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Infrared Thermography in Detecting Peripheral Arterial Disease in Diabetic Foot: A Scoping Review

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ABSTRACT
Early and accurate assessment of peripheral arterial disease (PAD) is crucial given its fatal complications such as amputation. Infrared thermography (IRT) offers various advantages in studying PAD. This study aims to map the use of Infrared thermography in detecting Peripheral Arterial Disease in diabetic feet. This review applies the scoping review method to review the literature related to Infrared thermography in detecting vascular disorders in diabetic legs. Article searches are conducted on five databases, namely Google Scholar, PubMed, EBSCO, ScienceDirect, and ProQuest. The Boolean keywords and codes used are "Infrared Thermography" AND "Diabetic foot" AND "Peripheral Arterial Disease". Searches are limited to articles published between 2018 and 2024. The journal selection process follows PRISMA's guidelines. The search process yielded 1,969 article titles relevant to the keywords and Boolean operators used. After being selected based on the research topic, 8 articles were left for analysis. IRT can be a useful tool for detecting PAD in diabetic foot. IRT can help track the progression of PAD and classify the foot as PAD without or prone with high accuracy

Keywords: Infrared thermography, Peripheral arterial disease, Diabetic Foot.

INTRODUCTION

Diabetic foot is a chronic serious complication that often occurs in people with diabetes mellitus (DM) (Altoijry et al., 2021). These complications can develop into a variety of more severe health problems, one of which is Peripheral Arterial Disease (PAD) (Azhar et al., 2023). PAD is one of the most feared complications of diabetes in diabetic foot cases (Tresierra-Ayala &; García Rojas, 2017). This is because PAD can increase the risk of injury and amputation of the foot (Normahani et al., 2018). The risk of amputation in diabetic patients with PAD is 15-20 times higher compared to diabetic patients without PAD (McGinigle & Minc, 2021). The prevalence of PAD in diabetics is estimated to reach 3-4 times compared to people who do not have diabetes (Chun et al., 2019). Global data shows that the prevalence of PAD reaches 202 million people (Akalu &; Birhan, 2020), and 12% of adults in the world have PAD (Noumegni et al., 2021). The high prevalence of PAD in people with diabetes is a serious concern for the world of health (Zou et al., 2022).

Early and accurate assessment of PAD disease is crucial given its fatal complications, such as amputation (Banik et al., 2020). Some non-invasive tools can be used to determine the severity of the disease and assess the affected blood vessels (Ilo et al., 2020). Conventional methods for diagnosing PAD such as Ankle-Brachial Index (ABI), treadmill tests, and ultrasonography have significant limitations (Crepaldi et al., 2023). Some methods cause discomfort to the patient (Altoijry et al., 2021). Procedures such as treadmill tests are also time-consuming, which can add to the burden on patients and the health system (Zenunaj et al., 2021).

Infrared thermography (IRT) exists as a non-invasive method that offers various advantages in assessing PAD (Ilo et al., 2020). IRT works by capturing heat radiation emitted by the surface of the skin of the foot (Crepaldi et al., 2023). Infrared sensors on IRT cameras convert this radiation into temperature, producing thermal images that show the distribution of heat in the legs (Chatchawan et al., 2018). Cooler areas in this image may indicate reduced blood flow due to PAD (Carlos Padierna et al., 2020). IRT involves no radiation or physical contact, as well as speed and ease in examination and allows for rapid evaluation of PAD-related energy beams (Ilo et al., 2019). However, despite its potential, scientific evidence on the use of IRT to diagnose PAD in diabetes is mixed and warrants further study (Crepaldi et al., 2023). This study aims to map the use of Infrared thermography in detecting Peripheral Arterial Disease on diabetic foot.

RESERCH METHOD

This study used the scoping review method to map and synthesize scientific evidence related to IRT in detecting vascular disorders in diabetic legs. The article selection process follows the PRISMA diagram and is tailored to the research objectives. Article searches are conducted on five databases, namely Google Scholar, PubMed, EBSCO, ScienceDirect, and ProQuest. Keywords and Boolean operators ("AND" and "OR") are used to narrow the search and find relevant articles. The Boolean keywords and codes used are "Infrared Thermography" AND "Diabetic foot" AND " Peripheral Arterial Disease ". Article search is limited to 2018-2024. The following table 1 explains the inclusion and exclusion criteria used to select articles.

