study by Salvi D, et al[151], they developed a mobile phone app (Figure 2.14) which enables patients to perform the 6MWT on their own, at their convenience or in the hospital setting, while augmenting the information collected during the test using off-the-shelf portable pulse oximeters. The study developed 2 algorithms to compute the distance walked during a 6MWT using sensors embedded in a mobile phone. One algorithm makes use of the global positioning system to track the location of the phone when outdoors and hence computes the distance travelled. The other algorithm is meant to be used indoors and exploits the inertial sensors built into the phone to detect U-turns when patients walk back and forth along a corridor of fixed length. There was included two algorithms in a mobile phone app, integrated with wireless pulse oximeters and a back-end server. Salvi D. et al. performed Bland-Altman analysis of the difference between the distances estimated by the phone and by a reference trundle wheel on 49 indoor tests and 30 outdoor tests, with 11 different mobile phones (both Apple iOS and Google Android operating systems). Also assessed usability aspects related to the app in a discussion group with patients and clinicians using a technology acceptance model to guide discussion. The mean difference between the mobile phone-estimated distances and the reference values was −2.013 m ±7.84 m for the indoor algorithm and −0.80 m ± 18.56 m for the outdoor algorithm. The absolute maximum difference was, in both cases, below the clinically significant threshold. A total of 2 pulmonary hypertension patients, 1 cardiologist, 2 physiologists, and 1 nurse took part in the discussion group, where issues arising from the use of the 6MWT in hospital were identified. The app was demonstrated to be usable, and the 2 patients were keen to use it in the long term.

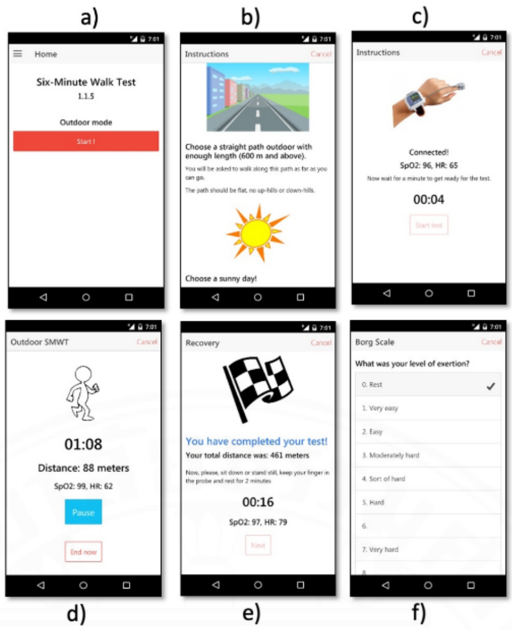


Figure 2.15 Screenshots of mobile phone app. (a) Home page, (b) instructions about how to perform the test, (c) connection to the pulse oximeter and baseline measurements at rest, (d) estimation of the distance during walk, (e) total distance estimation and recovery at rest, (f) Borg scale questionnaire[151]

In 2018, Ata R, et al[150], developed the VascTrac iPhone app as a platform for monitoring peripheral artery disease using a digital 6MWT. There was evaluating the accuracy of the built-in iPhone distance and step-counting algorithms during 6MWTs. 114 participants with peripheral artery disease performed a supervised 6MWT using the VascTrac app (Figure 2.15) while simultaneously wearing an ActiGraph GT9X Activity Monitor. Steps and distance-walked during the 6MWT were manually measured and used to assess the bias in the iPhone CMPedometer algorithms. The iPhone CMPedometer step algorithm underestimated steps with a bias of −7.2% ± 13.8% and had a mean percent difference with the Actigraph (Actigraph-iPhone) of 5.7% ± 20.5%. The iPhone CMPedometer distance algorithm overestimated distance with a bias of 43% ± 42% due to overestimation in stride length. Theirs correction factor improved distance estimation to 8% ± 32%. The Ankle-Brachial Index (ABI) correlated poorly with steps (R = 0.365) and distance (R = 0.413).

Figure 2.16 Consenting patients performed a 6MWT along a pre-measured 100-foot course with an iPhone in one hand and an ActiGraph GT9X attached at the waistband on the right hip(150)

In 2021, Mak J, et al(152), Assessed the reliability and repeatability of a home-based 6MWT compared to in-clinic 6MWTs in patients with cardiovascular disease. One hundred and ten patients scheduled for cardiac or vascular surgery were enrolled during a study period from June 2018 to December 2019 at the Palo Alto VA Hospital. Patients were provided with an Apple iPhone 7 and Apple Watch Series 3 loaded with the VascTrac research study application (Figure 2.16) and performed a supervised in-clinic 6MWT during enrolment, at 2 weeks, 1, 3, and 6 months post-operatively. Patients also received notifications to perform at-home smartphone-based 6MWTs once a week for a duration of 6 months. Test–retest reliability of in-clinic measurements and at-home measurements was assessed with an industry standard Cronbach’s alpha reliability test. Test–retest reliability for in-clinic ground truth 6MWT steps vs. in-clinic iPhone 6MWT steps was 0.99, showing high reliability between the two tested measurements. When comparing for in-clinic ground truth 6MWT steps vs. neighboring at-home iPhone 6MWT steps, reliability was 0.74.

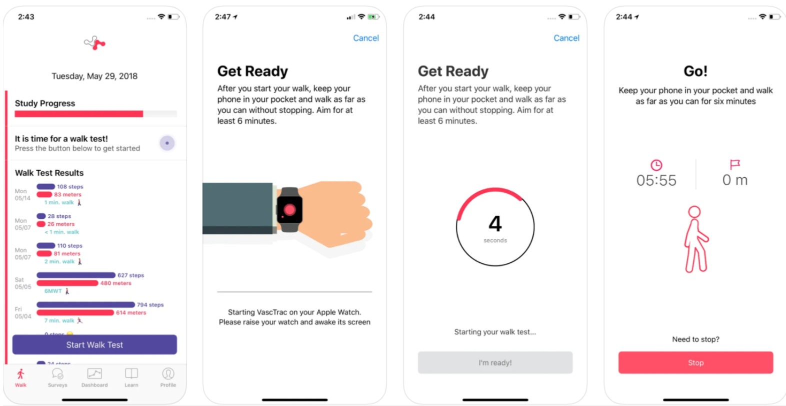


Figure 2.17 VascTrac research application(152)

These studies were conducted to investigate the accuracy of distance or step count between ground truth and application data. Accuracy is defined as how close the measured value is to the true value. And the amount of inaccuracy is the measurement error. Generally, accuracy is reported quantitatively using relative error.

$$\text{Accuracy} = 100 - \%\ \text{Error}$$

$$\text{Relative Error} = \frac{\text{measured value} - \text{expected value}}{\text{expected value}}$$

Ata R. et al[150]. used Bland-Altman (BA) plots evaluate the variation between the two measurement methods. Straightforward, yet effective, using the BA plot to compare two quantitative methods and gauge any possible bias between the two methods is rather effortless[153]. It also estimates an agreement interval within which 95% of the differences between two measurement techniques fall. Typically, BA plots use the magnitude of the error on the y- axis, but in instances where the magnitude of the error varies across measurements, it is more than adequate to use the percent error [154]. To quantify the error in iPhone measured steps and distance compared to the reference standard, the percent error for each participant was calculated using the following formula: % Error = (Measurement – reference) / reference x 100%

Salvi D. et al[151]. calculated accuracy by using the mean, median, and standard deviation of the difference between the reference values and the outputs from the algorithm; the mean, standard deviation, minimum and maximum of the absolute difference; and the Pearson correlation between estimated values and the reference values. In addition, they generated Bland-Altman plots to showed limits of agreement and the difference(bias) between the estimated distance walked and the absolute distance.

Mak J. et al[152]. was able to produce data for both the in-clinic ground truth and in-clinic phone 6MWTs as the mean ± standard deviation (SD). Futhermore, when calculating the mean error between the two methods, they used the following equation: % Error = (Clinic truth - Clinic phone) / Clinic truth

Some other studies used the Intraclass Correlation Coefficients (ICC) to finding the consistency of different methods or instruments such as reliability between new device and goal standard. Reliability values fall within a range from 0 to 1, with values approaching 1 indicating stronger reliability. Traditionally, methods like the Pearson correlation coefficient, paired t-test, and Bland-Altman plot have been employed to assess reliability. However, it's important to note that the paired t-test and Bland-Altman plot are primarily designed for analyzing agreement, while the Pearson correlation coefficient solely measures correlation. Ideally, a reliable measure should encompass both the degree of correlation and the level of agreement between measurements. The Intraclass Correlation Coefficient (ICC) serves as an example of such an index(155).

Additionally, Intrarater reliability (ICC 3,1 or Two-way mixed effects model) pertains to the consistency of data measured by a single rater across two or more measurement trials. The 2-way mixed-effects model will be used, if the selected raters are the only raters of interest. The results of this model only represent the reliability of the specific raters involved in the reliability experiment and cannot be generalized to other raters even if those raters have similar characteristics with those involved in the initial reliability experiment. Consequently, the 2-way mixed-effects model is less frequently applied in interrater reliability analyses. ICC values below 0.5 indicate poor reliability, between 0.5 - 0.75 indicate moderate reliability, between 0.75 - 0.90 indicate good reliability and exceeding 0.90 indicate excellent reliability(155).

