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Kertas Asli/*Original Articles*

A Review of the Analysis of Ground Reaction Force among Adults with Lower Limb Problems

(Tinjauan Analisis Daya Tindak Balas Tanah di Kalangan Orang Dewasa dengan Masalah Anggota Bawah)

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ABSTRACT

The ground reaction force (GRF) is the equal opposing load transfer from the body to the ground, also called vertical load transfer. The GRF would produce stress waves transmitted toward the lower extremities during the heel strike of a gait cycle. Too much force imposed on the lower extremities for an extended period will cause harmful effects such as injuries or alterations in gait. This article presents a review of the literature on GRF analysis among adults with lower limb problems where comparisons between healthy and unhealthy subjects were analyzed, focusing on the compensation in each lower limb. A literature search of published articles in Science Direct and PubMed databases from August 2015 to March 2021 was analyzed. The keywords used for the search were (plantar force OR vertical load transfer OR ground reaction force) AND (lower limb OR lower extremities OR leg OR foot) AND (impairment OR problem OR injury). The literature search identified 22 relevant studies which were screened independently by two reviewers. Lower limb problems such as unilateral transfemoral amputation, unilateral transtibial amputation, patellofemoral pain, anterior cruciate ligament injury, knee arthroplasty, knee osteoarthritis, diabetic foot, total hip replacement, pronated foot proved to alter the GRF significantly. Patients used to shift their weight on the opposite leg as compensation, which acts as a pain-free mechanism. This paper has provided sufficient understanding regarding GRF among adults with lower limb problems. The knowledge concerning compensation may help physical therapists implement the appropriate intervention for patients with lower limb problems.

Keywords: Foot; leg; lower extremity; maximum force; vertical load transfer.

ABSTRAK

Daya tindak balas tanah (GRF) ialah pemindahan beban lawan yang sama dari badan ke tanah, juga dipanggil pemindahan beban menegak. GRF akan menghasilkan gelombang tekanan yang dihantar ke bahagian bawah kaki semasa hentakan tumit ketika berjalan. Terlalu banyak daya yang dikenakan pada bahagian bawah kaki untuk tempoh yang lama akan menyebabkan kesan berbahaya seperti kecederaan atau perubahan dalam gaya berjalan. Artikel ini membentangkan tinjauan literatur tentang analisis GRF dalam kalangan orang dewasa dengan masalah anggota bawah di mana perbandingan antara subjek yang sihat dan tidak sihat dianalisis, memfokuskan pada pengimbangan pada setiap anggota bawah. Carian literatur artikel yang diterbitkan dalam pangkalan data Science Direct dan PubMed dari Ogos 2015 hingga Mac 2021 telah dianalisis. Kata kunci yang digunakan untuk carian adalah (daya plantar ATAU pemindahan beban menegak ATAU daya tindak balas tanah) DAN (anggota bawah ATAU bahagian bawah kaki ATAU kaki ATAU kaki) DAN (kemerosotan ATAU masalah ATAU kecederaan). Pencarian literatur mengenal pasti 22 kajian berkaitan yang disaring secara bebas oleh dua pengulas. Masalah anggota bawah seperti amputasi transfemoral unilateral, amputasi transtibial unilateral, sakit patellofemoral, kecederaan ligamen anterior cruciate, arthroplasty lutut, osteoarthritis lutut, kaki diabetik, penggantian pinggul total, kaki pronated terbukti mengubah GRF dengan ketara. Pesakit biasa mengalihkan berat badan mereka pada kaki bertentangan sebagai pampasan, yang bertindak sebagai mekanisme tanpa rasa sakit. Kertas kerja ini telah memberikan pemahaman yang mencukupi mengenai GRF dalam kalangan orang dewasa yang mengalami masalah anggota bawah. Pengetahuan mengenai pengimbangan boleh membantu ahli terapi fizikal melaksanakan intervensi yang sesuai untuk pesakit yang mengalami masalah anggota bawah.

