Palestinian Medical and Pharmaceutical Journal (PMPJ). 2022; 7(2): 177-186

Biomechanical changes in hallux valgus in running conditions: a systematic scoping review

Mosab Amoudi [1,]*

[1]Health Sciences Department, Arab American University, Palestine

*Corresponding author: mosab.amoudi@aaup.edu

Received: (20/2/2022), Accepted: (4/3/2022). DOI: https://doi.org/10.59049/2790-0231.1090

ABSTRACT

Hallux valgus (HV) is the most prevalent deformity of the big toe. Little was reported on HV's biomechanics/biomechanical performance under running conditions. This systematic scoping review was conducted to search the peer-reviewed literature for articles reporting the effects of running programs/interventions in patients with HV. Additionally, this study aimed to summarize the available evidence on biomechanics and the effects of running programs/interventions for patients with HV. Peer-reviewed articles were retrieved through a systematic search of the following databases: Scopus, Medline/PubMed, and Google Scholar. Because the data collected in this systematic scoping review were heterogeneous, the data were presented as qualitative/narrative synthesis. A total of 4,523 articles were initially identified through a systematic search of the databases. After removing the duplicates and screening against the inclusion and exclusion criteria, 6 articles were finally included. The studies included in this review were published from 2015 to 2022. The majority (66.7%) of the articles included in this review originated from China. Of the studies included, 2 (33.3%) used pre-and post-intervention design, 1 (16.7%) was a randomized controlled intervention, and the rest were cohort studies. The studies included in this review have shown that the biomechanical changes in HV have affected the knee joint movements in the affected patients. The studies included in this review showed that a 12-week minimalist footwear running program intervention resulted in varus realignment of the 1st metatarsophalangeal joint and reduced the von Mises stress in the 1st and 2nd metatarsals. HV can affect the biomechanics and performance of the foot of the affected patients. Despite the paucity of studies, barefoot/minimalist footwear running interventions might reduce pain and improve the performance of patients with HV. Future studies are still needed further to understand the biomechanical changes in HV under running conditions.

Keywords: Hallux valgus, Minimalist footwear intervention, Running, Pain, Quality of life.

INTRODUCTION

Hallux valgus (HV) is a health condition characterized by deformity, ill-positioning of the 1st metatarsophalangeal joint, lateral abduction of the big toe, and medial adduction of the 1st metatarsal bone [1]. The result is a broader forefoot with deformity of the ordinarily straight alignment of the 1st metatarsophalangeal joint. The term "Hallux valgus" was coined in 1870 by Carl Hueter [2].

According to recent studies, the HV angle, which is the angle between the 1st metatarsal and proximal phalanx, is often used to classify the severity of the deformity as mild (15º to 20º), moderate (20º to 40º), and severe (> 40º) [3-6]. Notably, the vast majority (> 90%) of HV patients have mild to moderate deformity. HV is the most prevalent deformity of the great toe [7]. A previous study reported that 84% of patients with bilateral deformities had HV [8]. It has been argued that genetic predisposition, job environment, pes planus (flat foot), and type of footwear were identified as risk factors for HV [1].

Previous studies have shown that HV affects the morphology of the foot and the biomechanics of performance. This can be translated into the dysfunction of the foot, deviations in gait, and impairment of the quality of life of patients with HV [9]. Previous studies have shown that patients with HV often complain of pain over the medial eminence, metatarsalgia, a medial deviation in the first ray, local skin/bursa irritation, and pronation and lateralization abduction of the great toe [1, 2, 8]. In HV, the range of motion and mobility of the subtalar, ankle, transverse tarsal joint, and metatarsophalangeal joint are often evaluated [10, 11].

Currently, there are many treatment options for patients with HV. These options include surgical and non-surgical interventions. Previous reports have described more than 100 surgical interventions that can be used to correct HV [2]. Although the non-surgical interventions are not effective in correcting the deformities, these interventions were shown to reduce signs and symptoms and improve the quality of life of patients with HV. Due to higher recurrence rates, non-surgical interventions can be prescribed for hypermobile patients who have neuromuscular diseases and those with ligamentous laxity [2]. Additionally, non-surgical interventions can also be recommended for patients with surgical contraindications like those with peripheral artery diseases.