Table 1. Inclusion and exclusion criteria

Selection Criteria	Inclusion Criteria	Exclusion Criteria
Language	English	In addition to English
Respondents	Diabetes Mellitus Patients	In addition to Diabetes Mellitus Patients
Year	2018-2024	Under 2018
Types of Studies	Quantitative research Qualitative research	Thesis Thesis Dissertation News articles Case study Conference abstract Unpublished primary studies Reviews

Topic	Use of IRT in detecting PAD in diabetic foot	In addition to the use of IRT in detecting PAD in diabetic feet
Availability	Full text	Non-Full text

RESULTS AND DISCUSSION

The search process yielded 1969 article titles relevant to the keywords and Boolean operators used. A total of 1 article was found on EBSCO, 50 articles on PubMed, 39 articles on ScienceDirect, 99 articles on ProQuest, and 1780 articles on Google Scholar. After being selected based on the research topic, 8 articles were left for analysis (Figure 1). One study had a cross-sectional design, three studies with an observational design and four other studies used an experimental design (Table 2). Five studies evaluated the diagnostic potential of IRT in assessing PAD (Ilo et al., 2019; Ilo et al., 2020; Carabott et al., 2021; Zenunaj et al., 2021; Crepaldi et al., 2023), one study analyzed relevant features extracted from images to build a PAD Classification model (Carlos Padierna et al., 2020), and two studies identified an association between foot temperature and peripheral artery disease in type 2 diabetes patients (Gatt et al., 2018; Antônio de Carvalho Abreu et al., 2022).

Seven studies used IRT Flir with the type (Ilo et al., 2019; Ilo et al., 2020; Carabott et al., 2021; Zenunaj et al., 2021; Gatt et al., 2018; Antônio de Carvalho Abreu et al., 2022; Crepaldi et al., 2023), and one study with the Xenics Goby 640 GigE Infrared camera (Carlos Padierna et al., 2020). From 8 room temperature studies to take foot temperature taken between 21-25 ^{o}C and temperature capture distance using IRT ranges from 80-150 cm from the foot. The findings of the journal are presented in Table 2.