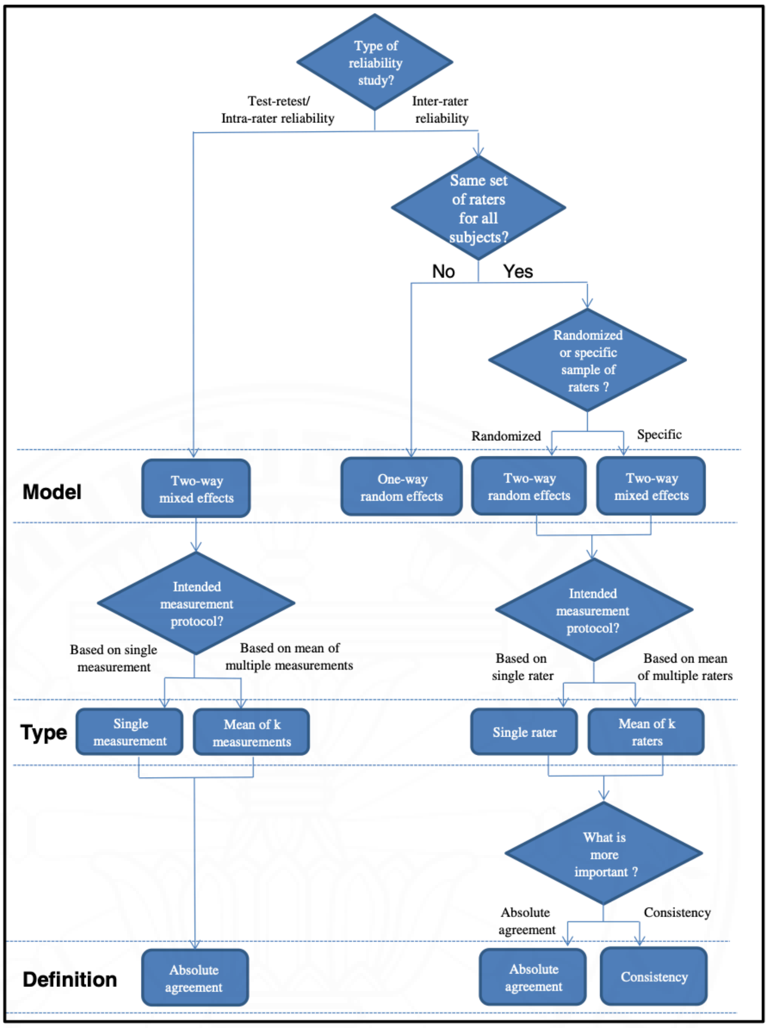


Figure 2.18 A flowchart showing the selection process of the ICC form based on the experimental design of a reliability study[155]

However, To establish generalizability for the medical device, it is essential to take into account both the Minimal Clinically Important Difference (MCID) and maximum permissible error (MPE). Medical devices or instruments typically have a MPE set at 5%.[156]. The systematic review investigated the MCID or the change in the 6-Minute Walk Test (6MWT) distance for individuals with various health conditions, including chronic obstructive pulmonary disease, lung cancer, coronary artery disease, diffuse parenchymal lung disease, non–cystic fibrosis bronchiectasis, and adults with fear of falling. The MCIDs, associated with an area under the receiver operating characteristic curve (ROC curve) of at least 0.70, ranged from 14.0 to 30.5 meters[157].

CHAPTER 3
RESEARCH METHODOLOGY

This chapter focused on the research methodology that used for the development of the walking test application and explored the accuracy between the mobile application with the smart band device prototype and a standard test in coronary heart disease, chronic kidney disease, chronic obstructive pulmonary disease and stroke patients

3.1 Study 1: Developing the mobile application and the smart band device prototype

3.1.1 Mobile application

In a previous study, the first screen of the 6-minute walk test (6MWT) mobile application presented a screen with personal information to fill out and only registered two vital signs: blood pressure and pulse. And after the test was concluded, there was no vital signs follow up for a comparison. But in a standard 6-minute walk test, blood oxygen saturation (SpO2) and Borg's scale were included in vital sign measurement. The participant results only showed just the total distance walked when the test was completed and then the data was saved in excel program (Figure 3.1)

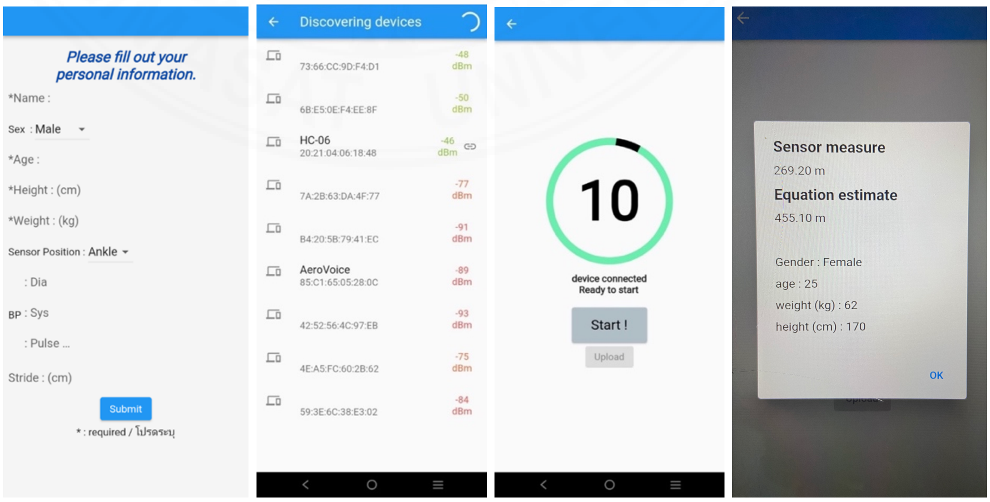


Figure 3.1 The mobile application 6MWT screens from previous study

The 6MWT application in this study would be more comprehensive, measuring and registering the vital signs before and after the test. All participant's information would be saved and could be accessed at any time. And since it's all saved and on record, the next time the participant is tested, there would be no need to re-enter any information.

The application designs were made using Microsoft PowerPoint (Figure 3.2) and the figure screens illustrate the user interface. Displayed in order were the following screens: main menu, participant information fill out, vital sign measurement, device connection, 6MWT start and countdown, test completion, participant information record, patient report, and contraindications and precautions.

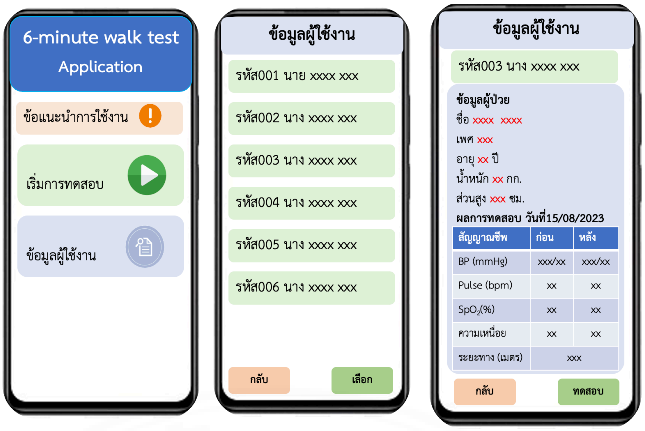


Figure 3.2 Design of application screens made from Microsoft PowerPoint

3.1.2 Pilot study on changing the position of smart band device

In the 2022 study conducted by Mekritthikrai N. et al., the dominant ankle of each participant served as the attachment point for a smart band device used to measure the distance in the 6-minute walk test. A pilot study was conducted to compare the distances recorded by the smart band device when attached to the ankle and wrist during a predetermined 60-meter walk. The results indicated that there were no statistically significant differences in the distances measured by the smart band device when attached at the ankle compared to the predetermined distance (p=0.29) or when attached at the wrist compared to the predetermined distance (p=0.658).

Consequently, based on the pilot study findings and expert suggestions, this study would utilize the smart band device attached to the wrist for measuring distance during the 6MWT. This approach was considered more comfortable for users. Furthermore, in future research, the smart band device would also be used to develop a pulse oximeter for measuring blood oxygen saturation and pulse rate.

However, this study conducted a pilot study to explore the correlation between the distance measured by the smart band device when attached to the ankle and when attached to the wrist in a small group of healthy people.

We conducted a pilot study involving a small number of stroke patients. The methodology for this group differs from that used for other diseases; specifically, we attached the smart band device to the non-affected hand, whereas in other conditions, it was attached to the dominant hand. Given that this condition was strongly associated with muscle deficits, the postural balance or arm swing during the 6-minute walk test

(6MWT) may affect the data collected by the 3-axis accelerometer in the smart band device. Therefore, our objective was to ensure that the smart band device prototype, along with the mobile application, could be effectively used in this patient group.

3.2 Study 2: The study will be exploring the accuracy between the mobile application with the smart band device prototype and the standard test

3.2.1 Research design

This study was a cross sectional study, to explored the accuracy of walking distance between the mobile application with smart band device prototype and standard 6-minute walk test (6MWT) in the 4 patient groups, which consisted of: coronary heart disease, chronic kidney disease, chronic obstruction pulmonary disease and stroke patients. The assessment of the 6MWT for each participant were done in 1 visit. Participants were required to wear the smart band device prototype on the wrist of their dominant hand, or if from the stroke group, on the wrist of their non-affected hand, then be asked to complete the conventional 6MWT.

3.2.2 Sample size

This study was an exploring the accuracy of walking distance between the mobile application smart band device prototype and standard 6-minute walk test. The minimum sample size of participants is 25 in order to properly assess the medical application for obscure diseases and health research.(158, 159) This study conducted 4 groups of patients; i.e. coronary heart disease, chronic kidney disease, chronic obstructive pulmonary disease and stroke patients. Consequently, there were 25 participants for each group and 100 participants in total.

3.2.3 Population and Samples

Population: Coronary heart disease, Chronic kidney disease, Chronic obstructive pulmonary disease, and Stroke patients

Samples: 25 participants per group

3.2.3.1 Inclusion criteria

- Coronary artery disease : CAD (25 participants)
  1) Male or female, age between 40-80 years old

2) Has been diagnosed with CAD by a doctor or patients who diagnosed to submit for coronary artery bypass graphing
3) Based on NYHA classifications, has been diagnosed between class I to III[160]
4) Has never undergone heart surgery
5) Able to communicate, understand and follow commands in Thai
6) Able to walk independently without walking aids
7) Heart rate between 60-100 bpm at rest
8) Normal BMI (18.5 – 22.90 kg/m^2)
9) Has received a Montreal Cognitive Assessment (MoCA) score equal or greater than 25/30

- Chronic kidney disease : CKD
  1) Male or female, age between 40-80 years old
  2) Has been diagnosed with CKD by a doctor or received hemodialysis/peritoneal dialysis for at least 6 months
  3) Able to communicate, understand and follow commands in Thai
  4) Able to walk independently without walking aids
  5) Normal BMI (18.5 – 22.90 kg/m^2)
  6) Has received a Montreal Cognitive Assessment (MoCA) score equal or greater than 25/30
- Chronic Obstructive Pulmonary Disease : COPD
  1) Male or female, age between 40-80 years old
  2) Has been diagnosed with COPD by a doctor
  3) Able to communicate, understand and follow commands in Thai
  4) Able to walk independently without walking aids
  5) Normal BMI (18.5 – 22.90 kg/m^2)
  6) Has received a Montreal Cognitive Assessment (MoCA) score equal or greater than 25/30
- Chronic stroke
  1) Male or female, age between 40-80 years old
  2) Has been diagnosed with chronic stroke by a neurologist for at least 6 months

3) No underlying surgery craniotomy
4) Able to communicate, understand and follow commands in Thai
5) Able to walk independently without walking aids
6) Normal BMI (18.5 – 22.90 kg/m^2)
7) Has received a Montreal Cognitive Assessment (MoCA) score equal or greater than 25/30

3.2.3.2 Exclusion criteria

1) High blood pressure greater than 180/100 mmHg at rest.