Previous studies have shown that patients with HV often change plantar pressures at the forefoot regions (notably in the proximal phalanx and 1st metatarsal) [12]. Due to non-restrictive conditions, barefoot walking might benefit the normal development of the foot's morphology and functional performance [13]. Additionally, previous studies have demonstrated the positive effects of barefoot and minimalist footwear running on the muscular strength of the foot [14, 15]. Moreover, Martini et al. showed that running with a minimalist shoe can change the plantar pressure in the forefoot region [16].

Little was reported on HV's biomechanics/biomechanical performance under running conditions. Additionally, little was reported on the effects of running interventions for patients with HV. Systematic scoping reviews have emerged to systematically map critical issues that underpin certain research areas and summarize the available evidence [17]. This systematic scoping review was conducted to search the peer-reviewed literature for articles reporting the effects of running programs/interventions in patients with HV. Additionally, this study aimed to summarize the available evidence on biomechanics and the effects of running programs/interventions for patients with HV.

METHODS

Study design: This systematic scoping review adhered to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses statement for scoping reviews (PRISMA-ScR) [18]. Previous protocols of systematic scoping reviews were used to inform the protocol used in this review [17, 19].

Search, and selection of the articles: Peer-reviewed articles were identified through a systematic search of the following databases: Medline/PubMed, Scopus, and Google Scholar. The search was conducted using medical subject headings and other key terms like hallux valgus, run, runner, running, jogging, cross country, trail runner, ultramarathon, and marathon. The terms were combined using Boolean tools like "OR" and "AND." The databases were searched as late as January 07, 2022.

Combining the terms ensured retrieval of the most significant number of articles before screening against the inclusion and exclusion criteria. This step should have reduced the risk of missing some critical articles. The outcomes of the search were combined, and duplicates were removed. The remaining articles were screened against the inclusion/exclusion criteria.

Inclusion and exclusion criteria: Articles were included when they reported on biomechanics under running conditions in HV or the effects of running on HV. Articles published in languages other than English were excluded. The search was not restricted to a specific publication period, type of article, or place of origin.

Data collection: A data extraction form was created specifically for this study. From each article, the following data were collected: authors, journal, year of publication, sample size, country of origin, study design, measurements, and main findings.

Because the data collected in this systematic scoping review were heterogeneous, the data were presented as narrative synthesis.

RESULTS

In this study, 4,523 articles were initially identified through a systematic search of the different databases. When the duplicates were removed, 3,436 articles remained. When these articles were screened against the inclusion/exclusion criteria, 87 articles were eligible for a full-text review. Of those, 6 articles were included for the narrative synthesis (Figure 1).

Characteristics of the studies included: The studies included in this review were published from 2015 to 2022. The majority (66.7%) of the articles included in this review originated from China. The rest of the studies originated from Germany and the US. Of the studies included, 2 (33.3%) used pre-and post-intervention design, 1 (16.7%) was a randomized controlled intervention, and the rest were cohort studies. The sample sizes used in the included studies ranged from 13 to 45.

Narrative synthesis: Because of the heterogeneous nature of the data collected, a narrative synthesis was adopted for this study. Table (1) summarizes the main findings of the articles included in this review.

Biomechanics of HV: Sun et al. studied the mechanics of lower extremities in young females with mild HV while jogging [20]. In their study, kinematics of the knee and distribution of plantar pressure were collected from patients with HV and healthy controls under jogging conditions at a natural speed. The findings demonstrated that the angles of the knee joints in the transverse and frontal planes were significantly different between patients with HV and normal controls under running conditions. The study showed that the initial adduction angle of the frontal plane in the normal controls was 1.73º vs. 8.33º in the patients with HV. The peak of the kneed abduction angle during the jogging gait cycle in the normal controls was 8.46º vs. 8.61º in the patients with HV.

On the other hand, the initial external rotation angle of the knee in the transverse plane was 21.93º in the normal controls vs. 4.89º in the patients with HV. Concerning plantar pressure, the study showed that regions of pressure bearing were offshore in the patients with HV. The study concluded that these biomechanical changes affected the knee joint movements in patients with HV. Additionally, patients with HV were at higher risk for knee osteoarthritis [20].

