The Effects of Prosthetic Knee Joints in Walking and Dual-Task Activity Performance in Transfemoral Amputees: A Systematic Review

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Abstract---

Objectives: The purpose of this systematic review is to study the effects of prosthetic knee joints in terms of temporal-spatial, kinetic and kinematic assessment during walking and dual-task activity in transfemoral amputees.

Methods: The search strategy was conducted based on five online databases; ScienceDirect, PubMed, Scopus, CINAHL and Medline. A total of 19 articles were selected in this review. From the reviewed articles, there is a total of 635 participants took part in the studies and the performance between transfemoral amputees, transtibial amputees, and healthy controls was analyzed. Fifteen reviewed articles were based on biomechanical gait assessment such as temporal-spatial, kinetic, and kinematics during walking. Another four reviewed articles studied on the assessment of dual-task activity.

Results: Patients with LEA especially transfemoral amputees have lower walking speed, stride length and step time but with a greater step width, step time asymmetry, variability, and cadence compared healthy controls. The amputees have a higher work rate, impulse, load rate, and force on intact sides. There were no significant changes in dual-task activity for both amputations except that there is a slight deterioration of performance in transfemoral amputees.

Conclusion: Transfemoral amputees have difficulty to gain proper gait pattern and stability during walking and performing the dual-task activity. The higher k-level function indicates the greater achievement in performing gait assessment and requires less cognitive attention. Further evaluation is needed as dual-task gait assessment can help to improve gait rehabilitation among transfemoral amputees.

Keywords--- *Transfemoral, Gait Analysis, Walking, Dual-Task, Temporal-Spatial, Kinetics, And Kinematics.*

I. INTRODUCTION

Walking is one of the fundamental human movements where numerous subdivisions of the musculoskeletal systems such as muscles, bones, joints, and ligaments develop a complex mechanical interaction under the control of the nervous system. On a daily basis, walking is not practically easy as it seems as there is literally involvement of multitasking activities. An individual must be able to adapt to the surrounding environment and concentrate on various stimuli or cognitive resources during walking. Walking patterns also affected due to varying terrain conditions.

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Received: 06 Feb 2019 | Revised: 07 Mar 2019 | Accepted: 30 Mar 2019

As the dynamic interactions between sensory afferents and central motor programs are important in the walking process, persons with lower extremity amputation (LEA) face mobility challenges as their sensorimotor function of the leg loss due to amputation. Individuals with LEA need to achieve sufficient postural stability and adaptation strategies in both intact and residual limbs. Persons with LEA not only deal with restrictions in walking, but they also encounter high chances of falling and difficulties in walking on challenging conditions such as uneven terrains, ramps, stairs, slopes and so on. Patient with a prosthesis at any level of amputation requires higher energy expenditure and cognitive resources than able-bodied.

The two most common levels of lower extremity amputation are usually above-knee (transfemoral) and below-knee (transtibial) amputations. Individuals with transfemoral amputations have higher metabolic costs for ambulation than individuals with transtibial amputations. Amputations usually resulting from vascular, diabetes disease, cancer, traumatic and congenital. Patients with vascular/diabetic complications especially older people have lower levels of mobility, a slow rate of healing, and higher chances of mortality compared to younger people due to health status and age. Studies show that within five years, more than 50% of the diabetes amputees require second leg amputation [1]. These complications also related to cognitive processes such as problem-solving, balance and concentration during walking.

Generally, patients with LEA will use the intact (non-amputated) side first then followed by the prosthetic (amputated) side because no power controlled on that side. There are multifactorial components related to the performance of walking. Specifically, persons with above-knee amputation loss the sensorimotor function of the knee joint. Therefore, different prosthetic components play an essential role in determining the performance of transfemoral amputees. The loss of knee joint is one of the factors contributes to instability during standing and walking [2]. Prosthetic knee mechanisms can be divided into two categories; passive and active mechanisms. There are various prosthetic knees available such as single-axis, stance-control, polycentric, manual lock, fluid controlled, hybrid and also microprocessors that apply the damping characteristics. The purpose of prosthetic knees designation is to imitate the anatomical knee joint function such as flexion and extension during walking.

Prosthetic knee selection for an individual is the crucial process and differ from one another. The considerations when choosing suitable prosthetic knees must include the background of individuals, total costs, capabilities, and performances. Advanced technology such as microprocessor-controlled knee joint has been designed to prevent the user form collapse. Currently, there is no lifting power motor available yet in the market. As the years go by, microprocessor-controlled knee joints are widely used especially among well-developed countries. However, the price is costly which makes passive mechanical knee joints still the relevant and affordable choices among locals in developing countries. With the recent technologies, various type of passive mechanical knee joints offers great quality as good active knee joints.