2) Heart rate more than 120 bpm at rest

3) SpO2 less than 90% at rest

4) Borg scale greater than 13/20 at rest

5) History of unstable angina or COPD with acute exacerbation prior to the test for 72 hours.

3.2.4 Methods

3.2.4.1 Participants

The participants included 25 patients with coronary heart disease or those who have undergone coronary artery bypass grafting, 25 patients with chronic kidney disease receiving hemodialysis, 25 patients with chronic obstructive pulmonary disease, and 25 patients with stroke. The total number of participants was 100 people.

We recruited coronary heart disease patients who have undergone coronary artery bypass grafting from Thammasat university hospital and test 6MWT by using 30-meters walkway in front of the In patient department, recruited chronic kidney disease patients who received hemodialysis at Hemodialysis Center of Thammasat University Hospital and test the 6MWT by using 15-meters walkway inside the department, recruited chronic obstructive pulmonary disease patients from Outpatient Department of Thammasat University Hospital and test the 6MWT by using 30-meters walkway at Physical Therapy Center of the Faculty of Allied Health Sciences, recruited stroke patients from Physical Therapy Center of the Faculty of Allied Health Sciences and Physical Therapy Department of Thammasat University Hospital and test the 6MWT by using 30-meters walkway at Physical Therapy Center of the Faculty of Allied Health Sciences.

The participants were required to perform conventional 6-minute walk test while wearing smart band device prototype to record walking distance. The distance from standard test and mobile application with smart band device prototype were recorded. Before and after the 6-minute walk test, Participants had their vital signs screened including blood pressure, blood oxygen saturation, pulse rate and exertion perceived rating measured by the standard equipments.

3.2.4.2 Protocol

For each patient who persists 30 minutes in 1 session, the participants were requested to complete a general health questionnaire, such as age, weight, height and then received a cognitive and memory assessments. After that, the participants were required to wear the smart band device prototype on the wrist of their dominant hand, or if from the stroke group, on the wrist of their non-affected hand, to record the walking distance and were required to perform a conventional 6-minute walk test which is considered a standard test. Before and after performing the 6-minute walk test, the participants had their vital signs screened such as blood oxygen saturation, pulse rate, blood pressure, and an exertion perceived rating by screened by using standard equipments.

1) Questionnaires

The participants were requested to complete a general health questionnaire, such as age, weight, height and then receive cognitive and memory assessments based on detection by using The Montreal Cognitive Assessment (MoCA). This session was completed within 15 minutes.

2) 6-minute walk test[6]

Participants performed the 6-minute walk test at Thammasat hospital and at the Physiotherapy and Hydrotherapy Unit, Faculty of Allied Health Sciences, and Thammasat University. All the testing was done indoors, along a extended, flat, straight, enclosed corridor with a hard surface, where participants were required to walk at least 30 meters.

Participants were required to wear the smart band device prototype on the wrist of their dominant hand, or if from the stroke group, on the wrist of their non-affected hand.

Before testing, the participants had their vital signs measured: blood oxygen saturation and pulse rate by a handheld pulse oximeter, blood pressure by a digital blood pressure monitor, and exertion perceived rating based on the Borg scale.

Participants need to listen to the instructions for the 6MWT, as following:

“The object of this test is to walk as far as possible in 6 minutes. You will walk back and forth in this hallway. Six minutes is a long time to walk, so you will be exerting yourself. You will probably find yourself out of breath or become exhausted. You are permitted to slow down, to stop, and to rest as necessary. You may lean against the wall while resting, but resume walking as soon as you are able. You will be walking back and forth around the cones. You should pivot briskly around the cones and continue back the other way without hesitation. Now I'm going to provide you an example. Please watch the way I turn without hesitation.”[6, 83]

In this case, the researcher will demonstrate by walking one lap and then ask participants to perform then test when they are ready, as following:

“Are you ready to do that? I am going to use this counter to keep track of the number of laps you complete. I will click it each time you turn around at this starting line. Remember that the object is to walk as far as possible in 6 minutes, but don't run or jog. Start now, or whenever you are ready.”

To start the mobile application, the researcher will press the "Start" button to initiate the 6MWT through the application. A notification from the smartphone application will be launched, prompting participants for every minute of progress:

a “You are doing well. You have 5 minutes to go.”

b. “Keep up the good work. You have 4 minutes to go.”

c. “You are doing well. You are halfway done.”

d. “Keep up the good work. You have only 2 minutes left.”

e. “You are doing well. You have only 1 minute to go.”

f. “15 more seconds, it'll be time to stop……and STOP, the test has been completed.”

After testing had finished, the participants again had their vital signs measured. The researcher recorded all vital signs measurements. The walking distance measured by the mobile application with smart band device prototype were shown on mobile screen. The researcher recorded the measurements from the walking distance with the mobile application, as well as from the conventional 6MWT.

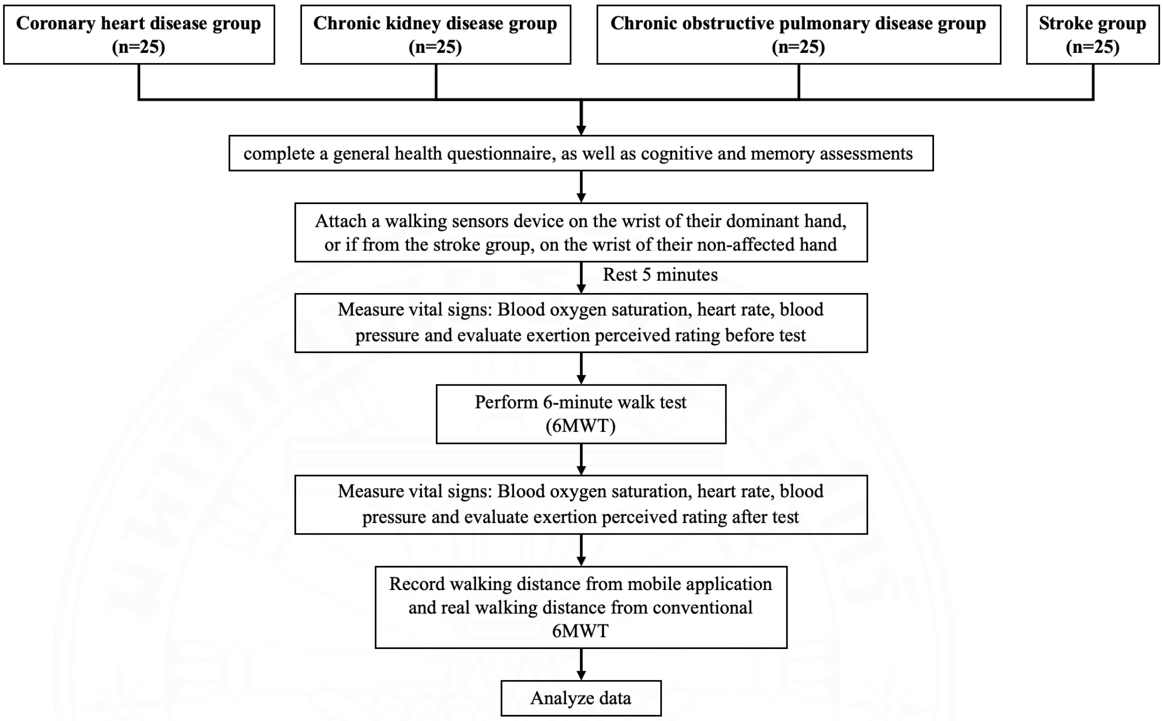


Figure 3.3 Flow chart of study methods

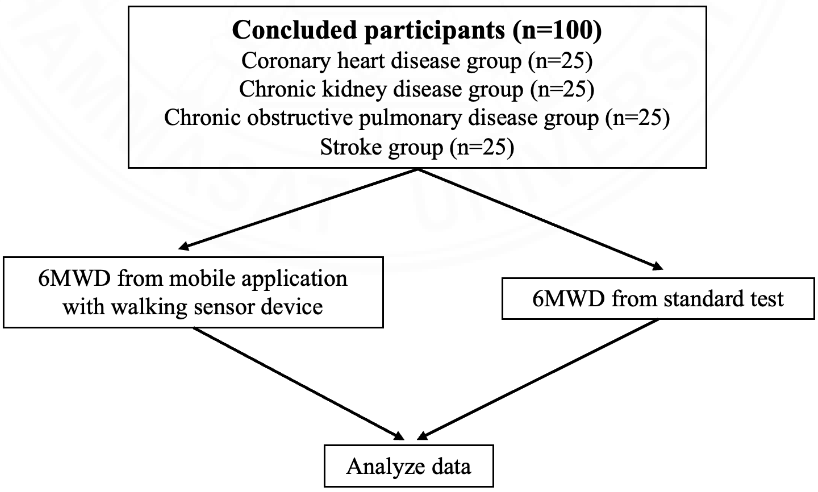


Figure 3.4 Flow chart of study protocol

3.2.5 Data analysis

Statistical analyses was performed with the Statistical Package for Social Sciences (SPSS) version 24. The demographics and clinical characteristics of individuals was analyzed using descriptive analysis. Data was presented as mean, standard deviation (mean ± SD). Data was verified for normality of distribution using the Shapiro-wilk test. Comparison of mean ± SD of distance measurements between mobile application with smart band device prototype and standard 6-minute walk test. Significant difference between the variables were determined using the paired T-test. Pearson correlation coefficient was used to find the association between 2 methods within patient for each group. Intraclass Correlation Coefficients (ICCs) model 3,1 (2-way mixed-effect model, consistency, single measurement) was used for intrarater reliability. The level of significance was set at p-value less than 0.05.