Kata kunci: Kaki; anggota bawah; daya maksimum; pemindahan beban menegak.

INTRODUCTION

The human lower limb is subject to many stresses and loads during movement. Alterations in lower limb biomechanics during movement lead to postural alignments and gait mechanics such as a decrease in stride length, increase in cadence, alteration in the sagittal plane hip, ankle kinematic and kinetic, and also GRF (Balasundaram & Choudhury 2018; Duffell et al. 2017). The GRF is the equal opposing action of load transfer from the body to the ground (Harithasan et al. 2017). It is vital as it significantly influences the force distribution across the joint during human movement. Human movement focusing on GRF have been studied in the past, mainly related to walking and running (Ismail et al. 2018; Deepashini et al. 2014).

The GRF must be equal on both feet during gait; however, inadequate force and pressure are distributed in abnormal gait due to lower limb problems (Abouhossein et al. 2019). Many factors contribute to lower limb problems, such as trauma, overuse injuries, or other diseases like osteoarthritis or rheumatoid arthritis (Abouhossein et al. 2019; Briani et al. 2018; Petrovic et al. 2017). Lower limb problems might cause alteration in the GRF. More loads are imposed on the opposite leg when a leg is injured. An increased load on the intact leg increases GRF due to a compensatory mechanism to protect the impaired side. Compensation is a natural attempt by the body to continue to function so that activities of daily living can resume as normal. This compensatory movement may lead to injury, low back pain and osteoarthritis, when one part of the lower limb isn't performing correctly, the other parts jump in and try to over-perform to make up for it (Abouhossein et al. 2019). Thus, GRF produces stress waves transmitted toward the lower limb, which are harmful when applied frequently for a long time (Briani et al. 2018).

Within a human movement, various patterns of compensation and the associated movement dysfunction limit an individual's capability in performance and increases the risk of future injury. There are many reviews on this topic, however limiting to a specific lower limb problem, or looking at different instruments, and different measured variables, thus it is important to have a review focusing on GRF and the many lower limb problems so that a wider view of this issues can be seen. Also, this may be a stepping point for looking into the more detailed, specific issues pertaining to GRF and lower limb problems so that proper intervention can be developed for the betterment of the patients. Therefore, this article provides essential information for researchers and clinicians regarding the alteration of the GRF and the compensatory movement in the human body due to lower limb problems. The knowledge may help them identify what kind of treatment and intervention should be for a patient with lower limb impairment. Also, an individual will have the opportunity to correct and neutralize the risks and damage associated with patterns when they have the ability to recognize the compensation patterns. Thus, leading to the development of more efficient biomechanical functions and movement quality.

METHODS

1. Data identification
   A literature search comprised published articles in Science Direct and PubMed databases from August 2015 to March 2021. The keywords used in this literature search were (plantar force OR vertical load transfer OR ground reaction force) AND (lower extremities OR lower limb OR leg OR foot) AND (impairment OR problem OR injury).

2. Article screening and eligibility
   Studies were included in the review if they met the following criteria: Articles were limited to those printed in English journals and full-text articles. The studies must present adults' GRF or plantar pressure with lower limb problems. Articles that are duplicated are excluded from the review.

3. Article included
   The titles and abstracts of studies identified in the literature search were screened independently by two reviewers to assess eligibility for a full-text paper. If the articles were relevant to the studies, the full text was obtained (Figure 1).