As transfemoral amputees lose the peripheral afferent feedback and efferent control, they may find it harder to ambulate as they need to concentrate on every step of walking while giving attention to cognitive resources. The attention must be shared when performing a cognitive task while walking simultaneously in order to achieve successful prosthetic ambulation and prevent the risk of falls. The performance in either single or both of the tasks is usually impaired due to delays in processing time and high rate of error. Hence, dual-task assessment is relevant to study the gait performance of the amputees in walking with multiple cognitive resources.

Dual-task gait assessment evaluates the simultaneous performance of a cognitive task and a gait activity. The deterioration in performance on single or both tasks is called dual-task interference. The differences between reaction times in both single and dual tasks will determine the dual-task cost. Different cognitive tasks in dual-task assessment produce different outcomes. Studies show that people have higher accuracy rates and shorter response times when performing a visual test than an auditory test [3]. The same goes for older patients, they may have difficulty in conducting dual-task assessment compared to younger patients. Young adults also caught with movement error when performing more than a single task at one time. The dual-task paradigm is significant in daily activities as it involves multi-tasking of motor and cognitive tasks. It also can be used to investigate the interactions between gait control and cognition. However, there is no reliable dual-task assessment protocol currently exists yet for the LEA population.

Rather than typical gait analysis, dual-task gait analysis may provide more information such as alterations in walking performances of the amputees. This can helps in improving the element of prosthetic knee joints in the future. There are several studies have been published on a range of motion and reduced knee moments of prosthetic knee, but no comprehensive studies review has been done on the effect of different prosthetic knee designs in dual-task assessment for above-knee amputees. Most studies that include dual-task assessment only focused on the variability of temporal-spatial parameters. Some studies stated that the cognitive task did not affect much in the walking performance of the amputees. These may occur due to the selection of concurrent tasks, a limited number of participants, (bold).

Therefore, the aim of this systematic review is to study the effects of prosthetic knee joints during normal walking and dual-task activitiesin terms of temporal-spatial, kinetic, kinematic. At the end of this review, we will able to identify the common research methods used in gait analysis of the amputees and summarize the outcomes in this literature.

II. METHODS

Search strategy

The search strategy wasperformedbased on electronic bibliographic databases on several platforms: ScienceDirect, PubMed, Scopus, and CINAHL, and Medline. The advanced search strategy was used which included Boolean operator: transfemoral AND (balance OR “dual-task”). The articles were also limited from January 2014 to May 2019 (5 years back). The articles type consists of the review and research articles. No other restrictions such as publication title, author, field, access type section. The search strategy also useda combination of keywords such as “gait”, “temporal-spatial”, “kinetic”, “kinematic”, “cognitive”. Another manual search has been conducted based on the reference lists from relevant articles in order to avoid the possibility of overlooked articles.

Eligibility

The screening process of titles and abstracts are the initial crucial part to ensure the relevancy of articles chosen. The titles and abstracts of all articles found from electronic and manual searches were independently screened for potential eligibility by two reviewers (NA and NAA). Two important factors in screening the Single-axis were to find whether transfemoral and passive mechanical knee prostheses included or otherwise the articles will be eliminated. The articles selected from the electronic databases must be: (1) in full-text English, (2) including at least one transfemoral amputee, (3) performing gait assessment, and (4) instrumented assessment on dynamic balance in terms of temporal-spatial, kinematic and kinetic, and (5) dual-task assessment. Any combination of lower-extremity amputation and prostheses type can be accepted as long as those two factors mentioned included. The combination could be considered such as transtibial amputees, healthy controls (able-bodied), or microprocessor knee joint. The articles were excluded if consist any of the following: (1) studies on balance other than gait, (2) participants with more than one amputation (bilateral), (3) single-subject design, (4) unoriginal article, (5) and published on platforms other than review and research articles.

Review process

Mendeley software implementation was used to remove duplicate articles from different databases. For some articles that provide inadequate information on abstracts were continued by further full-text evaluation. Another re-screening process of the eliminated articles has been done in order to prevent any misconception. Some of the vital pieces of information in the methodology were derived throughout the final process of selecting the articles. The information on the first author's name, year of publication, participants' demographic data (such as the cause of amputation, level of amputation, type of prosthetic knee joint, prosthetic K-level, physical characteristics), protocol, instrumentation, sampling rates, outcomes parameters, and measurement. For the knee joint mechanisms, we classified into two categories: passive mechanical (MECH) and active microcontroller (MP) instead of using their commercial names. Single-axis, multi-axis, manual, polycentric, hydraulic, and pneumatic are examples of passive mechanical knee joints.