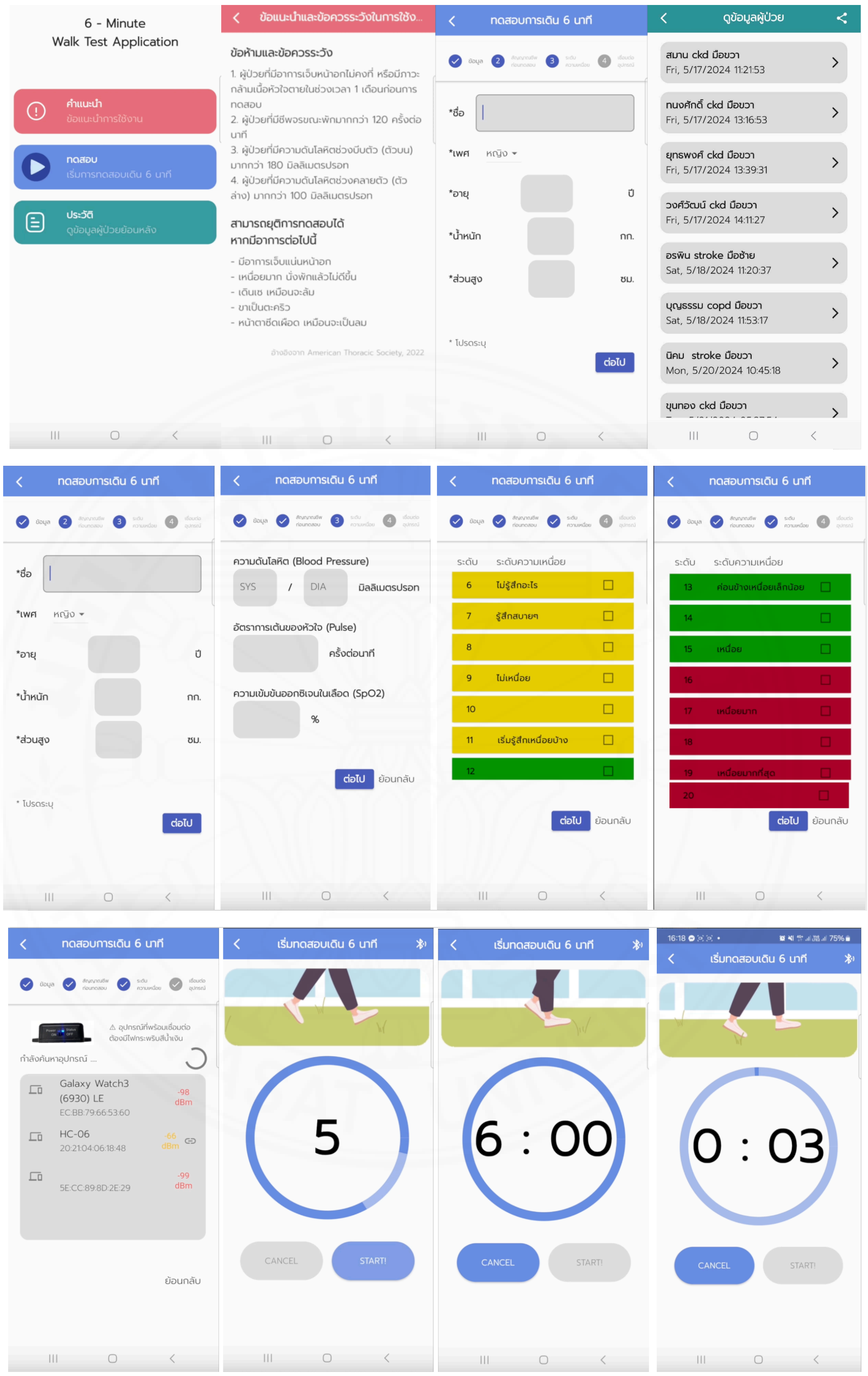
CHAPTER 4
RESULTS AND DISCUSSION

This chapter describes the results and discussion from the study: development of application and accuracy in participants.

4.1 Study 1: Developing the mobile application and the smart band device prototype

4.1.1 Mobile application

In this study we developed a more comprehensive 6MWT application. Upon opening the application, the main screen will have these three options to choose from: contraindications and precautions, testing, results history. While the contraindications and precautions section has only one page, the testing section has numerous steps. There are 3 different sections among these steps, starting with the first section (before testing): the initial filling out of demographics, the vital signs testing, the Borg scale testing and then finally, the smart band device connection page. The second section is the testing page, prompting when to start and stop the 6MWT. There were notifications to prompt participants at each minute of progress. After completion of the test, we move to the third and final section: the 2nd round of the vital signs and Borg scale testing. In the results history section, for each completed test, you will see the participant's name, demographics, vital sign before and after test, date and time, as well as the step count, distance covered in each minute and total distance walked.


6 - Minute
Walk Test Application
คำแนะนำ
ทดสอบ
ประวัติ
ข้อห้ามและข้อควรระวัง
สามารถยุติการทดสอบได้
หากมีอาการต่อไปนี้
ทดสอบการเดิน 6 นาที
ดูข้อมูลผู้ป่วย
*ชื่อ
*เพศ
*อายุ
*น้ำหนัก
*ส่วนสูง
ต่อไป
ย้อนกลับ
ความดันโลหิต (Blood Pressure)
SYS
DIA
มิลลิเมตรปรอท
อัตราการเต้นของหัวใจ (Pulse)
ครั้งต่อนาที
ความเข้มข้นออกซิเจนในเลือด (SpO2)
%
ระดับ
ระดับความเหนื่อย
Galaxy Watch3
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5
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CANCEL
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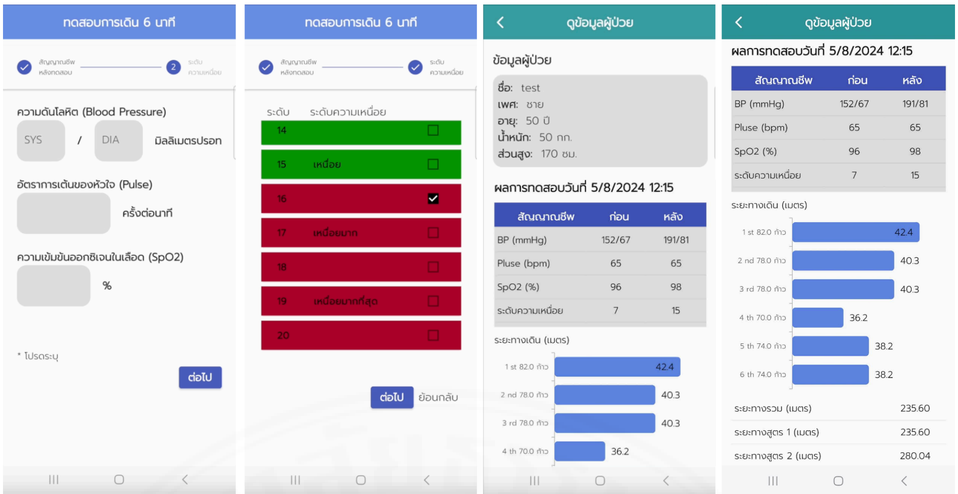

Figure 4.1 The developed 6MWT mobile application screens

4.1.2 Pilot study on changing the position of smart band device

In previous study, the smart band device was used on ankle and this study made a pilot study in 15 patients to compare variables among the 6MWD from application when attached the smart band device on ankle, wrist and conventional 6MWD, the results shown that had no statistically significant difference with good correlation between 6MWD from application while attached the device on wrist and conventional 6MWD (mean difference = -2.54 ± 17.99 meters, - 0.97 ± 6.12 %, p = 0.890; r = 0.682, p = 0.005). In contrast, there was statistically significant difference with excellent correlation between 6MWD from application while attached the device on ankle and conventional 6MWD (mean difference = 35.11 ± 9.26 meters, 13.36 ± 8.49 %, p = 0.002; r = 0.917, p < 0.001) (see table 4.1).

Table 4.1 Comparison between 6MWD from application on ankle, wrist and conventional 6MWD in 15 patients

Mean ± SD	Mean dif. ± SE	% Differential	P value
6MWD from App at ankle (297.99 ± 82.27) – conventional 6MWD (262.88 ± 89.90)	35.11 ± 9.26	13.36 ± 8.49	0.002*

6MWD from App at wrist (260.34 ± 84.39) – conventional 6MWD (262.88 ± 89.90)	-2.54 ± 17.99	- 0.97 ± 6.12	0.890
6MWD from App at ankle (297.99 ± 82.27) – 6MWD from App at wrist (260.34 ± 84.39)	37.65 ± 14.11	14.46 ± 2.52	0.018*

SD: Standard deviation; 6MWD: 6-minute walk distance, * Significant difference, $p < 0.05$

4.2 Study 2: The study will be exploring the accuracy between the mobile application with the smart band device prototype and the standard test

4.2.1 Demographics and characteristics of the participants

In this study, we recruited and conducted our 6MWT with 100 participants over the course of 5 months. These participants were split into 4 groups, each group consisting of 25, which were: coronary heart disease (CAD), chronic kidney disease (CKD), chronic obstruction pulmonary disease (COPD) and stroke. With the participants ages ranging from 41 to 80 years (mean age = 64.76 ± 7.62 years), consisting of 73 male and 27 female participants. Among them, the average diagnosis time was 57.39 ± 57.86 months (see table 4.2)

Table 4.2 Demographics and characteristics of the participants

	N (%)	Mean ± SD	Maximum	Minimum
Gender - Male - Female	 73 27			
Age (Years)	100	64.76 ± 7.62	80	41
Weight (kg.)	100	62.80 ± 13.19	97.0	39.0
Height (cm.)	100	162.70 ± 8.86	185	127
BMI (kg/m2)	100	23.69 ± 4.48	37.89	15.21

Diagnosis time (Mo.)	100	57.39 ± 57.86	240	1
Education				
- No education	3			
- Primary school	33			
Secondary school	28			
- High school	11			
- Undergraduate	20			
- Higher than undergraduate	5			
Vital signs before 6MWT	100			
- Systolic BP (mmHg)		138.29 ± 19.75	185	95
- Diastolic BP (mmHg)		75.92 ± 11.95	118	44
- Pulse (bpm)		75.17 ± 12.70	100	43
- SpO_2 (%)		98.52 ± 1.02	100	95
- Borg scale (score)		8.54 ± 1.62	11	6
Vital sign after 6MWT	100			
- Systolic BP (mmHg)		151.34 ± 27.82	244	97
- Diastolic BP (mmHg)		80.06 ± 12.45	116	44
- Pulse (bpm)		81.67 ± 15.50	122	42
- SpO2 (%)		98.53 ± 1.21	100	94
- Borg scale (score)		12.22 ± 2.09	17	7

SD: Standard deviation; BMI: Body mass index, BP: Blood pressure, SpO_2: Pulse oxygen saturation

4.2.2 Accuracy and reliability

The result of 6-minute walk test (6MWT) from all 100 participants shown, the 6MWD from mobile application was 304.34 ± 95.36 meters and conventional 6MWD was 289.05 ± 107.02 meters. There was statistically significant difference between 6MWD from mobile application and conventional 6MWD (mean difference = 15.29 ± 4.95 meter, 5.29 ± 10.84 %, p = 0.003) shown in table 4.3.