In a preliminary study, Jacobs et al. compared the impact of passive hallux adduction on the blood flow through the lateral plantar artery [21]. Their study measured the arch height index and blood flow before and after performing passive hallux adductions. The study showed that following passive hallux adductions, the blood flow was decreased by 22.2% compared to before performing passive hallux adductions. Blood flow changed negatively with the decrease in the arch height index. The study concluded that wearing narrow-toed shoes can significantly impact the blood flow in the feet of patients with HV. Patients with a lower arch height index are at higher risk of reduced blood flow after performing passive hallux adductions [21].

Xiang et al. studied the effects of manipulations of hallux abduction on the distribution of plantar pressure and intersegment kinematic changes [6]. Their study measured the distribution of plantar pressure and intersegment kinematics of the foot and lower extremities under walking and running conditions. The findings showed significant elevation in the peak pressure in the 3rd metatarsal and contact area in the 2nd metatarsal under running conditions. Additionally, peak pressure and pressure-time integral showed significant elevation in the 3rd metatarsal. The maximal force and impulse were also significantly increased in the 4th metatarsal.

Additionally, the foot progression angle of the frontal plane significantly increased during running. The study concluded that manipulations changed central and lateral redistribution of foot loading and forefoot intersegment flexibility. These changes can be considered in making baseline and post-intervention measurements in HV deformities [6].

Effects of interventional programs: In another pilot study, Xiang et al. studied foot morphologies and collected plantar pressure measurements of 11 patients with HV deformities [13]. Using a 12-week minimalist footwear running program intervention resulted in a significant decrease in the hallux abductus angle and forefoot width. Additionally, the 12-week intervention of the minimalist footwear running program also resulted in a significant increase in the metatarsal waist girth. The study also showed that peak pressure, force-time integral, and maximum force of the 1st metatarsal decreased significantly after the

12-week intervention of the minimalist footwear running program. These changes were attributed to the distribution of plantar pressures to other regions in the center of the foot. The study concluded that minimalist shoes could help deform the morphology of the forefoot and neutralize the load concentration in patients with mild to moderate HV [13].

In a recent study, Xiang et al. evaluated the effects of minimalist footwear running intervention for a patient with mild to moderate HV [22]. The investigators used computer tomography scans before and after a 12-week minimalist footwear running program intervention. The foot 3-dimensional (3D) geometries were used to develop foot finite element models before and after the interventional program. A total of 24 bones, 22 cartilages, 5 plantar fasciae, and a lumped encapsulated soft tissue were used in the models. The interventional program resulted in varus realignment of the 1st metatarsophalangeal joint. Additionally, the von Mises stress decreased by 72.1% (4.41 MPa) in the 1st metatarsal and 51.2% (4.18 MPa) in the 2nd metatarsal compared to the pre-intervention measurements. The study concluded that a 12-week minimalist footwear running program intervention resulted in shape adjustment and functional recovery of a mild to moderate case of HV deformity [22].

In a prospective randomized study, Plaass et al. studied the effects of a dynamic HV splint [23]. In this study, radiological and other clinical variables of the patients who underwent dynamic HV splint and no treatment were measured and evaluated. The study showed that the dynamic HV splint significantly reduced pain associated with walking and running and pain scores at rest. The study concluded that wearing a dynamic HV splint reduced pain relief among patients with symptomatic HV [23].

DISCUSSION

HV is the most prevalent deformity of the human foot. HV can affect the patients' gait and quality of life [9]. In this systematic scoping review, studies reporting on the biomechanics and performance of patients with HV under running conditions were identified, selected, and narratively summarized for the first time. The findings of this study could be informative to those seeking to understand the biomechanical changes in HV and design non-surgical interventions to reduce pain and improve the quality of life of the affected patients.

This study was conducted following the PRISMA-ScR. Adherence to the international guidelines for conducting systematic reviews can promote transparency in reporting the findings of these systematic reviews [18]. This study systematically searched Medline/PubMed, Scopus, and Google Scholar. These databases harbor the majority of the peer-reviewed scientific literature [24]. Using these databases should have allowed retrieval of most of the peer-reviewed articles published on the topic. This should have added strength to the findings of this study. Additionally, the systematic search of the databases was carried out using medical subject headings and relevant key terms. This should have added rigor to the search methodology used in this review [25].