III. RESULTS

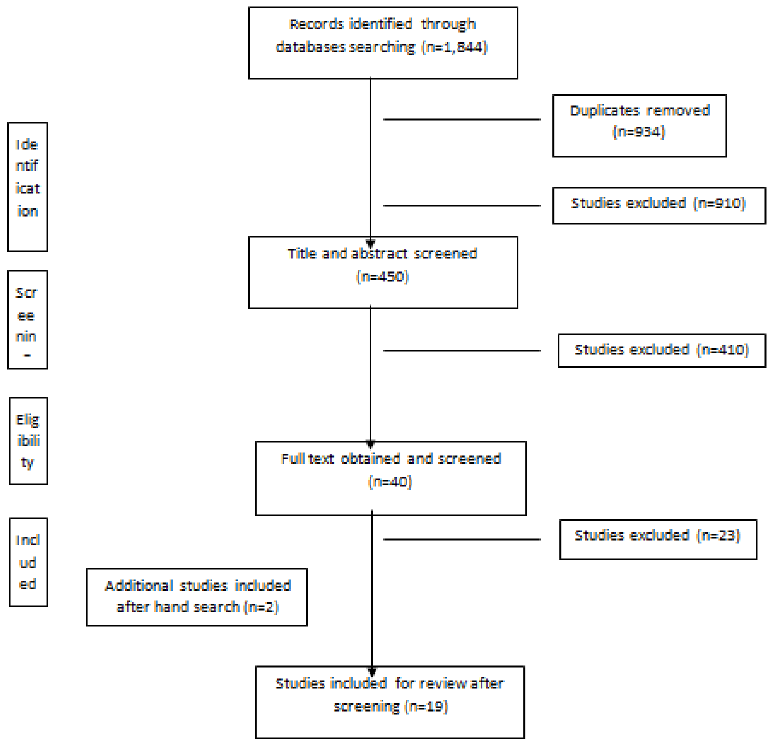

Figure 1 Flowchart of reviewed studies [4]

Literature search output

By referring to Figure 1, a total of 1,844 articles were found in five different electronic databases. The number of articles found in ScienceDirect, PubMed, Scopus, CINAHL, and Medline is 341, 66, 568, 649, and 220 respectively. The elimination process of duplicates and unrelated studies left 450 articles. The screening process of title and abstract eliminated 24 articles, and only 19 articles were selected to be reviewed.

Participants

Table 1 shows the various physical characteristics of the participants in the reviewed articles. The participants were categorized into lower extremity amputees and healthy controls (able-bodied). The total number of participants in the reviewed articles were 635 persons. The cause of amputation in the reviewed articles including trauma, vascular, cancer, sarcoma, diabetes mellitus, peripheral arterial disease, peripheral vascular disease, congenital. The participants were grouped between the type of amputation, Medicare Functional Classification Level, and the type of prosthetic knee joints. There are some articles that provided other information such as the prosthetic ankle joint, foot, side of amputation and body mass index. Two articles assessed on K2 to K4 levels [11, 19]. Seven articles focused on transfemoral amputees only [5, 6, 14, 16, 17, 19, 22], while six articles compared between transfemoral amputees and able-bodied [7, 9, 10, 11, 15, 20], and the rest included between the combination of transtibial, transfemoral, and able-bodied. One article categorized transfemoral amputees into two groups; exercise and control group [12]. The greatest number of participants throughout the reviewed articles were 176 persons while the lowest was 5 persons. Most of the participants were male, and four articles consisted of male participants only [6, 8, 10, 14]. One article did not provide any information on the participants' gender [5].

Table 1: Participants' demographic characteristic.

Study	**Etiology**	**Level**	**Type of Knee Joint**	**K-Level**	**No. of Participant**	**Gender**		**Age (years)**	**Height (cm)**	**Weight (cm)**	**Time Since Amputation (years)**
						Male	**Female**				
Bell et al (2016) [5]	Trauma	TFA	MECH MP	4	8 13	NI	NI	34.5 ± 5.15 31.54 ± 5.56	182.6 ± 5 178.3 ± 6	89.04 ± 10.96 87.16 ± 11.5	> 2
Okita et al (2018) [6]	Trauma, Tumor	TFA	MECH	3	7	7	-	40 ± 15	170 ± 5	74 ± 13	15 ± 17
Mohamed et al (2019) [7]	Trauma	TFA AB	MECH, MP	3, 4	2 14	2 6	- 8	32.5 ± 2.12 27 ± 7.5	179 ± 1.41 169 ± 9.2	69 ± 8.5 68.6 ± 12.5	NI
Okita et al (2018) [8]	Trauma, Tumor	TFA	MECH	3	6	6	-	40 ± 15	170 ± 5	74 ± 13	15 ± 17
Sturk et al (2018) [9]	Trauma, Osteosarcoma, Vascular	TFA TFA AB	MP MECH	3, 4 4	7 3	5 3	2 -	47.14 ± 8.63 47.33 ± 13.05 43 ± 8.6	173.29 ± 8.86 184 ± 1 178 ± 7	84.76 ± 9.86 86.63 ± 6.38 83.2 ± 10.1	16.14 ± 12.76 7.23 ± 7.23
Abouhossein et al (2019) [10]	Trauma	TFA AB	MECH, MP	3, 4	1 4	1 4	- -	52 31.5 ± 7.8	166 175.1 ± 6.4	66.7 81.3 ± 9.0	10
Zhang et al (2019) [11]	Trauma, Tumor	TFA AB	MECH	2-4	10 15	8 NI	2 NI	31.5 ± 7.9 NI	170.5 ± 3.8 NI	67.6 ± 6.0 NI	8 ± 6.75
Schafer et al (2018) [12]	Trauma, Malignancy, Vascular, Infection, Osteomyelitis	TTA/TFA TTA/TFA	MECH, MP	NI	7 8	4 1	3 7	60 ± 12 65 ± 16	172 ± 10 174 ± 13	92 ± 15 95 ± 25	10 ± 17 19 ± 20
Varrecchia et al (2019) [13]	Trauma	TTA TFA TFA	- MECH MP	NI	15 9 31	15 37	- 3	52.81 ± 14.51 54.94 ± 12.31	176.44 ± 5.40 172.85 ±	87.44 ± 11.08 83.47 ± 15.69	NI