However, the result of 6MWT in subgroup shown, there were no statistically significant difference in between 6MWD from mobile application and conventional

6MWD in CAD (Mean difference = 12.60 ± 9.28 meters, 4.09 ± 2.92 %, p = 0.187), CKD (Mean difference = 8.39 ± 8.46 meters, 2.81 ± 13.34 %, p = 0.331) and COPD group (Mean difference = 2.07 ± 7.98 meters, 0.62 ± 1.06 %, p = 0.798). In contrast, there was statistically significant difference in between 6MWD from mobile application and conventional 6MWD in stroke group (Mean difference = 38.10 ± 12.30 meters, 17.63 ±11.85 %, p = 0.005) (see table 4.3).

Additionally, A significantly excellent correlation and excellent reliability between 6MWD from mobile application and conventional 6MWD were found in all group, CAD, CKD and COPD group. For the stroke group, there were significantly excellent correlation and good reliability (see table 4.4).

Table 4.3 Comparison between 6MWD from application and Conventional 6MWD

Group	**6MWD from application (Mean ± SD)**	**Conventional 6MWD (Mean ± SD)**	**Mean dif. ± SE**	**% Differential**	**P value**
All group (N=100)	304.34 ± 95.36	289.05 ± 107.02	15.29 ± 4.95	5.29 ± 10.84	0.003*
CAD (n=25)	320.66 ± 89.91	308.06 ± 92.62	12.60 ± 9.28	4.09 ± 2.92	0.187
CKD (n=25)	307.07 ± 82.79	298.68 ± 95.54	8.39 ± 8.46	2.81 ± 13.34	0.331
COPD (n=25)	335.43 ± 90.56	333.36 ± 89.59	2.07 ± 7.98	0.62 ± 1.06	0.798
Stroke (n=25)	254.19 ± 102.27	216.10 ± 115.98	38.10 ± 12.30	17.63 ±11.85	0.005*

SD: Standard deviation, 6MWD: 6-minute walk distance, CAD: Coronary heart disease, CKD: Chronic kidney disease, COPD: Chronic obstruction pulmonary disease, * Significant difference, $p < 0.05$

Table 4.4 Correlation between 6MWD from application and Conventional 6MWD of all group and subgroup

Group	Concurrent validity		Intra-rater reliability	
	Pearson correlation (r)	**p-value**	**Cronbach alpha (95% CI)**	**p-value**
All group (n=100)	0.887	< 0.001*	0.932	< 0.001*
CAD (n=25)	0.871	< 0.001*	0.929	< 0.001*
CKD (n=25)	0.897	< 0.001*	0.941	< 0.001*
COPD (n=25)	0.902	< 0.001*	0.950	< 0.001*
Stroke (n=25)	0.849	< 0.001*	0.888	< 0.001*

CAD: Coronary heart disease, CKD: Chronic kidney disease, COPD: Chronic obstruction pulmonary disease, * Significant difference, $p < 0.05$

Furthermore, we had recorded the 6MWD per minute by conventional 6MWT and 6MWT mobile application in 86 participants. The results found that the distance from application were higher than distance from conventional test in each minute abd the perspective tend to be lower at a time (see figure 4.2).

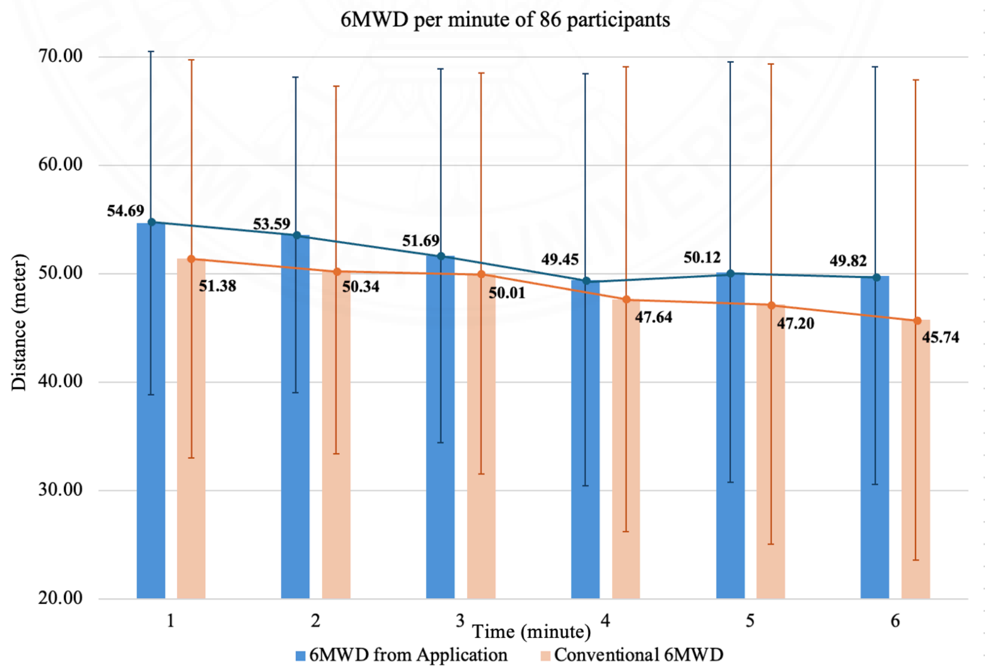

Figure 4.2 The 6MWD from mobile application and conventional 6MWD per minute of 86 participants

4.3 Discussion

The aim of this study was to explore the correlation of distance and time between the mobile application with the smart band device prototype and standard 6-minute walk test in 100 participants including of coronary heart disease, chronic kidney disease, chronic obstruction pulmonary disease and stroke patients.

Phase 1: we developed the 6MWT application to enhance the software based on the standard 6MWT by adding application screens included contraindications and precautions, vital sign before and after test and the results history. This development would make it easier for assessors to compare results in each session for individual participants. Moreover, this application provides the ability to track the distance per minute, offering valuable insights for both patients and examiners. By monitoring the progression of walking distance at each minute interval, it enables a clearer understanding of the patient's performance trends over time. This feature not only enhances the clinician's ability to assess and adjust treatment plans on an individualized basis, but also offers patients a more comprehensive view of their functional progress, ultimately supporting more targeted and effective therapeutic interventions.

Phase 2: Changing the position of smart band device from ankle to wrist. In previous study, the smart band device was used on ankle and this study made a pilot study in 15 patients to compare variables among the 6MWD from application when attached the smart band device on ankle, wrist and conventional 6MWD, the results shown that had no statistically significant difference between 6MWD from application while attached the device on wrist and conventional 6MWD (mean difference = -2.54 ± 17.99 meters, $p = 0.890$), with good correlation ($r = 0.682$, $p = 0.005$), with differential percentage - 0.97 ± 6.12 %. Consequently, 6MWD from application when attached the smart band device on wrist was the most resemble to real distance and we used wrist as a smart band device's position in the study.

Phase 3: exploring the accuracy between the mobile application with the smart band device prototype and the standard test. The 6MWD from mobile application was 304.34 ± 95.36 meters and conventional 6MWD was 289.05 ± 107.02 meters. Respectively, Mean distance difference was 15.29 ± 4.95 meter and the percentage of mean distance difference from mobile application and conventional was 5.29 ± 10.84 %. The distance from application was higher than conventional 6MWD.

In the study of Salvi D. et al[151], shown that mean difference between the mobile phone-estimated distances and the reference values from 6MWT was −2.013 ±7.84 meters for the indoor algorithm and −0.80 ± 18.56 meters for the outdoor algorithm in pulmonary hypertension patients. In another study, Mak J. et al[152]. found high reliability (0.99) between step from ground truth 6MWT and step from using apple watch series 3 in cardiovascular patients. In contrast, the study of Shah et al[161]. reported that absolute error distance from digital device and manual test was 18.36 ± 18.79 meters with ICC = 0.97 in older adults with impaired fasting glucose. In another stady of Ata R, et al[150], found that the iPhone CM Pedometer distance algorithm overestimated distance with a bias of 43 ± 42% compared to manual 6MWT due to overestimation in stride length of 114 participants with peripheral artery disease.

To establish generalizability for the medical device, it is essential to consider both the Minimal Clinically Important Difference (MCID) and maximum permissible error (MPE). The MPE of medical devices or instruments typically has an MPE set at 5%[156] while the result of this study shown that percentage of mean distance difference was 5.29 ± 10.84 % , which exceeds the MPE. However, when considered subgroups, the groups that were accepted by the MPE criteria included CAD (with a 4.09 ± 2.92% mean difference), CKD (with a 2.81 ± 13.34% mean difference), and COPD (with a 0.62 ± 1.06% mean difference). In contrast, the stroke group exhibited higher mean difference of 17.63 ± 11.85%, which exceeds the 5% threshold defined by the MPE for medical devices. This suggests that the results from the stroke group may have a disproportionate impact on the overall findings, potentially influencing the overall accuracy and reliability of the results. According to the systematic review investigated the MCID or the change in the 6MWD for individuals with various health conditions, including chronic obstructive pulmonary disease, lung cancer, coronary artery disease, diffuse parenchymal lung disease, non-cystic fibrosis bronchiectasis, and adults with fear of falling. The results showed that the MCIDs were associated with an area under the receiver operating characteristic curve (ROC curve) of at least 0.70, ranging from 14.0 to 30.5 meters[157]. However, the mean distance difference in this study was 15.29 ± 4.95 meters, which remains within that range. These findings suggest that the results from these populations cannot be generalized, as the error associated with the application of the 6MWT exceeded the MCID. This means that the observed improvements in the 6MWT distances may not accurately reflect true patient progress. Instead, the results could be influenced by measurement errors, potentially leading to a misinterpretation of patient improvement. However, if consider from the result of 6MWT in subgroup, there were no statistically significant difference in between 6MWD from mobile application and conventional 6MWD in CAD (mean difference = 12.60 ± 9.28 meters, p = 0.187), CKD (mean difference = 8.39 ± 8.46 meters, p = 0.331) and COPD group (mean difference = 2.07 ± 7.98 meters, p = 0.798). In contrast, the stroke group showed a significant difference (mean difference = 38.10 ± 12.30 meters, p = 0.005). Based on the MCIDs for 6MWT in various health conditions[157], The results of this study shown that mean difference of 6MWD in the populations of CAD, CKD, and COPD groups did not fall within the established MCID range of 14.0 to 30.5 meters, which mean these populations can be generalized excepts stroke patients.