Although many articles were initially retrieved, only 6 studies met the inclusion criteria and were finally selected. This should have reflected the paucity of studies on the topic [2, 6, 20-23]. This study's findings should be considered a call for researchers and funding bodies to conduct more studies. In this review, most of the studies were published between 2015-and 2022. These findings might indicate a recent focus on the topic.

Moreover, the studies originated from China, Germany, and the US. HV deformities could either be inherited or acquired. Previous studies have shown that wearing high-heeled shoes, accidents, arthritic changes in joints, and some neurological disorders such as spastic diplegia and cerebral palsy cause HV deformities [26]. The choice of the intervention strategy can primarily be affected by the cause and severity of HV [26, 27]. Additionally, a systematic review with meta-analysis estimated a high pooled prevalence rate of HV at 23% (95% CI of 16.3% to 29.6%) in the general population of these societies [28]. In China, Germany, the US, and other industrialized countries, women probably wear high-heeled shoes more often than in other cultures [27]. This study's findings should be considered a call for researchers in different regions of the world to conduct more studies on the biomechanics of HV under running conditions.

The studies included in this review have shown that the biomechanical changes in HV have affected the knee joint movements in the affected patients [6, 20, 21]. These findings suggested that patients with HV were at higher risk for knee osteoarthritis [20]. The findings reported in this review were consistent with recent evidence on the association between HV and osteoarthritis [4, 5]. Under running conditions, the peak pressure in the 3rd metatarsal, contact area in the 2nd metatarsal significantly increased, and peak pressure and pressure-time integral in the 3rd metatarsal significantly increased [6]. These findings showed that patients with HV redistribute foot loadings and intersegment forefoot flexibility. These findings help measure baseline and post-intervention changes when treating/managing HV deformities [6].

The studies included in this review showed that a 12-week minimalist footwear running program intervention resulted in varus realignment of the 1st metatarsophalangeal joint and reduced the von Mises stress in the 1st and 2nd metatarsals [13, 22, 23]. These shape adjustments and functional recovery of the deformities were consistent with the changes in plantar pressure in the forefoot region among patients with HV [12]. Because barefoot or minimalist footwear running is non-restrictive, these conditions were shown to support the normal development of morphology and functional performance of the foot [13]. It has been argued that barefoot and minimalist footwear running can improve muscular strength and functionality of the foot [14, 15].

Limitations of the study: This systematic scoping review has some limitations. First, articles published in languages other than English were excluded. This could have impacted the findings of this study as actual results could have been published in other languages. Second, this was a systematic scoping review. It has been argued that evidence synthesized through systematic reviews with meta-analysis could be considered superior to that synthesized narratively in a systematic scoping review. Third, the quality of the included studies was not assessed using the standard assessment tools. Although assessing the quality of the studies included could have added another dimension to the results reported in this study; however, this systematic scoping review aimed to provide an overview of the evidence. Because this systematic scoping review was not aimed at synthesizing evidence from the included articles, an assessment of the quality and risk of bias was not required [19].

CONCLUSION

In conclusion, HV can affect the biomechanics and performance of the foot of the affected patients. Despite the paucity of studies, barefoot/minimalist footwear running interventions might reduce pain and improve the performance of patients with HV. Future studies are still needed further to understand the biomechanical changes in HV under running conditions.

Table (1): A summary of the included articles.

#	Authors (year)	Objectives	Sample size	Measurements	Main findings
	Biomechanics				
1	Sun et al (2015)	To measure the kinematics of the knee and distribution of plantar pressure among patients with HV and normal controls under	Female volunteers (n = 16)	• Weight, height, length of the leg, and widths of the ankle and knee • 3D motion of the lower limb • In-shoe plantar pressure	• Significant differences in the angles of a knee joint in the transverse and frontal planes among patients with HV and normal controls • The peak knee abduction angle during the jogging gait cycle (normal controls = 1.73º, patients with HV = 8.33º)