		AB			40			-	7.95 -	-	
Hafner et al (2015) [14]	Trauma, Tumor	TFA	MECH	3	12	12	-	58.8 ± 6.1	NI	87.88 ± 14.96	28.9 ± 12.5
Shirota et al (2015) [15]	Trauma, Sarcoma	TFA AB	MECH, MP	3	8 8	7 4	1 4	47 ± 12 24 ± 2	NI 170 ± 7	NI 64.3 ± 9.5	19.4 ± 13.9
Azuma et al (2019) [16]	PAD, Trauma, Tumor	TFA	NI	NI	30	24	6	54 ± 19	NI	NI	25.67 ± 16.5
Kendell et al (2015) [17]	Trauma, Tumor, Frostbite	TFA	7 MP, 4 MECH	NI	11	9	2	57 ± 13	NI	75 ± 10	NI
Clemens et al (2018) [18]	Non-vascular	TTA TFA	MECH, MP	NI	20 20	8 13	12 7	53.4 ± 11.2 42.5 ± 16.1	173 ± 7.7 175.6 ± 10	NI NI	8.6 ± 7.1 10.9 ± 13.7
Prinsen et al (2014) [19]	Trauma, Infection, Osteosarcoma	TFA	MECH	2-4	10	6	4	56	NI	NI	33.5
Morgan et al (2015) [20]	Trauma, Tumor, Vascular, Infection	TFA AB	MP	4	14 14	9 9	5 5	53.8 ± 13.6 53.8 ± 13.4	175 ± 8 176 ± 11	78.5 ± 16.4 77.2 ± 13.7	21.6 ± 15.3
Hunter et al (2018) [21]	Vascular Non-Vascular	TTA TTA TFA	MECH, MP	NI	20 20 20	19 17 13	1 3 7	60.36 ± 7.84 55.85 ± 14.08 58.21 ± 14.88	NI NI NI	33.01 ± 7.40 27.41 ± 4.00 27.63 ± 5.11	3.49 ± 3.68 20.43 ± 17.61 15.55 ± 15.43
Gozaydinoglu et al (2019) [22]	Trauma	TFA	MECH, MP	NI	40	30	10	37 ± 9.9	NI	NI	12.7 ± 9.4
Frengopoulos et al (2017) [23]	PVD, Diaebetic, Trauma, Other	TTA/TFA	MECH, MP	NI	176	123	53	64.27 ± 13.23	NI	NI	NI

CS = Controls, AB = Able-Bodied, TTA= Transtibial Amputee, TFA= Transfemoral Amputee, MECH = Mechanical Passive, MP = Microprocessor, NA = Not Applicable, NI=No Information, PAD=Peripheral Arterial Diseases, DM=Diabetes Mellitus, PVD=Peripheral Vascular Diseases

Table 2: Data extraction from the reviewed article

Study	Protocol	Instrumentation	Sampling Rate (Hz)	Outcomes Measures	Findings
Bell et al (2016) [5]	At least three trials in each session as participants walk at a self-selected velocity down an inclined walkway (7 m long, 1.22 m wide) set to a slope of 10°. Handrail use was permitted, but participants were asked to only use assistance if needed.	Vicon, AMTI force plate	120 (Kinematic) 1200 (GRF)	Velocity of descent, step length, step length asymmetry, Prosthetic knee flexion, prosthetic limb steps, prosthetic limb impact peaks, prosthetic and intact limb support moments Stance time asymmetry, ankle excursion, intact limb braking and propulsive forces Hip excursions	MP ↑, MECH similar Similar to both IS=PS
Okita et al (2018) [6]	Ramp descent with a self-selected, comfortable speed in two conditions: with activated stance-yielding (Activated condition) or with deactivated stance-yielding (Deactivated condition).	MAC3D, Kistler force plate	120 (Kinematic) 1200 (GRF)	Walking speed, stride length, and maximum values during early stance for knee angle and lower limb joint moment Vertical and horizontal ground reaction forces, maximum early-stance lower limb extension moment, bilaterally, and maximum early-stance knee flexion angles for the prosthetic side	Deactivated=activated
Mohamed et al (2019) [7]	Two sequential 2s static calibration trials where the participant was asked to stand perfectly still. Three constrained chair rise trials. Walking trials at slow, preferred, and fast speed, from 0 to 100% gait cycle (heel strike to heel strike). At least three repetitions of each gait speed. 30s rest between similar	Vicon T160, Kistler force plates	NI	Stride parameters Phase parameters External work rate (CoM) Internal (joint) power	IS≈PS, MP>AB>MECH MP>MECH>AB A: IS>PS (except MECH double stance) IS>PS PS: Ankle & knee: AB>TFA

