



Monitoring of external predisposing factors for Diabetic Foot: A literature review and physicians' perspectives

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Abstract

Background: Diabetic foot is one of the most important complications of diabetes caused by the existence of some destructive factors in different anatomical locations of feet. Management and monitoring of these factors are very important to decrease or avoid ulcerating lesions of the foot. The purpose of this study is to identify and introduce the predisposing factors and anatomical locations associated with these destructive factors.

Methods: First, we conducted a comprehensive review of different databases to identify the factors and associated anatomical locations from the previous studies. Then, we designed a questionnaire and invited physicians and specialists to express their perspectives on these factors and locations. The data were analyzed using SPSS version 23. Frequency, percentage, mean and standard deviation of these variables were calculated.

Results: Based on the literature review, four factors, including pressure, moisture and sweat, temperature, and acceleration were identified as factors destructive to the tissues of the diabetic foot and worsen ulcers. The view of specialists approved the results of the literature review. Besides, there was an insignificant difference between the results of the literature review and the specialists' view in terms of anatomical locations that need to be continuously monitored.

Conclusion: Monitoring the pressure in heel, first metatarsal, and first metatarsal head; moisture and sweat under the fingers, hallux and heels as well as the temperature at the first metatarsal, first metatarsal head, and the third metatarsal head are important in preventing ulceration, destructing the foot tissue, and accelerating the treatment process.

Keywords: Diabetic foot, Monitoring, Factors, Foot ulcer

Conflicts of Interest: None declared

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Introduction

One of the most important complications of diabetes is diabetic foot, by which about 15 to 25 percent of diabetics are affected (1). According to the World Health Organization, diabetic foot is defined as infection, ulceration, or destruction of the deep soft tissues associated with neurological abnormalities and peripheral vascular involvement in the lower limbs (2). Every 20 seconds, one foot in the world is amputated due to diabetes although more than 80 percent of these cases are preventable (3). Foot ulcer is the most important affecting factor for infection in diabetic

patients (4). Therefore, without providing the necessary care, these ulcers can lead to infection, gangrene, amputation and even death (5).

One of the most common causes of diabetic foot ulcers is neuropathy. Neuropathy leads to the absence of sensation or deformation of the foot. In this group of patients, even a small trauma may lead to a chronic ulcer. Furthermore, continuous walking on the injured foot with the absence of the sense of pain and pressure lead to failure in the treatment process because with the presence of periph-

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↑What is "already known" in this topic:

Many parameters related to foot and footwear may result in or exacerbate foot ulcers in patients with diabetes.

→What this article adds:

In order to prevent the formation of wounds in the diabetic foot, the parameters that cause diabetic foot ulcers, such as pressure, temperature, and humidity should be monitored, measured and managed.

eral vascular disease, ulcers will develop to an ischemic ulcer and a non-improved wound (6). In addition to this internal factor, many external factors related to the foot and shoes such as pressure, temperature, humidity, foot movement in shoes, shoe straps, insoles, depth and stiffness of shoes can increase the diabetic ulcers. Each of these external aspects requires the patient's attention to monitor the condition of the wound (7).

It has been shown that preventive actions have a positive impact on the quality of patients' lives and reduce healthcare costs (8). Therefore, the primary advice for preventing diabetic foot ulcers is daily inspection and continuous monitoring of foot, temperature control and orthotic shoes (9). In order to prevent the formation of wounds in the foot, the parameters that cause diabetic foot ulcers, such as pressure, temperature, and humidity should be monitored, measured and managed (10).

Diabetic foot problems have been presented as the main cause of illness, disability, and mortality in diabetic patients (11). Although different studies have been conducted to identify and introduce the influential factors, no comprehensive review has been done to investigate the mentioned parameters and important anatomical locations for monitoring these factors. Therefore, the aim of this study is to identify external factors that may result in forming and deteriorating the diabetic foot and major anatomical locations of this problem.

Methods

The study was conducted in the two following phases

1. A comprehensive review of the literature

A comprehensive review of the literature was conducted to identify the external factors and the anatomical locations for monitoring these factors. PubMed/Medline, Web of Science, ProQuest, Scopus, Google Scholar, Science Direct, and Springer web sites were searched. The search process was performed using Medical Subject Headings (Mesh) terms and the synonyms. The articles published between January 2005 and October 2017 were searched. Published articles in scientific conferences and journals were selected. A sample of the search strategy in PubMed/Medline is given in Table 1. We customized this strategy for other databases.