Moreover, there were several studies have investigated the MCID for 6MWT across various patient groups. For instance, Gremeaux et al. (2011)[162] reported that the MCID for the 6MWT in patients with acute coronary syndrome undergoing cardiac rehabilitation was 25 meters. Similarly, Shoemaker et al. (2013)[163] found that the MCID for the 6MWT in patients with chronic heart failure was 30.1 meters. Based on these established MCID values, the results of the current study indicate that the CAD group, with a mean difference of 12.60 ± 9.28 meters in 6MWD, did not fall within the established MCID range.

In the case of CKD patients, Segura et al. (2011)[164] reported an MCID for the 6MWT of 66.3 meters in a cohort of 36 individuals undergoing hemodialysis. The CKD group in the current study, with a mean difference of 8.39 ± 8.46 meters in 6MWD, did not meet the established MCID for this population.

For COPD patients, Rasekaba et al. (2009)[165] reported an MCID of 54 meters, while a systematic review by Huang et al. (2016) (165), which included 3 articles, suggested an MCID range of 25 to 48 meters. In the present study, the COPD group demonstrated a mean difference of 2.07 ± 7.98 meters in 6MWD, which does not fall within the established MCID range for this population.

For stroke patients, Perera et al. (2006)[166], identified an MCID of 50 meters for geriatrics and chronic stroke patients, while Tang et al. (2012) [167] reported an MCID of 34.4 meters in chronic stroke patients. The results of the current study indicate that the stroke group, with a mean difference of 38.10 ± 12.30 meters in 6MWD, did not fall within the MCID range established by Perera et al., but did fall within the MCID range reported by Tang et al.

The results of this study indicated that the mean difference in 6MWD for the populations with CAD, CKD, and COPD did not fall within the established MCID range for each condition. This suggests that these populations can be generalized based on the findings. However, in the case of stroke patients, while the 6MWD change did not fall within the MCID range established by Perera et al., it was within the MCID range reported by Tang et al. This discrepancy highlights the need for further investigation before drawing definitive conclusions for this group.

However, when consider about concurrent validity and intra-rater reliability, there were found excellent correlation ($r = 0.849$, $p < 0.001$) and good reliability (ICC = 0.888, $p < 0.001$) in stroke group

As the adding feature in application that provides the ability to track the distance per minute. We analysed the trend of 6MWD per minute that revealed distinct patterns across the different patient groups (see in Appendix E).

In CAD patients, the walking distance was highest during the first minute, followed by a gradual decline, after which the distance stabilized over the remaining five minutes. The gradual decline of distance after first minute may be attributed to the pathophysiology, where plaque accumulation in the arterial walls causes narrowing and obstruction of blood flow. This reduced perfusion increases the heart's workload, leading to symptoms such as angina, fatigue, and shortness of breath. These symptoms tend to worsen during physical or emotional exertion due to the body's increased oxygen demand[121, 122]. After the decline, the walking distance stabilizes as the patient adjusts their pace to prevent exacerbating symptoms, reflecting the heart's inability to meet the oxygen demands during prolonged exertion.

In CKD patients, the walking distance was elevated during the first two minutes but decreased progressively over the following four minutes. Long-term hemodialysis patients often experience muscle wasting or sarcopenia due to factorssuch as malnutrition, inflammation, and metabolic changes. Additionally, anemia, caused by reduced erythropoietin production and impaired red blood cell production, decreases oxygen delivery to tissues. This leads to increased fatigue and reduced walking distance, as the body struggles to meet the muscles' oxygen demands during physical activity[127, 128].

For COPD patients, the distance was notably higher in the first three minutes, with a subsequent decline over the last three minutes. As pulmonary function declines, COPD patients experience increased breathlessness, fatigue, and difficulty maintaining speed. Exertional hypoxemia and muscle fatigue from inadequate oxygen supply further impair performance. This decline in walking distance results from the combined effects of respiratory limitations, muscle fatigue, and cardiovascular deconditioning[136].

In contrast, stroke patients exhibited a relatively stable walking distance throughout the entire six minutes. Patients with cerebrovascular disease have brain-related pathologies that result in muscle weakness, requiring increased energy expenditure for activities. This leads to faster onset of fatigue, poor cardiovascular endurance and reduced activity levels[142]. Although stroke-related muscle weakness and spasticity could impair endurance. However, compensatory mechanisms, such as increased reliance on the unaffected limb or postural adjustments might help maintain a consistent pace.

In a study by Chang HC, et al, reported that patients with cerebrovascular disease had shorter stride length, lower stride frequency, slower stride velocity, lower stride cadence, longer stance time, longer swing time, and needed more time to walk compare with the healthy group[22].

In this study, the assessor identified several factors among stroke patients that could affect the accuracy of walking distance calculations in the application system. Observations included inconsistent walking steps, shorter step lengths not aligned with patient height, and variability in arm swing, such as some patients holding their arms together, displaying reduced arm movements and atypical arm movements. These factors represent potential confounding variables that may compromise the precision of distance measurements provided by the application.

In the study of Wagenaar et al[168], study about arm swing patterns, the results shown that arm swing pattern in healthy individuals are depends on walking speed, walking at comfortable velocities ($\geq$ 0.8–1.0 m/s) exhibits a 1:1 coordination pattern, where each arm swing corresponds to one stride of the contralateral leg. At reduced velocities (0.3–0.7 m/s), this ratio changes to a 2:1 pattern, with two arm swings per stride. In the related study by Van et al[(169)], were study in stroke patients and results shown that the 15 stroke patients demonstrated a 1:1 arm-to-leg swing ratio, with one arm swing per stride, while 9 patients exhibited a 2:1 ratio, with two arm swings per stride. Patients with the 2:1 ratio exhibited greater spasticity in the shoulder internal rotator muscles on the affected side and displayed slower walking speeds compared to those in the 1:1 ratio group.

In this study, the mobile application calculated walking distance based on individual stride length and cadence[(170)]. The stride length was calculated by individual height. Previous study shown using this method had differential percentage from 6MWD from application and conventional 6MWD only - 3.59%. in healthy populations[(12)] and healthy population usually assumes a 1:1 ratio of gait to arm swing which is normal gait pattern and related to this method. However, if stroke patients in this study exhibit a 2:1 gait-to-arm swing ratio where two arm swings correspond to one stride, the application may inaccurately record two step counts for each actual stride, effectively doubling the calculated distance. Moreover, stroke patients often have shorter stride lengths that are not related to their height, representing height-based stride length references unsuitable for this population. Additionally, this study focused on stroke patients who were able to walk independently without the use of gait aids, without considering the type of stroke. However, in reality, the level of spasticity can significantly affect the walking sensor and application calculations.

CHAPTER 5
CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusion

The establishing of convenient 6-minute walk test by using mobile application with smart band device to evaluate physical performance. This study found accuracy of walking distance between mobile application with prototype of smart band device and standard walking test in coronary heart disease, chronic kidney disease and chronic obstruction pulmonary disease patients. While the findings can be generalized to these groups, further consideration is needed for stroke patients.

5.2 Limitation

This study had limitations. This mobile application could use only android OS system. Therefore, this application should be applied in the larger group to analyze in subgroup such as age range, diagnosis time range or education level. In this study, CKD patients used a 15-meter walkway, which may have influenced the number of turns and subsequently affected the distance counting system in the application. However, the study found that these factors had minimal effects on the overall results when analyzed individually. Accordingly, the further study should consider factors that might affect to distance of 6MWT to improve using this application in the future.

5.3 Clinical implication

Associated with results of this study, The physical therapist, nurse, medical professional and researcher can utilize 6-minute walk test application with smart band device to evaluate monitor and follow up physical performance in healthy people, coronary heart disease, chronic kidney disease and chronic obstruction pulmonary disease patients.

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APPENDICES

APPENDIX A
THE DATA COLLECTION FORM

แบบบันทึกข้อมูล

No. ....

วันที่ทำการเก็บข้อมูล........./........./........

ข้อมูลทั่วไป

☐ โรคหลอดเลือดหัวใจ ระยะเวลาที่ถูกวินิจฉัย ....ปี EF .... FC ....

☐ โรคไตวายเรื้อรัง ระยะเวลาที่ถูกวินิจฉัย ....ปี ระยะเวลาที่ได้รับการฟอกเลือด ....ปี

☐ โรคปอดอุดกั้นเรื้อรัง ระยะเวลาที่ถูกวินิจฉัย ....ปี

☐ โรคหลอดเลือดสมอง ระยะเวลาที่ถูกวินิจฉัย ....ปี

1. เพศ ☐หญิง ☐ชาย อายุ .... ปี หรือ เดือนและปีเกิด ..../............
2. น้ำหนัก ....กิโลกรัม ส่วนสูง .... เซนติเมตร
3. ท่านมีโรคประจำตัวหรือไม่ [ ] ไม่มี [ ] มี โปรดระบุ...

   [ ] เบาหวาน/รับประทานยา เป็นมานาน ....ปี [ ] ความดันโลหิต/รับประทานยา เป็นมานาน ....ปี
4. [ ] ไขมันสูง/ รับประทานยา เป็นมานาน ....ปี อื่นๆ โปรดระบุ .... ปี
5. 6MWT แบบมาตรฐาน

	Baseline	End of Test	
Time (Minutes)			จำนวนรอบการเดิน:.............. (x 30 เมตร) +
Blood pressure (mmHg)			Final partial lab: ....เมตร
Heart Rate (bpm)			= 6MWD: ....เมตร
Dyspnea (Borg scale)			
Fatigue (Borg scale)			
SpO_2 (%)			

หยุดหรือหยุดชั่วคราวก่อน 6 นาที ☐ ไม่ใช่ ☐ ใช่ เหตุผล..