Figure 1. PRISMA flowchart article search process

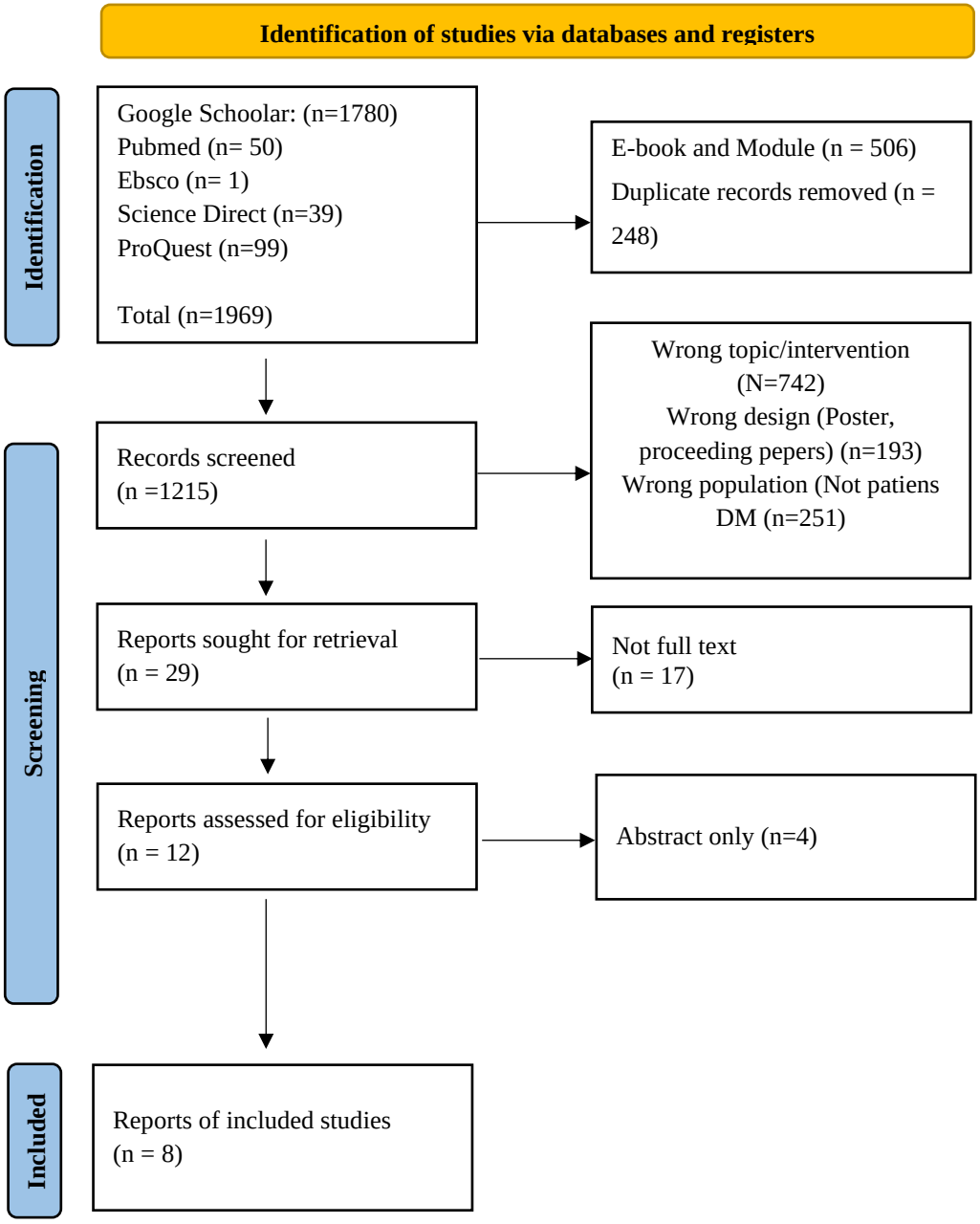

Table 2. Journal findings

Author/Year	Purpose	Respondents	Design	Findings
Ilo et al., (2019)	Evaluate the potential of IRT in assessing vascular disorders in diabetic foot compared to conventional noninvasive measurements.	DM patients (n = 118) and healthy control group (n = 93)	Experiment	IRT can reveal differences in local temperature, dappled color, and higher average temperature in high-risk diabetic feet with vascular disorders of diabetic feet.
Carlos Padierna et al., (2020).	Analyze relevant features extracted from IRT images of the upper side of the foot and toes and build a Support Vector Classification model to classify PAD.	DM group (n = 23) and control group (n = 20).	Experiment	Patients with diabetes and PAD showed lower energy intensity than the control group, showing a significant difference.
Ilo et al., (2020)	Evaluate the clinical diagnostic potential of IRT compared to conventional noninvasive measurements for PAD	93 healthy control patients and 164 PAD patients	experiment	IRT is effective in distinguishing temperature differences between feet and can be useful diagnostically.
Carabott et al., (2021)	Analyze differences in temperature changes in patients with and without PAD in the T2DM population using the angiosome concept.	The number of samples was not mentioned but participants were categorized in no PAD, mild PAD or heavy PAD group.	Experiment	Patients with PAD exhibit much higher forelimb temperatures, according to the angiosome concept. Foot elevation does not significantly affect the thermal pattern

Zenunaj et al., (2021)	Evaluate the usefulness of IRT as a diagnostic tool to assess the severity of peripheral artery disease in patients with PAD undergoing Infrafemoral endovascular revascularization procedures.	The number of samples was not mentioned but respondents were taken from 2020-2021 in PAD patients	Observational	IRT can be a valuable tool in evaluating the clinical presentation and severity of blood perfusion in the legs of symptomatic PAD patients, as well as in evaluating the technical success of endovascular revascularization.
Gatt et al., (2018)	Identify the relationship between higher temperatures in the front of the foot and PAD in type 2 diabetes patients, and to explore the potential use of infrared thermography as a non-invasive tool in early detection and monitoring of peripheral artery disease in diabetic patients	223 DM patients	Observational	There was a significant difference in front leg temperature between the group of participants with type 2 diabetes and peripheral artery disease (DM+PAD) compared to the group of participants with type 2 diabetes alone. Participants with DM+PAD showed higher temperatures at the front of the feet compared to participants with type 2 diabetes alone.
Antônio de Carvalho Abreu et al., (2022)	evaluate the correlation between ABI and IRT photography in patients with PAD	52 high-risk patients with PAD	Cross sectional	There is a strong correlation between ABI and IRT photography in patients with non-calcified arteries.
Crepaldi et al., (2023)	Assess changes in foot temperature using IRT before and after the exercise program, and to check if there are gender differences in response to the exercise program	76 PAD patients	Observational	A structured low-intensity exercise program significantly increased leg temperature and exercise capacity without any difference related to gender.

This literature review found eight studies exploring the use of IRT to detect PAD in diabetic foot. Five studies evaluated the diagnostic potential of IRT in assessing PAD (Ilo et al., 2019; Ilo et al., 2020; Carabott et al., 2021; Zenunaj et al., 2021; Crepaldi et al., 2023), one study analyzed relevant features extracted from images to build a PAD classification model (Carlos Padierna et al., 2020), and two studies identified an association between foot temperature and PAD in type 2 diabetes patients (Gatt et al., 2018; Antônio de Carvalho Abreu et al., 2022). These findings suggest that IRT may be a useful tool for detecting PAD in diabetic foot.