At first, the titles and abstracts of the retrieved papers were screened. Next, based on the inclusion and exclusion criteria, the articles were selected. Then, fulltexts of the articles were studied; and the name of the factors and anatomical locations were extracted. The data were collected using a data extraction form.

The inclusion criteria were as follows: articles published in English, access to the fulltexts of the articles, and data on the factors affecting foot ulcer. Exclusion criteria were as follows: articles addressing other aspects of diabetes

and diabetic foot, non-English papers, books, book chapters, letters to the editor, and the abstract of the conferences.

2. Investigating specialists' point of view regarding the important factors

At this phase, a questionnaire was developed to collect the data. Endocrinologists and physical medicine specialists were asked regarding the possible important factors and related anatomical locations. The questionnaires were distributed among physicians and then collected after several days.

The questionnaire consisted of two parts. The first part included the specialists' demographic data, and the second part included the questions related to the factors and anatomical locations in the form of five-point Likert scale. Five questions were developed to be asked about the importance of factors and 26 and 13 questions regarding the anatomical locations for monitoring pressure and temperature, respectively. Moreover, open questions were used to identify the major anatomical locations for monitoring the foot's moisture, sweat, and acceleration.

Face and content validity of the questionnaire were confirmed by two physical medicine specialists and endocrinologists. Based on the received opinions, some anatomical locations were removed from the questionnaire. Validity of the questionnaire was analyzed using Cronbach's Alpha (0.934).

In this study, all physical medicine specialists and endocrinologists affiliated to Iran University of Medical Sciences (24 specialists) were invited to study, and finally, 19 questionnaires were completed and analyzed. In order to analyze the data, each factor and anatomical sites were scored from 1 to 5 (very low important to very important). Then the frequency, percentage, mean and standard deviation were calculated. All analyses were conducted in SPSS 23.

Results

The frequency of female participants was higher than males. The majority of participants were 45 to 55 years old. Most of them had 1 to 10 years of experience (57.9 percent) (Table 2).

Regarding the literature review, abstracts and titles of 600 retrieved papers were screened. After removing the duplicates and irrelevant studies and considering the inclusion and exclusion criteria, 100 studies were included in the analysis (Table 3).

According to the review, plantar pressure with 78 references (12-89), moisture and sweat with 29 references (27, 28, 34, 51-55, 57, 58, 72-75, 78, 81, 83, 86, 87, 90-99), foot temperature with 27 references (28, 34, 51-55, 57, 58, 72-76, 78, 81, 82, 87, 100-108) and acceleration on foot with 5 references (28, 82, 109-111) were the most

Table 1. Keywords and search strategy

Row	Keywords
1	(Diabetic foot OR diabetic feet OR diabetic neuropathies OR foot ulcer* OR planter ulcer)
2	(Risk factor OR high risk OR foot biomechanics OR foot fissures)
3	(Plantar* OR peak pressure OR pressure* OR moisture* OR temperature* OR heat OR sweat OR friction OR accelerate OR force OR high-heeled OR force transducer)
Search strategy	[(1) AND (2) AND (3)]

Table 2. Participants' demographics

Variables		Frequency	Percentage
Sex	Male	7	36.8
	Female	12	63.2
Age	25-35	4	21.1
	36-45	4	21.1
	46-55	7	36.8
	>55	1	5.3
	No response	3	15.8
Education degree	Specialist	9	47.4
	Sub-specialist	10	52.6
Type of medical Specialties	Endocrinologist	13	68.4
	Physical medicine	6	31.6
	1-10	11	57.9
Years of service	11-21	3	15.8
	>21	5	26.3

frequently cited factors, respectively (Table 3).

Moreover, according to Table 3, from the specialists' points of view, pressure, moisture and sweat, temperature, and acceleration are important to be monitored, respectively. Only three participants suggested other factors such as foot size, foot shape, muscle strength, color, foot ulcers (each of these have been mentioned once).