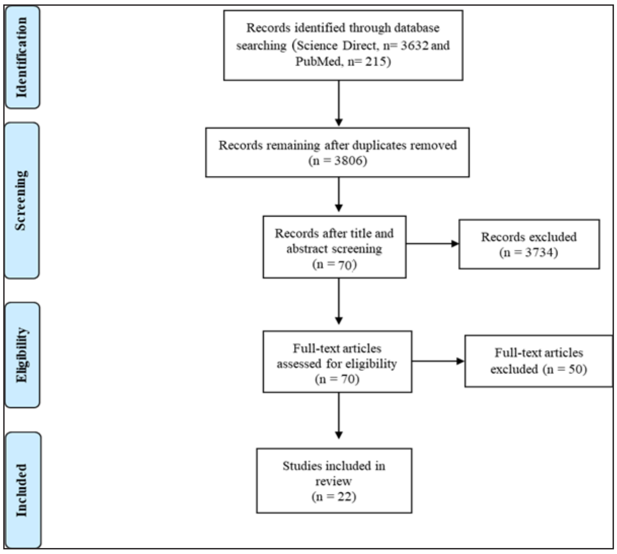

Figure 1. The review flow diagram

RESULT

The literature search identified 22 relevant studies that assessed the alteration in GRF with nine lower limb problems. Among the 22 studies conducted, 3 articles observed GRF among unilateral transfemoral amputees, 4 articles among unilateral transtibial amputees, 2 articles reported patellofemoral pain, 3 articles among anterior cruciate ligament patients, 2 articles observed among knee arthroplasty patients, 2 articles reported on knee osteoarthritis, 2 articles reported on diabetic foot, 2 articles reported about total hip replacement, and 2 articles on pronated foot. Information on the 22 included studies qualified for further review is summarized based on the review context in Table 1.

Table 1. Alteration of GRF (GRF) among adult with lower limb problem

Lower Limb Problems	Study	Objective	Participants	Results
Unilateral transfemoral amputation (UTFA)	Abouhossein et al. 2019	To investigate the short-term process of adaptability for UTFA for two types of prosthetic knees based on the correlation between heel vertical velocity and transient loading rate (slope of GRF).	n=5 (1 UTFA and 4 healthy males)	A negative correlation of GRF and linear velocity indicates that UTFA adaption to different prosthetic knees in the short term is achievable with a slower than self-selected speed.
	Soares et al. 2016	Principal component analysis (PCA) to compare the GRF and center of pressure (COP) displacement waveforms obtained during gait between able-bodied subjects and both limbs of individuals with transfemoral (TF) amputation.	n=32 (12 TF; 11 male, 1 female and 20 physically active able-bodied)	In the stance phase, the prosthetic limb waveform presented reduces vertical GRF compared to the control group in self-selected speed.
	Carse et al. 2020	To quantify the magnitude of the differences in gait profile score and other gait outcomes between a large and more representative group of individuals with UTFA and a group of unimpaired healthy adults.	n=70 (60 UTF and 10 control group)	Reduction in anterior propulsion GRF on the prosthetic side in late stance, self-selected comfortable walking speed.
Unilateral transtibial amputation (UTTA)	Karimi et al. 2017	To investigate joint contact forces calculated by a musculoskeletal model in the intact side and compare it with those of unimpaired subjects.	n=17 (7 UTTA and 10 unimpaired subjects)	There are no significant differences in the peak GRF between subjects.
	Schmalz et al. 2019	To investigate biomechanical gait parameters when walking on a specifically designed ramp involving abruptly changing inclination angles.	n=14 (4 UTTA and 10 control groups)	The first peak of the vertical GRF was significantly smaller than for the control group.
	Nakajima et al. 2018	To compare the gait pattern in vascular TTA with diabetic peripheral neuropathy with that in traumatic TTA.	n=18 (10 vascular TTA with diabetic peripheral neuropathy and traumatic TTA)	The anterior GRF was smaller on the non-amputated side in vascular TTA subjects than the traumatic TTA in self-selected speed.
	Actis Nolasco, et al. 2018	To characterize the low back biomechanics of people with and without unilateral TTA during sit-to-stand using musculoskeletal modeling.	n=16 (8 UTTA and 8 without TTA)	Those with TTA were more asymmetric than the control. There is greater vertical GRF in the intact leg and greater posterior and medial force generation in the prosthetic leg.