6. 6MWT บนแอปพลิเคชัน

	Baseline	End of Test
Time (Minutes)		
Blood pressure (mmHg)		
Heart Rate (bpm)		
Dyspnea (Borg scale)		
Fatigue (Borg scale)		
SpO_2 (%)		

6MWD from app: ....เมตร

แบบบันทึกความแข็งแรงของกล้ามเนื้อขา (handheld)

Variable	Trial 1 (kg)	Trial 2 (kg)
ขาข้าง		
ขาข้าง		

APPENDIX B

The Montreal Cognitive Assessment (MoCA)

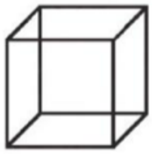
MONTREAL COGNITIVE ASSESSMENT (MOCA)

ชื่อ :
ระดับการศึกษา : วันเดือนปีเกิด:
เพศ : วันที่ทำการทดสอบ :

VISUOSPATIAL / EXECUTIVE — คะแนน

[ ]

คัดลอกลูกบาศก์



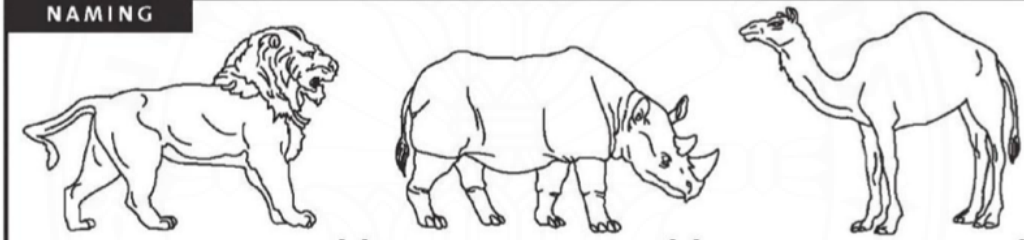
[ ]

วาดหน้าปัดนาฬิกา บอกเวลาที่ 11.10 น. (3 คะแนน)

[ ] รูปร่าง [ ] ตัวเลข [ ] เข็ม

___/5

NAMING



[ ] [ ] [ ]

___/3

MEMORY

อ่านชุดคำเหล่านี้แล้วให้ผู้ทดสอบทวนซ้ำ ทดสอบ 2 ครั้ง และถามซ้ำอีกครั้งหลัง 5 นาที

	หน้า	ผ้าไหม	วัด	มะลิ	สีแดง
ทวนครั้งที่ 1					
ทวนครั้งที่ 2					

ATTENTION

อ่านตัวเลขต่อไปนี้ตามลำดับ (1 ตัว/วินาที)
ให้ผู้ทดสอบทวนซ้ำตามลำดับ [ ] 2 1 8 5 4
ผู้ทดสอบทวนซ้ำแบบย้อนลำดับ [ ] 7 4 2
___/2

อ่านออกเสียงตัวเลขต่อไปนี้ แล้วให้ผู้ทดสอบเคาะโต๊ะเมื่อได้ยินเสียงอ่านเลข " 1 " (ไม่มีคะแนนถ้าผิดเกิน 2 ครั้ง)
[ ] 5 2 1 3 9 4 1 1 8 0 6 2 1 5 1 9 4 5 1 1 1 4 1 9 0 5 1 1 2
___/1

เริ่มจาก 100 ลบไปเรื่อยๆทีละ 7 [ ] 93 [ ] 86 [ ] 79 [ ] 72 [ ] 65
ลบถูก 4 หรือ 5 ตัว ได้ 3 คะแนน , 2 หรือ 3 ตัว ได้ 2 คะแนน , 1 ตัวได้ 1 คะแนน , 0 ตัว ไม่ได้คะแนน
___/3

LANGUAGE

Repeat : ฉันรู้ว่าจอมเป็นคนเดียวที่มาช่วยงานวันนี้ [ ]
แมวมักซ่อนตัวอยู่หลังเก้าอี้เมื่อมีหมาอยู่ในห้อง [ ]
___/2

Fluency / บอกคำที่ขึ้นต้นด้วยตัวอักษร " ก " ให้มากที่สุดใน 1 นาที ก [ ] _____ (N ≥ 11 words)
___/1

ABSTRACTION

บอกความเหมือนระหว่าง 2 สิ่ง เช่น กล้วย-ส้ม : เป็นผลไม้ [ ] รถไฟ - จักรยาน [ ] นาฬิกา - ไม้บรรทัด
___/2

DELAYED RECALL

		หน้า	ผ้าไหม	วัด	มะลิ	สีแดง	
DELAYED RECALL	ให้ทวนชุดคำที่จำไว้ก่อนหน้านี้ โดยไม่มีการให้ตัวช่วย	[ ]	[ ]	[ ]	[ ]	[ ]	ให้คะแนนเฉพาะคำที่ทวนได้โดยไม่ให้ตัวช่วย
Optional	Category cue						
	Multiple choice cue						

___/5

ORIENTATION

[ ] วันที่ [ ] เดือน [ ] ปี [ ] วัน [ ] สถานที่ [ ] จังหวัด
___/6

Translated by Solaphat Hemrungrojn MD
Trial version 01 Updated August 31, 2011

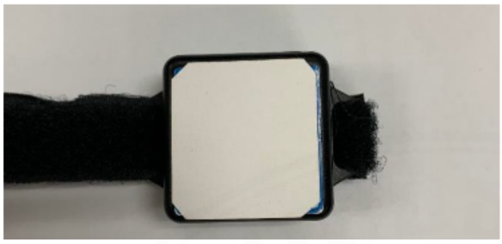
ค่าปกติ ≥ 25/30

คะแนนรวม ___/30
เพิ่ม 1 คะแนน ถ้าจำนวนปีการศึกษา ≤ 6

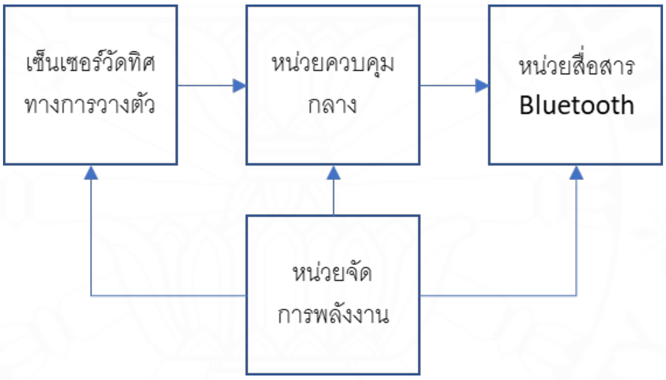
APPENDIX C

The detail of smart band device prototype

- External elements of smart band device



- Diagram of system components



- This study used Terra R.[170] equation to calculate total distance in 6 minutes

$$\text{Distance (meters)} = \text{number of steps} \times \text{stride length}$$

Number of steps recorded from 3-axis accelerometer in smart band device and stride length calculated using Zhao N.[171] relations proportional to the user height as reference table.

Number of steps per 2 seconds	Step Length (*meters*)
2 or 3	Height/3
4	Height/2.5
5	Height/2
≥ 6	Height/1.5

- Features of walking sensors

Features	Prototype
Sensor for measuring posture	3-axis accelerometer capable of measuring at a maximum acceleration of 2,8,16 g, a typical measurement frequency of not less than 20 times per 1 second.
Total weight	8 grams (without battery)
External dimensions	9x60x40 mm. (approximately)
Enclosure material	Plastic PLA (polylactic acid), melt Temp 157 degree Celsius
Processor	32-bit, 24MHz with Bluetooth Low Energy Power supply voltage 3.0V CR2016 Power consumption at active mode, at 24MHz, 7.1mA Power consumption at sleep mode, at 24MHz, 1.3 µA
Bluetooth	Version 4.1 (BLE) Frequency range 2400-2482 MHz Output power 0dBm (1mW radiofrequency) Power consumption for 0dBm transmission 16.5mA
Power source	Battery type CR2032 coin battery
Power consumption (All systems)	< 15mW for active mode

- Electrical and electromagnetic safety tests

MEFU
Mefu Technology Co., Ltd.

ที่ MF 1/2565

1 กุมภาพันธ์ 2565

เรื่อง แจ้งผลการตรวจสอบเรื่องความปลอดภัยทางไฟฟ้าของอุปกรณ์วัดการเคลื่อนไหว

เรียน ดร. ชูศักดิ์ ธนวัฒโน หัวหน้าทีมวิจัยการประมวลสัญญาณชีวการแพทย์ สวทช.

เนื่องด้วยบจ.เมฟู เทคโนโลยี ได้รับอุปกรณ์เครื่องวัดการเคลื่อนไหว (NaTu) ซึ่งเป็นต้นแบบที่ผลิตโดยหน่วยงานของท่าน (สำนักงานพัฒนาวิทยาศาสตร์และเทคโนโลยีแห่งชาติ หรือ สวทช.) เพื่อตรวจสอบความปลอดภัยทางไฟฟ้า เมื่อวันที่ 10 มกราคม 2565 โดยอุปกรณ์ทำหน้าที่วัดท่าทางการนอนเป็นอุปกรณ์ที่ใช้แบตเตอรี่ชนิดมาตรฐานและเป็นแบบใช้ครั้งเดียวไม่มีการชาร์จซ้ำ และแบตเตอรี่เป็นแบบความจุประมาณ 60mAh และมีแรงดันไฟฟ้าต่ำ (3V.) การกินกระแสขณะใช้งานประมาณ 0.01 mA (ค่าเฉลี่ย) ประกอบกับอุปกรณ์ไม่มีส่วนใดสามารถนำไฟฟ้ามาสู่ร่างกายผู้ใช้งานได้

ดังนั้นบริษัทฯ มีความจำนงแจ้งให้ท่านทราบว่าอุปกรณ์มีความปลอดภัยทางไฟฟ้าระดับดีมากโดยไม่มีอันตรายต่อร่างกายมนุษย์

ขอแสดงความนับถือ

นายพงศ์อมร อมรชัยกิจ
กรรมการผู้จัดการ
บจ. เมฟู เทคโนโลยี

บจ. เมฟู เทคโนโลยี 402/4 ม.8 ถ.พหลโยธิน ต.คูคต อ.ลำลูกกา จ.ปทุมธานี 12130 โทรศัพท์ 084-722-1313, 085-138-7542