Based on the review of the literature, heel, first metatarsal head, fifth metatarsal head, hallux, and first metatarsal bone were identified as the five anatomical locations need to be monitored for pressure. Besides, five anatomical

locations including first metatarsal bone, first metatarsal head, third metatarsal head, fifth metatarsal head, and the middle of the foot were identified as the most important locations that should be monitored for temperature. It should be noted that regarding moisture and sweat as well as acceleration, the selected papers had not introduced any certain anatomical location (Table 4). According to the findings (Table 4), five locations including first finger, first metatarsal head, heel, first metatarsal and third metatarsal head were prioritized to be monitored for pressure (mean ≥ 4). Additionally, according to the specialists'

Table 3. Required factors for monitoring the diabetic foot based on literature review and specialists' perspectives

Factors	Number of References	References	Specialists' perspectives					Mean \pm SD
			Frequency (percentage)					
			Very important	Important	Moderate important	Low important	Very low important	
Foot pressure	78	(12-89)	14 (73.7)	2 (10.5)	3 (15.8)	0 (0)	0 (0)	4.58 \pm 0.76
Moisture	29	(27, 28, 34, 51-55, 57, 58, 72-75, 78, 81, 83, 86, 87, 90-99)	6 (31.6)	8 (42.1)	4 (1.21)	1 (5.3)	0 (0)	4.00 \pm 0.88
Foot temperature	27	(28, 34, 51-55, 57, 58, 72-76, 78, 81, 82, 87, 100-108)	8 (42.1)	8 (42.1)	3 (15.8)	0 (0)	0 (0)	4.26 \pm 0.73
Acceleration	5	(28, 82, 109-111)	5 (26.3)	5 (26.3)	4 (21.1)	3 (15.8)	2 (10.5)	3.42 \pm 1.34

Table 4. Anatomical locations for monitoring foot pressure based on literature review and specialists' perspectives

Anatomical locations	Results of the literature review		Specialists' perspectives
	Number of references	References	
Heel	23	(19-23, 26, 33, 34, 36-39, 41, 49, 50, 80, 85, 86, 112)	4.47 \pm 0.69
First metatarsal head	17	(20-22, 25, 32, 36, 39, 42, 47, 49, 50, 77-80, 82, 86)	4.68 \pm 0.67
Fifth metatarsal head	16	(19, 20-22, 25, 32, 35, 36, 39, 42, 49, 50, 77-79, 113)	4.00 \pm 0.81
Hallux	15	(15, 18, 23, 26, 29, 30, 37, 40, 42, 43, 78, 79, 85, 86, 89, 113)	4.06 \pm 0.69
First metatarsal	14	(12, 13, 15, 23, 26-28, 38, 40, 43, 46, 87, 89)	4.22 \pm 1.00
Third metatarsal head	13	(19-22, 25, 32, 36, 39, 47, 50, 79, 80, 82)	4.11 \pm 0.73
Second metatarsal Head	12	(20-22, 25, 32, 36, 39, 47, 48, 51, 77)	4.26 \pm 1.04
Fourth metatarsal head	11	(19-22, 25, 32, 36, 39, 77, 78, 86)	3.84 \pm 1.01
Second metatarsal	10	(13, 15, 18, 23, 26, 40, 51, 77, 87, 89)	3.88 \pm 0.99
Fifth metatarsal	9	(13, 26, 28, 38, 45, 49, 80, 87, 89)	3.44 \pm 0.89
First finger	8	(19, 28, 34, 48, 77, 82, 86, 87)	4.74 \pm 0.56
Fourth metatarsal	5	(15, 18, 26, 47, 89)	3.41 \pm 0.71
Third metatarsal	4	(12, 18, 45, 89)	3.47 \pm 0.71
Toe	3	(26, 36, 42)	3.77 \pm 0.77
Third finger	3	(79, 82, 87)	3.44 \pm 0.89
Calcaneus	3	(24, 25, 25)	3.47 \pm 1.12
Fifth Finger	2	(30, 79)	3.44 \pm 0.89
Lateral Mid-foot	2	(26, 34)	3.35 \pm 0.66
Mid-foot	1	(87)	2.76 \pm 3.35
Fourth finger	1	(85)	3.24 \pm 0.66
Second finger	1	(19)	3.88 \pm 0.99

Table 4. Ctd

Anatomical locations	Results of the literature review		Specialists' perspectives
	Number of references	References	Mean±SD
Instep	1	(23)	3.06±1.14
Navicular	1	(19)	2.94±0.82
Medial forefoot	5	(31, 34, 48, 77, 78)	* *
Under the metatarses	2	(14, 44)	* *
Lateral forefoot	3	(30, 31, 34)	* *
Central forefoot	2	(30, 31)	* *
Metatarsal joints and Falangular Joint first	2	(35, 85)	* *
Fifth metatarsal phalangeal joint	2	(35, 85)	* *
Proximal inter phalangeal	1	(35)	* *

*These locations were removed from the questionnaire because of the specialists' views on the content validity of the questionnaire.