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Patellofemoral pain (PFP)	Alvim et al. 2019	To compare kinematics and muscle induced acceleration patterns between PFP subjects and healthy controls during the preparation phase of the single leg triple hop test.	n=21 (11 PEP and 10 physically active women)	There is an increase in GRF in the late stance phase, where the muscles deliver the highest forces, projecting the body upwards and forwards until the foot loses contact with the platform.
	Briani et al. 2018	To investigate the immediate effects of patellofemoral joint (PFJ) loading on pain and vertical GRF loading rate.	n=34 women with PFP, with (condition 2) and without (condition 1) being previously submitted to a PFJ loading protocol in order to or not to exacerbate their knee pain).	There is an increase in vertical GRF loading rate among women in condition 2 compared to condition 1 during stair ascending and stairs descent. If there is a higher level of pain, higher vertical GRF is produced.
Anterior Cruciate Ligament Injury (ACLI)	Bakker et al. 2016	To study ACL strain during jump landing by investigating its correlation with sagittal plane kinetic/kinematic parameters and by creating an empirical model to estimate the maximum strain.	n=7 healthy subjects	Higher GRF was produced due to body stiffness that correlated with ACL strain.
	Butler et al. 2016	To examine how landing mechanics change in patients after ACL reconstruction between 6 months and 12 months after surgery.	n=15 after ACL reconstruction surgery	Non-surgical limbs exhibit a more significant peak impact of vertical GRF compared with the surgical limb.
	Sanford et al. 2016	To explore differences between ACL reconstructed subjects' and control subjects' GRF during squatting.	n=16 (8 ACL reconstructed subjects and 8 healthy uninjured height- and weight-matched control subjects)	There is an asymmetry GRF among the ACL reconstructed subjects, unlike the normal controls. The ACL reconstructed subjects tended to shift more of their body weight to the contralateral limb.
Total Knee Arthroplasty (TKA)	Braito et al. 2016	To compare gait characteristics and knee extensor strength after medial unicondylar knee arthroplasty (MUKA) vs TKA, given the same standardized approach in both groups.	n=32 (17 minimally invasive surgery-TKA and 15 minimally invasive surgery-MUKA)	There is no significant difference in the GRF.
	Christensen et al. 2018	To compare inter-limb asymmetry differences during both level and decline walking tasks at six months following TKA compared to asymmetry present in an age, gender, body mass index and activity level with matched healthy cohort.	n=57 (42 TKA and 15 healthy-matched peers)	The vertical GRF in TKA group is higher than in the control group.

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Knee Osteoarthritis (KOA)	Davis et al. 2019	To compare sagittal walking gait biomechanics between participants with KOA who increased quadriceps strength following a lower-extremity strengthening intervention (responders) and those who did not increase strength following the same strengthening protocol (non-responders) both at baseline and following the lower extremity strengthening protocol.	n=53 KOA were enrolled in 10 sessions of supervised, progressive lower extremity strengthening	Individuals with KOA demonstrate lower vertical GRF in the first peak of stance, more significant at midstance, and less in the second peak of stance phase.
	Duffell et al. 2017	To characterize this relationship and to relate biomechanical and structural parameters in a subset of OA patients.	n=109 (25 unilateral medial KOA and 84 healthy participants)	There is an increase in GRF in experimental subjects (KOA).
Diabetic Foot	Fernando et al. 2016	To compare the gait parameters of cases with diabetes-related foot ulcers to controls.	n=146 (21 with diabetes-related neuropathic plantar foot ulcers, 69 with diabetes without a foot ulcer history (diabetes controls) and 56 healthy controls)	There are greater vertical GRF in diabetes-related neuropathic plantar foot ulcers than diabetic patients with foot ulcer history.
	Petrovic et al. 2017	To establish whether there are differences in the external moment arm (ExtMA) and effective mechanical advantage (EMA) at the ankle in patients with diabetes and diabetic peripheral neuropathy (DPN) compared to controls.	n=67 (31 non-diabetic controls, 22 diabetes patients without peripheral neuropathy and 14 moderate/ severe DPN)	GRF were significantly higher in DPN group and diabetic group compared to control subjects.
Total Hip Replacement (THR)	Esposito et al. 2018	To understand mid-term effects of crutch length setup on quiet standing and walking two months post-op when crutch use was no longer required.	n=30 post-THR surgery patients, assigned randomly to elbow flexed (EF) or elbow extended (EE) crutch set-up groups	GRF parameters were not significantly different between weight acceptance and push-off peaks for both limbs when comparing EE and EF groups. Force impulse increased dramatically in both operated limb and unaffected limbs for the EF group compared to the EE group.
	Lunn et al. 2019	To examine functional differences in THR patients when stratified either by age or by functional ability as defined by self-selected walking speed.	n=164 (137 THR and 27 healthy control)	There is a consistent and systematic reduction of GRF parameters between the low functional group compared to the high functional group and control group. The high functioning group were closely aligned functionally with the control group.