TEST REPORT

Report No. ....:	**10/64-103**
Equipment Under Test (EUT) No...:	**EM-64-0599**
TISI No. ....:	-
Testing Laboratory ....:	**Electrical and Electronic Products Testing Center**
Address ....:	141 Thailand Science Park, Phahonyothin Road, Khlong Nueng, Klong Luang, Pathum Thani 12120, Thailand.
Applicant's name ....:	**National Science and technology Development Agency (NSTDA)**
Address ....:	A-MED, Biomedical Signal Processing Research Team (BSP) 112 Thailand Science Park, Paholyothin Road, Klong 1, Klong Luang, Pathumthani 12120
Manufacturer's Name ....:	**Biomedical Sihnal Processing Research Team (BSP) - AMED**
Address ....:	112 Thailand Science Park, Paholyothin Road, Klong 1, Klong Luang, Pathumthani 12120
Standard ....:	IEC 60601-1-2:2014
Non-standard test method.......................:	-
Test item description .... :	NaTu Sleep Monitor
Trademark ....:	NaTu
Model/Type reference ....:	V 2021
S/N..:	-
Ratings ....:	3 Vdc
Date of receive ....:	1 April 2021
Date of tested ....:	2 April, 5 - 6 May 2021
Date of issue: ....:	7 May 2021

Tested by	Approved by
(MR. Prajak Choieklin)	(MR. Anake Meemoosor)
Engineer	Operation Manager

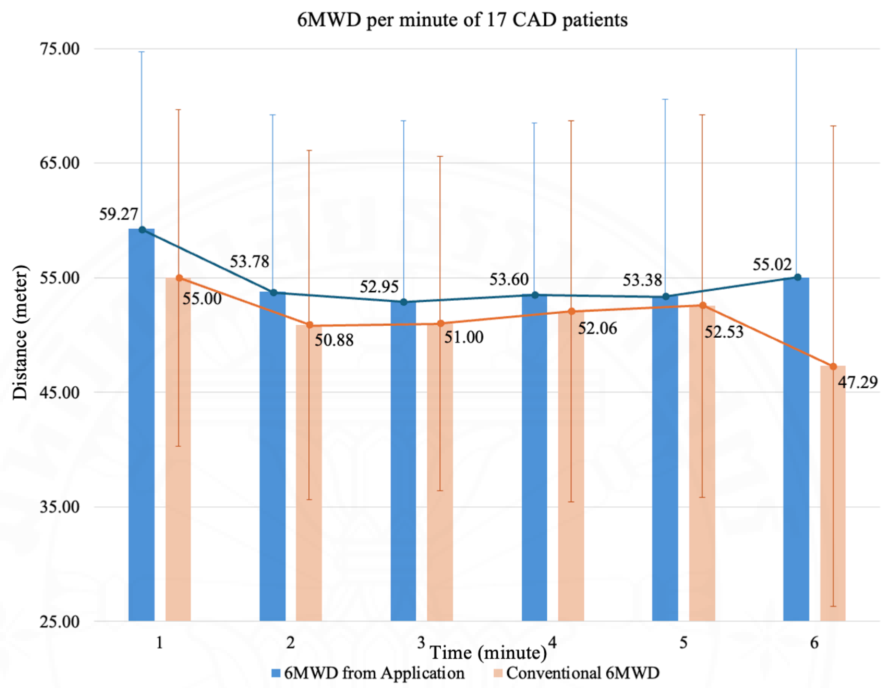
APPENDIX D
The detail of methodology

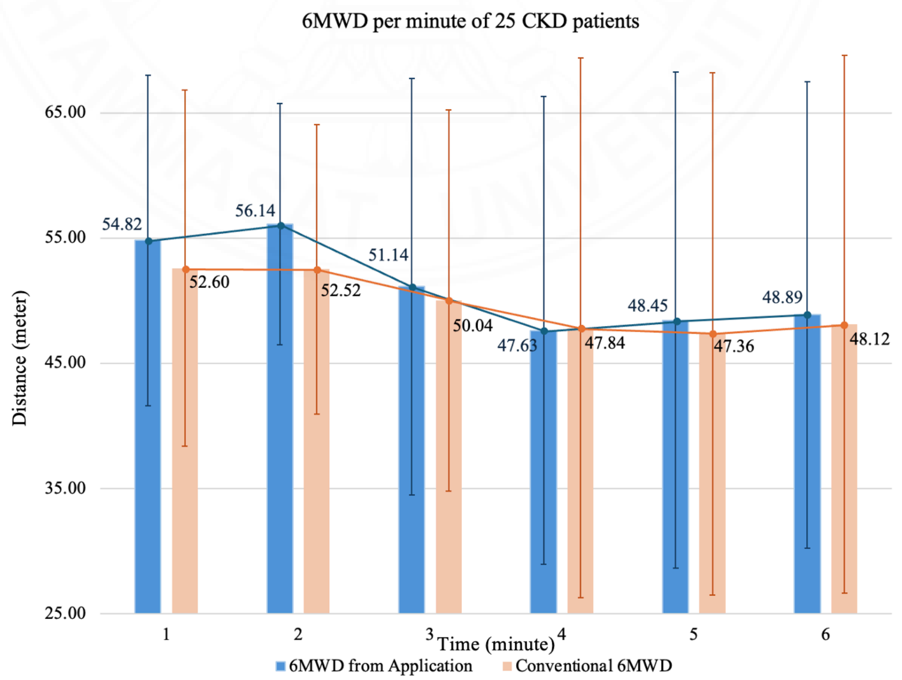
- 30 - meters walkway

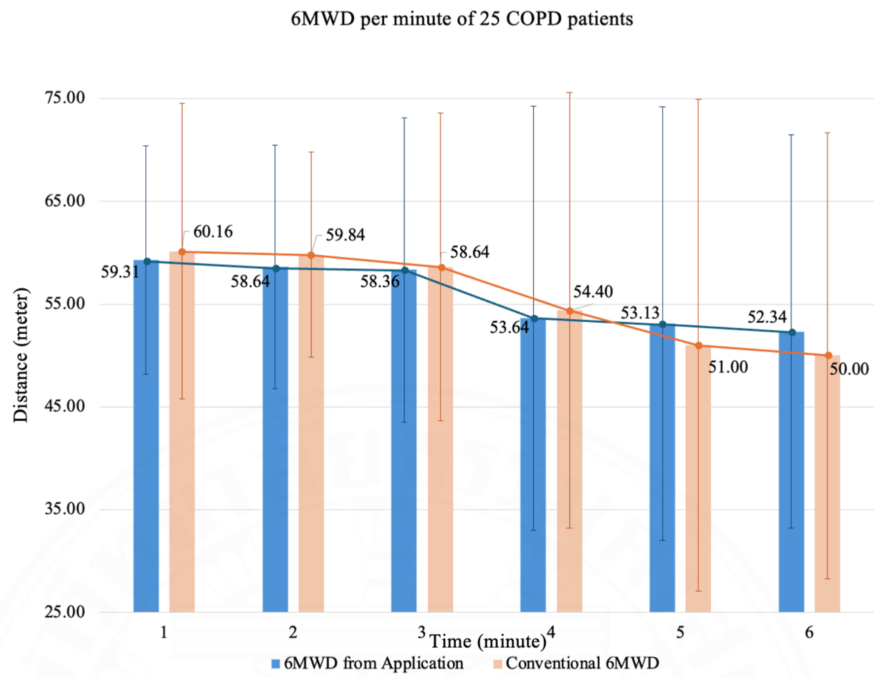
- Device on wrist and application

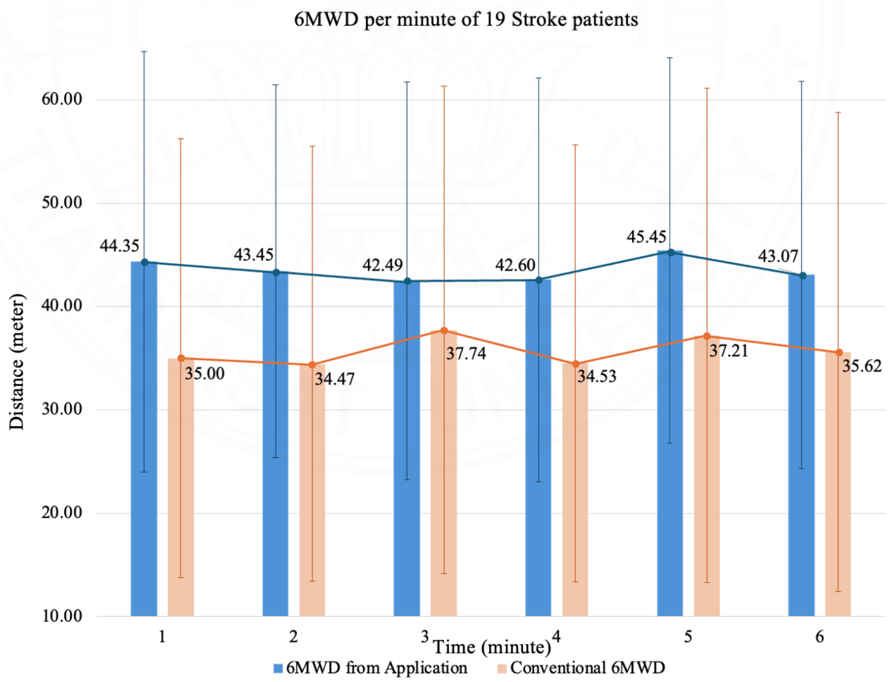
APPENDIX E

Comparison between 6MWD from mobile application and conventional 6MWD per minute in each group






6MWD per minute of 25 COPD patients
Distance (meter)
75.00
65.00
55.00
45.00
35.00
25.00
60.16
59.84
58.64
54.40
59.31
58.64
58.36
53.64
53.13
52.34
51.00
50.00
1
2
3
4
5
6
Time (minute)
6MWD from Application
Conventional 6MWD


6MWD per minute of 19 Stroke patients
Distance (meter)
60.00
50.00
40.00
30.00
20.00
10.00
44.35
43.45
42.49
42.60
45.45
43.07
35.00
34.47
37.74
34.53
37.21
35.62
1
2
3
4
5
6
Time (minute)
6MWD from Application
Conventional 6MWD