#	Authors (year)	Objectives	Sample size	Measurements	Main findings
		jogging conditions			• The peak of the knee abduction angle during the jogging gait cycle (normal controls = 8.46º, patients with HV = 8.61º) • The initial external rotation angle of the knee in the transverse plane (normal controls = 21.93º, patients with HV = 4.89º) • Regions of plantar pressure bearing were offshore in the patients with HV • Patients with HV were at higher risk for knee osteoarthritis
2	Jacobs et al. (2019)	To compare the effects of passive hallux adduction on the blood flow through the lateral plantar artery	Volunteers (n = 45)	• Arch height index • Ultrasound imaging • Electrocardiogram • Blood pressure • Blood flow velocity	• There was a 22.2% reduction in the blood flow after passive hallux adduction • As the arch height index decreased, the blood flow negative changed • The vessel diameter in pre- and post- passive hallux adduction differed significantly (pre-passive hallux adduction = 0.129 ± 0.05 cm, post-passive hallux adduction = 0.120 ± 0.05 cm) • Patients with lower arch height index were at higher risk of reduced blood flow when performing passive hallux adductions
3	Xiang et al. (2020)	To study the effects of manipulations of hallux abduction on the distribution of plantar pressure and intersegment kinematic changes	Volunteers (n = 13)	• Walking and running speeds • Dynamic plantar loading patterns • Motion capture • Maximum force • Force-time integral/impulse • Contact area • Peak pressure • Pressure-time integral	• There was a significant elevation in the peak pressure in the 3rd metatarsal and contact area in the 2nd metatarsal under running conditions • There was a significant increase in the peak pressure and pressure-time integral in the 3rd metatarsal • There was a significant elevation in the maximal force and impulse in the 4th metatarsal • During running, there was a significant increase in the foot progression angle of the frontal plane • Changes in the central and lateral redistribution of foot

#	Authors (year)	Objectives	Sample size	Measurements	Main findings
					loading and intersegment forefoot flexibility can be used in making baseline and post-intervention measurements in HV deformities
	Effects of interventional programs				
1	Xiang et al. (2018)	To study foot morphological deformation and changes in plantar pressures after a 12-week running intervention using minimalist running shoes among patients with mild and moderate HV deformities	Patients with mild and moderate HV deformities (n = 15)	• Foot morphology scanning (X-ray imaging) • Measurement of plantar pressure • Measurement of 3D foot surface • X-ray imaging	• Following the 12-week running intervention using minimalist running shoes, there was a significant decrease in the peak pressure, force-time integral, and maximum force of the 1st metatarsal • These changes were attributed to the redistribution of plantar pressure to other regions in the center of the foot • The use of minimalist shoes can help deform the morphology of the forefoot and neutralize the load concentration in patients with mild-moderate HV
2	Xiang et al. (2022)	To evaluate the effects of minimalist footwear running intervention for a patient with mild to moderate HV	Patients with mild and moderate HV deformities (n = 15)	• Computer tomography (CT) images • Foot finite element models • Plantar pressure	• The 12-week intervention of the minimalist footwear running program resulted in varus realignment of the 1st metatarsophalangeal joint • The von Mises stress decreased by 72.1% (4.41 MPa) in the 1st metatarsal and by 51.2% (4.18 MPa) in the 2nd metatarsal compared to the pre-intervention measurements • The 12-week intervention of the minimalist footwear running program resulted in shape adjustment and functional recovery of a mild to moderate case of HV deformity
3	Plaass et al. (2020)	To study the effects of a dynamic HV splint for patients with symptomatic HV	Control group (n = 26), intervention group (n = 29)	• X-ray imaging • Range of motion • Metatarsalgia • The American Orthopedic Foot and Ankle Society - Hallux metatarsophalangeal interphalangeal scale • Foot and ankle outcome score	• There was a significant reduction in pain during running and walking • There was a strong trend of reduction in the pain subscale of the foot and ankle outcome score • Wearing a dynamic HV splint resulted in pain relief among patients with symptomatic HV