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Pronated Foot	Farahpour et al. 2016	To investigate the effects of excessive foot pronation and the association of low back pain with excessive foot pronation on the GRF components during shod walking.	n=30 (15 subjects with pronated feet only and 15 with pronated feet and low back pain)	Low back pain patients with foot pronation displayed higher vertical GRF and higher loading rate.
	Mohammadi et al. 2018	To determine the changes in foot kinetic parameters in the pronated compared to the normal foot structures.	n=30 (15 with asymptomatic pronated feet and 15 normal subjects)	Vertical GRF is higher in pronated foot subjects than in normal subjects.

DISCUSSION

The GRF is the central aspect that should be looked at in patients with lower limb problems due to the alteration induced by compensatory body mechanics (Zadpoor & Nikooyan 2012). However, the compensation occurs is different according to the types of lower limb problems. Many lower limb problems or impairments in the lower extremities can be seen in our daily lives. The discussion below suggests how these problems were reported to influence the GRF.

UNILATERAL TRANSFEMORAL AND TRANSTIBIAL AMPUTATION

In this lower limb problem, adaptation, protection, and compensation were the main issues. It was reported that GRF decreased as the amputee learned to adapt to the prosthetic knees during slow walking compared to control subjects (Abouhossein et al. 2019). In addition, studies reported an asymmetrical loading on both legs among amputee subjects where smaller GRF was generated on the prosthesis side compared to the non-affected side (Abouhossein et al. 2019; Actis et al. 2018a; Nakajima et al. 2018). The GRF on the prosthetic limb decreased compared to the intact limb as a protective mechanism of the residual limb; thus, subjects tend to put more load on the intact limb (Soares et al. 2016). The unloading of bone on the residual limb caused a decrease in bone mineral density (Carse et al. 2020). Also, the causes were a more significant displacement of the trunk centre of mass from its neutral position and weakness of push-off in a late stance on the prosthesis side (Nakajima et al. 2018; Actis et al. 2018b). Thus, for an amputee with a new prosthetic knee, the rehabilitation strategy may focus on imposing a slower than the self-selected speed at the beginning. Once they become more familiar, the prosthetist may allow the amputee to walk faster.

Amputees also present a decrease in hip extensor associated with hip flexion contracture, leading to gait and socket fit problems. These patients also have reduced hip abductors, flexors and extensors and increased anterior pelvic tilt (Carse et al. 2020). Amputees may reduce the external hip adductor by moving the center of mass laterally to the stance side to compensate for the weak hip abductor. This movement may be achieved by increasing the trunk side flexion (Carse et al. 2020). Contradictly, Karimi (2017) reported no significant differences in GRF components between the amputee and healthy subjects (Karimi et al. 2017). The result may be due to the prosthesis selection, proper socket fit, and prosthesis alignment. Thus, rehabilitation such as physical education, incorporating an adequate prosthesis, and fitting is mandatory for dealing with amputees.