Table 5. Anatomical locations for monitoring foot temperature based on literature review and specialists' perspectives

Anatomical locations	Number of References	References	Mean±SD
First metatarsal	5	(28, 67, 102, 106, 107)	3.75±1.00
First metatarsal head	4	(100-102, 105)	3.67±1.04
Third metatarsal head	4	(100-102, 105)	3.20±0.94
Fifth metatarsal head	4	(79, 101, 102, 105)	3.21±0.97
Medial mid-foot	4	(100-102)	3.56±1.15
Heel	3	(100-102)	3.69±1.25
First finger	3	(28, 100, 101)	4.00±1.02
Calcaneus	2	(28, 80)	3.13±0.99
Fifth metatarsal	1	(28)	3.25±1.00
Fourth metatarsal head	1	(100)	3.13±0.99
Hallux	1	(105)	3.40±1.12
Cuboid	1	(105)	2.93±1.03
Cuneiform	1	(105)	2.80±0.86

views, five locations including first finger, first metatarsal, heel, first metatarsal head and medial mid-foot were the most important locations to be monitored for temperature (Table 5).

Regarding the mentioned anatomical locations to be monitored for moisture and sweat, only a limited number of participants answered the open question related to this factor. They mentioned these locations: under fingers, in the fingers, and heels (seven people for each), the exterior part of the foot (six people), middle part of the foot front and the central part of the foot front (three people), hallux (two people), first metatarsal bone, first metatarsal head, second metatarsal head, third metatarsal head, on the foot and ankles (one person for each).

The specialists also considered heel (ten people), first metatarsal head (seven people), second metatarsal head, third metatarsal head (six people for each), fourth metatarsal head, fifth metatarsal head and the toes (five people), hallux (three people), first metatarsal, cuboid and navicular (two people for each), toe, Mid-foot, calcaneus and instep (one person for each) as important location to be monitored for acceleration.

Discussion

We found that pressure, moisture and sweat, temperature and acceleration are important, and among them, the pressure is more important than the other factors to be monitored. Payne et al. presented the plantar pressure as the major non-traumatic mechanical risk for the diabetic foot (114). Pham et al. and La salvia et al. also showed that there is a direct relationship between foot ulcer and increased topical pressure in a way that ulcer is initiated as a result of undesirable pressure and then it will lead to break the protective layers of the skin and in turn result in an ulcer (115, 116).

According to the above-mentioned discussion, two questions are posed: 1. Why are the pressure and moisture more important than the temperature? 2. Why are moisture and sweat necessary and essential for the diabetic foot, unlike the temperature and pressure?

In response to the first question, Payne et al. study can be considered. They presented the local increase of the plantar pressure as the major non-traumatic mechanical risk for the diabetic foot (114). Moreover, Brand reported that the pressure might cause an increase in temperature, destruction of the texture, and ulcer (117). Hall et al. also reported that a six-minute walk could result in a 5 °C increase in the temperature. Therefore, the temperature of the plantar can be increased as a result of forces or mechanical pressures in plantar (118). Shah mentioned that principles for treating diabetic foot are changing in nutrition, blood glucose and infection control, effective debridement, dressing and maintaining the ulcer moisture and sweat and eliminating the foot pressure, but he did not consider the temperature in the treatment principles (119). According to Bolton et al., the treatment of the foot ulcer consists of two phases: first, the exact diagnosis of the ulcer and the damaged tissue, and second, detailed assessment of ulcer in which following processes should be provided: cleaning, pain-reduction, removing necrotic tissue and adding moisture to dry ulcer and managing the excessive moisture and sweat (120).

Similar to the Shah's study, Bolton et al. considered the moisture and perspiration as a principle in the treatment of the foot ulcers and focused on its control to improve the foot ulcers. In addition, Volmer et al. declare that sweat secretion as a result of autonomic neuropathy increases blood perfusion from the deep layer and leads to the skin overheating (121).

Therefore, according to the previous statements, it can

be declared that temperature cannot be denied as a parameter to monitor the diabetic foot. However, similar to the findings in the review of the literature and specialists' view, in order to monitor the diabetic foot, pressure, moisture and perspiration should be in a higher priority than temperature, but the temperature cannot be ignored.