	speed conditions and at least 60 s between different speed conditions.			Work rate of gravity	Hip: TFA>AB IS: Ankle: No difference Hip & knee: TFA>AB AB>MP>MECH
Okita et al (2018) [8]	Ramp descent on a 10-segment experimental ramp that was placed on force plates (decline: 5° [8.75%], horizontal length: 3.9 m, width: 0.6 m).	MAC3D, Kistler force plate, Cortex	120 (Kinematic) 1200 (GRF)	GRF, Hip extension moment (ramp) Flexion moment (ramp)	PS>IS Knee: PS>IS Ankle: IS>PS Stance control>Without stance control
Sturk et al (2018) [9]	Using self-paced mode, participants completed two to three walking trials through a virtual park scene. Each walking condition was a 20-m section (LW: level walking, DS: downhill slope, US: uphill slope, TS: top-cross-slope, BS: bottom-cross-slope, HL: rolling-hills, MLT: medial-lateral translations, RO: simulated rocky).	Vicon	100 (Kinematic)	Medial-lateral margin of stability Step parameters Gait variability	K3>K4<AB K3>K4>AB AB>K4>K3
Abouhossein et al (2019) [10]	Level ground walking trials with three different speeds; self-selected pace, faster and slower.	Qualisys ProReflex MCU240, QTM, AMTI force plate,	450 (Kinematic) 1200 (GRF)	Transient loading rate Heel vertical velocity	Week 1: IS>PS, MP>MECH>AB Week 2: reduced Week 2<Week 1 A>NA
Zhang et al (2019) [11]	Walk at their self-selected speed. At first under initial alignment following with the malalignments in random order. After the adjustment of each alignment, the subject walk for 2 min to adapt to that alignment. Under each alignment contain data of eight trials.	Vicon, AMTI force plate	100 (Kinematic) 1500 (GRF)	Speed, stride length Stride width, step time Medial GRF peaks and impulse on both sides and load rate Propulsive and braking peaks, vertical impulse, and medial and vertical load rates of GRF	TFA<AB TFA>AB, PS>IS Malalignment:=initial alignment IS: TFA>AB IS>PS, TFA<AB
Schafer et	Ten trials along a 10m	Qualisys Track	100	Falls	Exercise

al (2018) [12]	walkway, at their self-selected walking speed. At least six trials (range: 6–10 trials) for each participant.	Manager, Kistler force plate	(Kinematic) 1000 (GRF)	Speed (cadence), force, power absorption & generation	group<Control group Exercise group>Control group, Intact>Prosthetic
Varrecchia et al (2019) [13]	Able-bodied and subjects with TTA and TFA underwent an initial training session to become familiar with the assessment procedures then walk with their shoes at comfortable self-selected speeds along a walkway while looking forward. At least ten trials were recorded for each subject and for each speed. To avoid fatigue, groups of three trials were separated by 1-min rest periods in subjects with amputation.	SMART-DX 6000, Kistler force plate	340 (Kinematic) 680 (GRF)	Step length, step width, double support duration, pelvic obliquity, trunk lateral bending and trunk rotation RoMs	TTA/TFA>AB, Genium(MP)>Mech
Hafner et al (2015) [14]	Participants were required to walk across a variety of terrain types (e.g., level hall, level carpet, stairs, and ramp) and report the ability to safely use the prosthesisprior to leaving the laboratory. Participants returned to the laboratory to be evaluated regularly throughout the study. Outcomes were assessed weekly when participants were in baseline phases (Baseline 1 and 2) and monthly when they were in the interventionphases (Intervention 1 and 2).	SportCount Chrono 100 stopwatch	NI	Prosthesis Evaluation Questionnaire–Mobility Scale (PEQ-MS), Activities-Specific Balance Confidence scale (ABC) Timed Up and Go test [TUG], stairs, and ramp), outdoor tests (walking courseand perceived exertion), step activity monitor, self-report surveys(mobility, balance confidence, physical function, fatigue,and general health), and fall incidence	Adaptive control>Passive control
Shirota et al (2015) [15]	An initial five minutes of undisturbed walking was used to obtain an estimate of swing phase duration, necessary for the tripping device controller. The remainder of the data were recorded during continuous walking in trials of 10 s separated by at least 1 min. Trips	Cortex, Split-belt force treadmill	100 (Kinematic) 1000 (GRF)	Elevating, Lowering, Delayed Lowering	TFA<AB
Azuma et al (2019) [16]	Each participant performed Berg Balance Scale, TUG-t, and	Stopwatch	NA	Berg Balance Scale TUG-t time	Ambulatory aid<Without aid