PATELLOFEMORAL PAIN

Patients with patellofemoral pain exhibit higher GRF than healthy subjects due to compensatory movement such as alteration in knee kinematics (Briani et al. 2018). It is the pain that occurs at the front of the knee and regularly just behind the kneecap. Higher GRF is harmful when applied frequently for a long time (Briani et al. 2018). A decreased knee flexion was a compensatory strategy to reduce pain due to the lower extremity absorption mechanisms as a result of friction and wear-and-tear on the structures of the knee (Briani et al. 2018; Alvim et al 2019). As there is a relationship between pain and GRF, interventions should reduce GRF by understanding knee pain pathomechanics, which is crucial to improving the treatment plan. A combination of soft tissue therapy and effective stretching techniques on the overactive and/or tight muscles and activation exercises to strengthen and facilitate proper firing sequences of the underactive muscles would be recommended (Briani et al. 2018; Alvim et al. 2019). Besides, the combination of muscular, kinematic, and dynamical alteration of the lumbar, pelvis, hip, knee, or ankle joints can also be used as a compensatory strategy to reduce pain (Alvim et al 2019).

ANTERIOR CRUCIATE LIGAMENT INJURY

A more significant peak impact of GRF was observed on experimental subjects, with higher GRF on a non-surgical limb than on a surgical limb (Butler et al 2016). In jumping tasks among healthy participants, compensation occurs during landing due to body stiffness. ACL strain during jump-landing may contribute to an ACL injury (Bakker et al. 2016). Also, another study showed an asymmetrical GRF in patients after ACL reconstruction surgery. Greater GRF was found on the uninjured leg (Sanford et al. 2016). During squatting, ACL-reconstructed subjects also shifted their body weight to the contralateral limb (Sanford et al 2016). It was known that these patients used intralimb or interlimb compensation strategies during bilateral movement to achieve their moving target (Baumgart et al. 2017). This compensation strategy can be seen among ACL reconstructed patients whose weak quadriceps show divergence during weight acceptance. Eccentric quadriceps contraction was required to control knee flexion and shock absorption (Baumgart et al. 2017). Altered load distributions across the knee joint due to changes in loading pattern may put subjects at risk for future complications such as osteoarthritis.

KNEE ARTHROPLASTY

Christensen et al. (2018) reported that the GRF in the total knee arthroplasty group was higher than in healthy subjects because knee arthroplasty patients exhibit greater physical exertion (Christensen et al. 2018). Meanwhile, Braito et al. (2016) reported no significant differences between the group of knee arthroplasty and healthy subjects (Braito et al. 2016). However, another article stated knee arthroplasty patients exerted significantly less force on their affected limb than on non-affected limbs during stance phase gait (Burnett et al. 2015). These findings occurred because these patients were scheduled to undergo total knee arthroplasty within four weeks, thus avoiding aggravating pain by placing imprudent force on that limb (Burnett et al. 2015). The avoidance is a pain reduction mechanism where these patients compensate by placing greater force and spending more time on their non-affected limb while completing the task of supporting the body throughout the stance phase (Braito et al. 2016; Burnett et al. 2015). As there is very limited and inconclusive evidence on knee arthroplasty and GRF, more studies are needed to understand the underlying mechanism pertaining to knee arthroplasty, in the hope of limiting further damage to the operated and also other joints in the lower kinetic chain.

KNEE OSTEOARTHRITIS

The vertical GRF was higher during 6-30% of the stance, then decreased simultaneously during 42-60% of the stance (Davis et al. 2019). The lower GRF occurs because patients absorb and generate less energy and power at the hip, knee and ankle (Davis et al. 2019). Thus, it reduces the reaction force at the knee (Davis et al. 2019). Whereas, at peak GRF the knee adduction increases on the affected side and decreases the hip adduction angle (Duffell et al. 2017). These patients have loaded their arthritic knee joints beyond what they would expect. Another article reported that osteoarthritis patients had significantly lower and less symmetrical push-off force and push-off impulse due to weakness during the terminal stance phase, which was also a factor in slower walking speeds (Wiik et al. 2017). Osteoarthritis patients walked more slowly and asymmetrically following the previous study, with shorter step lengths and wider-based gait (Wiik et al. 2017). Slower walking speed may be secondary to loss of muscle power around the surrounding joint. This loss may be due to pain and progressive attrition of muscle power due to the decreasing activity found in the biomechanically faulty knee (Wiik et al. 2017). Understanding the loading characteristics and abnormal mechanics in knee OA pathogenesis may help prevent or delay this condition from occurring.