In response to the second question, it is necessary to remind that the foot skin will be dry because of inadequate perspiration and moisture. Therefore, the protective function of the skin will be fragile, and the damage risk will increase, and because of autonomic neuropathy, conditions such as arterial sclerosis, Charcot foot, neuropathic edemas, and other changes will happen (121). There are several hypotheses for emphasizing on the moisture and perspiration to the extent necessary to improve the diabetic foot ulcers. Landsman et al. have recognized excessive wetness or moisture as a cause of separating and destructing the tissue levels, spreading infection and turning it into a deep ulcer (98). Accordingly, it can be argued that both little and excessive moisture and perspiration will increase the risk of forming and worsening the diabetic foot ulcers; therefore, its amount should be considered and monitored.

The findings derived from the literature and specialists' perspectives showed that monitoring the pressure of the first finger, the first metatarsal head, the heel, the first metatarsal, the third metatarsal head, the fifth metatarsal head and the hallux is significant to prevent the ulcerating, tissue destructing and accelerate the treatment process in this group of patients. Singh et al. and Lavery et al. believe that the pressure peak occurs in the heel, metatarsals, and first fingers in diabetic patients (52, 122). The reason of increased pressure in the metatarsal head is found at the phase of the pressing on the foot when the heel come apart from the ground, and the whole body weight is on the front part of the foot and in this case, the heel and the mid-foot cannot bear extra body weight, but the pressure of the metatarsal heads may increase to 414 kilopascal (123).

Although some participants in the study emphasized on monitoring the moisture and perspiration in some specific locations of the foot, based on the review of the literature, certain anatomical locations were not found. Landsman et al. also believe that the moisture and perspiration are not related to a certain point of anatomical location on the foot, but it usually can be seen more around the ulcer (98). Coates et al. also did not present a certain anatomical location to monitor the foot perspiration and moisture (28).

Based on the review of the literature, five anatomical locations including the first metatarsal, the first metatarsal head, the third metatarsal head, the fifth metatarsal head and middle of the foot to monitor the temperature has been more introduced. Moreover, specialists emphasized on the first finger, first metatarsal, heel, the first metatarsal head and the medial mid-foot for monitoring the planar temperature. Enkhzul et al. considered the toe, the first metatarsal head, the third metatarsal head, the fourth metatarsal head, the middle of foot, and heels to monitor the foot temperature (100). Coates et al. also suggested calcaneus, the first metatarsal and first finger to be monitored for temperature (28). Bus et al. believe that increasing the local temperature can occur in the interior medial

of the left foot and under the first metatarsal head area in the right foot. They also declared that increasing local temperature is a warning sign to destruct the skin in the future (67). Erdenechimeg also suggested that the first metatarsal head, the third metatarsal head, the fifth metatarsal head, the toe, interior of the mid-foot and the heel should be monitored in terms of the temperature (101).

This study has some limitations. First, the specialists in one of the medical sciences universities in Iran were surveyed; therefore, the results cannot be generalized to the whole specialists in the country. Second, although we invited all of the specialists, most of the participants had less than 10 years of experience. However, we think that this did not affect our study because their viewpoints are in line with the literature. Third, the first phase of the study is not a systematic review. Forth, we aimed to identify the factors and related anatomical locations. Therefore, all types of studies with different methods were included. It is clear that the quality of all studies is not at the same level and finally, in this study, we considered only the external factors related to diabetic foot, and we did not consider other factors such as neuropathy.

Conclusion

According to the findings, we can conclude that among the destructive parameters, monitoring the pressure and temperature considering the related anatomical locations is very important to prevent ulcerating, destructing the foot tissue and accelerating the process of the treatment for this group of patients. Monitoring the pressure in the first finger, the first metatarsal head, the heel, the first metatarsal, the third metatarsal head, the fifth metatarsal head and the hallux as well as monitoring the temperature in the first finger, the first metatarsal, the first metatarsal head, the third metatarsal head, the fifth metatarsal head, the heel and middle of the foot are more important than other anatomical locations. The results of this study can be considered as a base to formulate and develop educational programs aimed to enhance the diabetics foot care, pave the ways to identify the foot problems in patients immediately and decrease the diabetic foot complications in patients with increased knowledge and the self-management performance of this group of patients.

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Ethical Consideration

This study was approved by research ethics committee of Iran University of Medical Sciences (IR.IUMS.REC.1396.32532).

Conflict of Interests

The authors declare that they have no competing interests.

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