	6MWT. The results were analyzed and compared between the two groups classified based on the use of ambulatory aids.				Young>old
Kendell et al (2015) [17]	Walk along a level hallway (5 trials), foam mats (5 trials), 7° incline (10 trials: 5 ascending and 5 descending, up and down a 12-step stairwell (4 trials: 2 ascending and 2 descending).	F-Scan Mobile System	120	Six parameters were examined: anterior-posterior and medial-lateral center-of-pressure direction changes, sensor cell loading frequency (cell triggering), maximum lateral force position, double support time, and stride time.	IS>PS
Clemens et al (2018) [18]	Assessment of Component Timed-Up-and-Go (cTUG) test turning once in each direction, both toward the intact and toward the prosthetic limb. An instrumented walkway captured temporal-spatial parameters during the performance of the 180° turn task of the cTUG, while a custom iPad application recorded time and number of steps to perform the turn.	Zeno Electronic Walkway, Protokinetics	120 (Kinematic)	Time for turn, 180° turn task	Intact>Prosthetic, TFA>TTA
Prinsen EC et al (2014) [19]	Assessment of their own non-microprocessor controlled knee and with the Rheo Knee® II. The low-profile Vari-Flex with EVO foot was installed in both knee conditions, followed by eight weeks of acclimatisation. The order in which knees were tested was randomized.	CAREN platform	NA	Timed "up & go" test, Timed up and down stairs test, Hill Assessment Index, stairs Assessment Index, standardized walking obstacle course and one leg balance test.	MECH≈MP
Morgan et al (2015) [20]	Auditory analog of the Stroop test while seated. Auditory stimuli that consisted of the words "high" and "low" said in a high or low pitch while walking over the foam surface. Self-selected speed over a low-density, closed-cell foam surface located centrally along an 8.8-m	Qualisys Motion Capture System, Visual3D	120 (Kinematic)	Walking speed, stride lengths, step times Step width, step time asymmetry, variability, cadence	TFA<AB, DT<ST TFA>AB, DT>ST

Received: 06 Feb 2019 | Revised: 07 Mar 2019 | Accepted: 30 Mar 2019

	walkway.				
Hunter et al (2018) [21]	Sitting position and stood up upon listening to the word go, walked 3m, performed a 90° turn, walked 7m, turned180°, retraced the L shape, and returned to the sitting position. Then, L Test with the cognitive task of serial subtractions by 3's from a number randomly selected between 100 and 150.	Stopwatch	NA	Single-task L test, ICC, dual-task L test	TTA(non-vascular)> TTA(vascular)>TFA
Gozaydinoglu et al (2019) [22]	Neuropsychological subtests (serial subtraction test, verbal phonetic fluency test, and semantic verbal fluency test). Points considered during the assessments are as follows; all the assessments were done by the same physiotherapist, participants completed a couple of trials before starting the neuropsychological subtests, and before each test started participants took a 2 min break. All tests have been administered by the dual-task method during ambulation.	Stopwatch	NA	Body image perception and cognitive performance. Body image perception and MoCA score Psychosocial adjustment, prosthesis satisfaction and MoCA scores Activity restriction and MoCA scores Subtraction test scores and psychosocial adjustment, activity restriction, and prosthesis satisfaction scores	Significant Significantly and negative correlated Positive Moderate Weak
Frengopoulos et al (2017) [23]	2-minute walk test (2MWT), and presence of comorbidities. The MoCA was administered within 1 week of admission to the inpatient rehabilitation program. The L Test and 2MWTwere assessed within 48hours of discharge from the inpatient prosthetic rehabilitation program.	Stopwatch	NA	MoCA scores with 2MWT MoCA scores with L Test	Positive Negative

AB=Able-bodied, MECH = Mechanical Passive, MP=Microprocessor, NI=No Information, IS=Intact Side, PS=Prosthetic Side, CoM=Centre of Mass, MoCA=Montreal Cognitive Assessment, ICC=Intraclass Correlation Coefficients, RLL=Residual Limb Length, ST=Single Task, DT=Dual Task, A=Amputated, NA=Non-Amputated