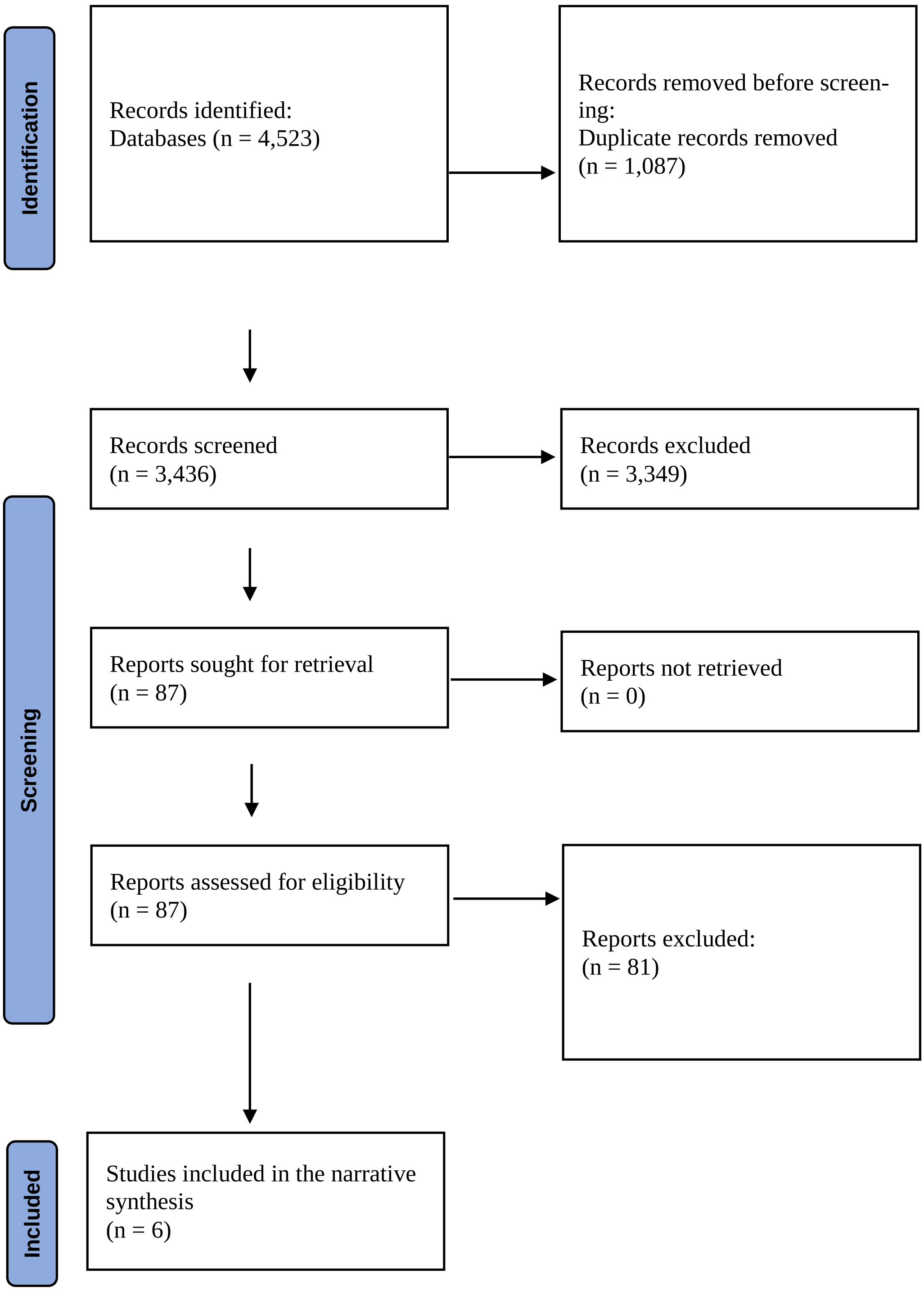

Figure (1): PRISMA flowchart of the selection process.

Ethics approval and consent to participate: This was a systematic scoping review. Therefore, ethics approval and consent to participate are not applicable.

Consent for publication

Not applicable.

Availability of data and materials

All data relevant to this study were included in the manuscript, figure, and table.

The data sets used to generate the figure and table are available from the corresponding author upon reasonable request.

Author's contribution

Mosab Amoudi: conceptualization, writing-original draft, data curation, formal analysis, funding acquisition, investigation, methodology, project administration, resources, software, supervision, validation, visualization, and writing review & editing.

COMPETING INTEREST

None.

FUNDING

Any specific funding did not support this study.

ACKNOWLEDGMENTS

The author would like to thank the Arab American University, Palestine, for making this study possible.

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