DIABETIC FOOT

The GRF in patients with diabetes mellitus was higher than in healthy subjects (Petrovic et al. 2017). Moreover, it was highest when patients were associated with diabetic peripheral neuropathy and diabetic foot ulcer (Petrovic et al. 2017). For patients with diabetic peripheral neuropathy, the GRF would increase with faster walking speed (Petrovic et al. 2017). The patients' strategy reduces effective mechanical advantage (EMA) around the ankle joint (Petrovic et al. 2017). This statement is supported by an article stating that the neuropathy group had a significant increase in the first and second peaks of GRF compared to the diabetic foot and control group (Saura et al. 2010). This overload might be related to the adaptation in the intrinsic musculature of the foot, which has dynamic and static alterations overloading the forefoot (Saura et al. 2010). It is also stated that the plantar overload combined with reduced protective sensibility advocates the occurrence of cutaneous ulcers and Charcot's Arthropathy (Saura et al. 2010). Besides, increasing anterior and posterior GRF among diabetic foot ulcer groups proved that mechanical loading on an ulcerated limb substantially increases during gait with slower walking speeds and smaller steps length (Fernando et al. 2016).

TOTAL HIP REPLACEMENT

There is a symmetrical GRF among patients with total hip replacement and the control group (Lunn et al. 2019). Even two months post-surgery patients who applied elbow flexion and elbow extension crutches showed that the application did not influence these parameters after the surgery which indicates that total hip replacement surgery did not alter the GRF (Esposito et al. 2018). Meanwhile, Martinez-Ramirez et al. (2014) stated that patients with total hip replacement showed greater average GRF during walking for both involved and uninvolved lower limbs post-total hip replacement (Martinez-Ramirez et al. 2014). It was reported that before surgery, patients used their uninvolved legs as extra support for the injured lower limb, causing prolonged duration during the stance and swing phase (Martinez-Ramirez et al. 2014). However, GRF and time parameters such as stance time significantly improved after a total hip replacement (Martinez-Ramirez et al. 2014).

PRONATED FOOT

Patients with pronated feet exhibit higher vertical GRF than normal subjects (Mohammadi et al. 2018). Authors suggest that these patients wear foot orthosis to reposition the tibia and femur in their normal condition and optimize the lower limb joint (Farahpour et al. 2016). However, another article reported that GRF might not be affected by foot orthosis (Gijon-Nogueron et al. 2018). Meanwhile, Farahpour et al. (2016) study were among the population with the pronated foot alone and pronated feet with low back pain. Foot pronation subjects with low back pain exhibit higher vertical GRF (Farahpour et al. 2016). The results reveal that GRF findings among patients with lower back pain with a pronated foot may have clinical values on the prognosis and rehabilitation of mechanical LBP patients.

CONCLUSION

GRF is a measurement we can use to identify any alteration in gait among patients with lower limb problems. One such identification is the patterns of compensation in the lower limbs among those with lower limb problems. Compensation may increase inefficiencies and can even lead to injury when the human body tries to "compensate" for an injury because bones, muscles and tissue are all connected and designed to work together. The changes in GRF between the intact and impaired leg will help acknowledge the patient and clinician regarding the compensation that occurred in the patient's body mechanics. With this knowledge, the clinician may apply the appropriate intervention to improve the patient's quality of life. In addition, as the GRF in lower limb problems was the main focus of this study, further looking at the lower limb muscle activation patterns and strength may also be an added value in looking at a holistic approach for intervention.

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