Study procedure

Fifteen reviewed articles focused on the dynamic gait assessment on spatiotemporal, kinematics and kinetics while four articles assessed on balance based on the spatiotemporal and cognitive dual-task. The outcome measurement consists of index assessment, temporal-spatial, kinematics and kinetics, single-task and dual-task. Two force plate was mostly used either Kistler or AMTI to assess the pattern of balance variable and thereby evaluate balance performance. The common frequency for kinematic motion and ground reaction forces is 120 Hz and 1200 Hz respectively. Balance also evaluated by the integration of force plate with other systems, such as Vicon System [5, 7, 9, 11], Qualisys [10, 12, 20] and other instrumentation such as Ma3D, Smart Track Manager, Cortex, F-scan Mobile System, and Caren platform. Most data exported to Visual3D and MATLAB that identify and extract kinematics and kinetics as well as ground reaction forces. Fifteen reviewed articles performed gait analysis on level walkway [9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 21, 22, 23], six articles on inclined or declined walkway [5, 6, 8, 9, 14, 17], three articles on timed up and go [14, 16, 18], an two articles on L test [21, 23] at either self-paced or slow, normal and fast speed. In some studies, balance skills were evaluated using functional assessment, such as Hill Assessment Score [5, 19], Berg Balance Scale [16], Shapiro-Wilk test [5, 17], Activities-Specific Balance Confidence scale [14]. The cognitive task used the Stroop test, neuropsychological subtest and Montreal Cognitive Assessment (MoCA).

Variability in the measured parameters

Hill Assessment Index Score of the passive mechanical group show the greater result when using X2, while the microprocessor group has similar result during initial and X2 session. One article showed the highest Activity Balance Confident Scale compared to the average scores for persons with TFA [14]. MoCA scores had a small positive correlation with the 2MWT (rZ.29, P<.01), and a small negative correlation to the L Test [22]. PEQ-MS consists of a relation between both transition (sit-to-stand) and ambulation. The result showed that trauma TFA has value above average. This was proven as the TUG-Comfortable time decreased.

Temporal-spatial parameter

All reviewed articles mentioned temporal-spatial parameters such as walking speed, step length, step time, cadence, and asymmetry. Temporal-spatial parameters were likely influenced by the flexion of prosthetic knees. The prosthetic side of amputees has greater stride width and step time compared to intact side [8, 11]. Phase parameters for the intact side were greater except for the mechanical double stance.

Kinetics and Kinematics parameters

Microprocessor group has greater performance when using X2® AND Genium where it increased the prosthetic knee flexion at initial contact and swing, as well as longer prosthetic limb steps, increased self-selected velocity, and prosthetic limb impact peaks while improving peak asymmetry [5, 13]. Intact side of the amputees was likely the same for stride parameters and hip excursions. The prosthetic side has greater ground reaction force, hip extension moment, and knee flexion moment [8, 11]. The intact side has a greater external work rate (CoM), ankle flexion moment, vertical impulses, transient loading rate (during Week 1) [7, 8, 11, 17]. TFA walked slower and have shorter intact limb step compared to TTA and healthy controls [11, 15, 20].

Dual-task assessments

The cognitive task used including Stroop Effect (auditory), neuropsychological subtest [20, 21, 22, 23]. The single-task activity is performed where walking and cognitive assessment done individually whereby dual-task means the combination of these two tasks. Analysis of a single task and dual-task determine the response latency and accuracy. Participants with TFA have slower walking speed with a wider step and asymmetry compared to healthy controls for both single and dual-task conditions [16, 17]. There was not much difference in performance between single and dual-task indicating that a cognitive task did not differentially affect walking between groups. In comparison between lower extremity amputations, TFA participants have slow and negative responses compared to TTA participants where non-vascular TTA performed better than vascular TTA.

IV. DISCUSSIONS

The purpose of this systematic review was to summarize the recent studies on biomechanical assessment of transfemoral amputees in ambulating with additional cognitive resources. The biomechanical assessment parameters consist of temporal-spatial, kinetics, and kinematics. The main outcomes of this review were to compare the effect of different prosthetic knees on transfemoral amputees in walking and dual-task assessment.

The studies divided into two categories where the first 15 reviewed articles studies on the assessment of amputees in terms of temporal-spatial, kinetics and kinematics outcomes. The last 4 articles reviewed on dual-task gait assessment with temporal-spatial parameters. Seven articles have transfemoral participants only [5, 6, 14, 16, 17, 19, 22] whereas others included transtibial amputees and healthy controls. The outcomes were described by comparing the performance between transfemoral and transtibial amputees with healthy controls, prosthetic functional levels, prosthetic knee joints, and single-task versus dual-task.

In order to understand pathological gait, it is important to grasp the activity in normal gait. Healthy control participants acted as references or ‘normal’ data in order to analyze the balance walking pattern of the lower extremity amputees. Seven articles assessed on normal gait based on participants’ preferred paced and two included slow, fast-paced walking assessment. Other assessments including normal walking on an uneven surface, ascend and descend slopes and stairs, 90° or 180° turn test, L test, 2 Minute Walk Test (2MWT), time up and go (TUG).

Stability and balancearepart of the crucial factors in helping rehabilitation for a better lifestyle among amputees. The main highlighted topic of the reviewed articles was to identify the balance-related factor regarding the prosthetic knee joints. The studies including gait analysis on temporal-spatial, kinematics and kinetics outcomes. Some articles categorized the outcomes by type of prosthetic knee joints, or Medicare Functional Classification Level. Variation of the categorization of prosthetic knee joint such as between passive and active mechanism, make this review comes with a limitation.

Reviewed articles proved that able-bodied performed better in most conditions followed by transtibial amputees and the least was transfemoral amputees. Amputees with Level 4 classification has better performance compared to Level 3 or lower. For comparison between passive mechanical knee joints, prostheses with stance control yielding better compared to prostheses without stance control. Transfemoral amputees with an adequate amount of practice with their prosthetic legs show positives result in terms of compared to transfemoral amputees with a lacking amount of walking exercises.

Three articles that performed experiments based on weekly assessment shows that the final week of the amputees has better balance assessment in every aspect compared to the initial week [10, 14, 19]. Other observations could be seen that older participants have more difficulty and slightly negative feedbacks compared to younger participants. No comparison assessment has been made between male and female participants where in fact that there are a few articles did not include female participant at all.

Across the measured outcomes, it can be said that the type of knee control was responsible for changes observed in the study. The comparison between knees with passive and active controls of health, function, and mobility of TFA patients can be observed during studies. However, based on the poor measurement results shows that the active knee may not be suitable for older patients with TFA [16].

Literally, there were no significant differences in 6MWT between participants with mechanical (passive) and microprocessor (adaptive) knees. The research observed that adaptive knee technology is more useful at facilitating walking over short distances rather than walking at longer distances. Even though there were no significant differences in measurement, the improvement in walking course time still can be seen for the active knee condition [14].

Based on the dual-task assessment, the cognitive task did not affect walking much between TFA and healthy controls. The visible changes can be observed when TFA patients walked slower with a wider step and greater asymmetry under both conditions [20]. Visual inspection also indicated that only slight differences between test and re-test assessments for the dual-task protocol for TTA, TFA, and healthy control groups [21].

The amputees have a higher work rate, impulse, load rate, and force on intact sides. It shows that the amputees were highly depended on the intact limbs in walking compared to the prosthetic sides. Patients with LEA have lower walking speed, stride length and step time but with greater step width, step time asymmetry, variability, and cadence than healthy controls. The obvious results can be seen in transfemoral amputees compared to transtibial amputees.

The higher gait deviations were expected as the level of an extremity is higher. Due to the loss of anatomy part including sensory and muscles from the results of amputation, transfemoral patients consumed more energy and have less stability in performing successful ambulation compared to transtibial patients. Gait rehabilitation is important in order to help the amputees to gain a normal gait pattern with a sufficient amount of training sessions. Besides initial training provided during post-amputation under the supervision of a physical therapist, the follow-up training with a new prosthetic provided by the prosthetist is also a crucial process for the amputees to adapt to the changes and gain confidence in walking with the new equipment.

There are several limitations when conducting this review where the search strategy was limited to only five electronics databases. There might some related articles missed out on other platforms. The reviewed articles also limited to only full-text English publications. There are several articles cannot be accessed for further evaluation. The inclusion criteria were limited to the gait task, therefore the results on other assessments were excluded in this review. The studies were divided into two categories; biomechanical assessment and dual-task assessment because there is no comprehensive studies have been done on the effect of prosthetic knee joints for both assessments. Future studies also should clearly mention the type of prosthetic used, prosthetic k-level, and other patient characteristics. In addition, the most important thing is to separate passive and active mechanisms into two different groups because this will affect the legality of the analysis.

V. CONCLUSION

Based on this review, it can be concluded that most transfemoral amputees had trouble to gain proper gait pattern and stability compared to transtibial amputees. Most healthy controls have a higher balance, control, and stability compared to lower extremity patients. Patients with LEA use more effort in their amputated side (prosthetic side) when performing the walking task. The cognitive task has minimal impacts on the LEA although there are slight differences in walking performance between healthy controls and the amputees. TFA patients have a greater impact on imbalance compared to TTA patients. Prosthetic knees with a higher level of Medicare Functional Classification Level provides better performances in walking. However, not all patients require active microcontroller knee joints to perform better in movement. A computerized mechanism may have more advantages than mechanical but it does not necessarily mean better. Mechanical knee joint is still preferred by patients as it is lighter in weight, smaller, affordable and does not require charging like microcontroller. Thus, further evaluation of the effect of prosthetic knee joints toward transfemoral amputees can help other researchers to improve the design and quality of the passive prosthetic mechanism.

VI. ACKNOWLEDGMENT

This review work was financially supported by the Malaysia UM/MOHE/HIR grant (Project No: FP003-2017A)

Conflict of interest

The authors do not have any conflict of interest which could affect the outcomes of this study.

Conflicts of interest: None

Source of funding: UM/MOHE/HIR Project No. FP003-2017A.

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