Study Ilo et al., (2020) IRT is effective in distinguishing temperature differences between feet and can be diagnostically useful. The study showed that the difference in skin temperature between the legs was greater in the PAD group compared to healthy controls, suggesting the potential for IRT to detect asymmetric temperature patterns associated with PAD (Ilo et al., 2020). The findings of Ilo et al., (2019) also show that IRT can reveal differences in local temperature, mottled color, and higher average temperature in high-risk diabetic feet with vascular disorders in diabetic feet (Ilo et al., 2019). In addition, IRT can also reveal temperature differences between angiosome areas, subclinical infections, and areas of high pressure in the feet of diabetics (Ilo et al., 2019). This suggests that IRT has potential as a non-invasive diagnostic tool that can be used to evaluate angiosome disorders in the feet of diabetic patients (Ilo et al., 2019).

Study Carabott et al., (2021) Patients with PAD have much higher forefoot temperatures, according to the angiosome concept. By monitoring temperature changes in the lower extremities over time, thermography can help track the progression of PAD and assess response to treatment interventions (Carabott et al., 2021). A temperature difference greater than a certain threshold may indicate a pathological process in the legs (Carabott et al., 2021).

Findings (Zenunaj et al., 2021) IRT can be a valuable tool in evaluating the clinical presentation and severity of blood perfusion in the legs of symptomatic PAD patients, as well as in evaluating the technical success of endovascular revascularization. Infrared Thermography (IRT) shows a significant difference in skin temperature between the symptomatic limb and the contralateral limb, with an average temperature difference of 1.7°C (Zenunaj et al., 2021). The technical success rate of the revascularization procedure is 100%, with a significant increase in temperature across the foot points analyzed (Zenunaj et al., 2021). IRT is considered a safe, reliable, and simple application, providing valuable insights into the clinical presentation and severity of leg blood perfusion in symptomatic PAD patients (Zenunaj et al., 2021).

Findings (Crepaldi et al., 2023) It was shown that a structured low-intensity exercise program significantly increased leg temperature and exercise capacity without any differences related to gender. IRT allows rapid evaluation of radiation energy from the patient's body and is safe for the patient. IRT has been used to diagnose lateral PAD, with significant changes occurring after 5 weeks of training (Crepaldi et al., 2023). After a structured exercise program at home, the foot temperature in both legs showed a significant upward trend. There is an average variation of 1.3°C for the more severely impaired limb and 0.9°C for the contra limb.

Findings Antônio de Carvalho Abreu et al., (2022) showed a strong correlation between ankle-arm index (ABI) and photographic temography in patients with non-calcified arteries. Study Antônio de Carvalho Abreu et al., (2022) also found that photographic temography can be a promising method for the evaluation of peripheral artery disease (PAD) especially in

cases where ABI is unreliable due to calcified arteries (Antônio de Carvalho Abreu et al., 2022). Findings (Gatt et al., 2018) found a significant difference in front leg temperature between the group of participants with type 2 diabetes and peripheral artery disease (DM+PAD) compared to the group of participants with type 2 diabetes alone (Gatt et al., 2018). Participants with DM+PAD showed higher temperatures at the front of the feet compared to participants with type 2 diabetes alone (Gatt et al., 2018).

Study Carlos Padierna et al., (2020) shows that representative infrared thermography photography can effectively classify the foot as a foot without or prone to PAD. The classification method for PAD in patients with type 2 diabetes using IRT and machine learning showed 92.64% accuracy, 91.80% sensitivity, and 93.59% specificity (Carlos Padierna et al., 2020). The method is considered effective and has the potential to be a useful tool in identifying PAD in diabetic patients (Carlos Padierna et al., 2020). Research Carlos Padierna et al., (2020) also showed that diabetic patients with peripheral artery disease (PAD) had lower energy intensity than the control group in the 12 features analyzed. This shows that the use of infrared thermography can distinguish between normal or risky cases of PAD with high accuracy (Carlos Padierna et al., 2020).

CONCLUSION

A review of the literature suggests that IRT can be a useful tool for detecting PAD in diabetic foot. IRT can help track the progression of PAD, assess response to treatment, and evaluate the clinical presentation and severity of blood perfusion. IRT can also classify feet as feet without or prone to PAD with high accuracy. The researcher would like to thank the support from BPPM Faculty of Health Sciences, Universitas Brawijaya through the PI Grant scheme (reference number 5761/UN10.F17/PT.01.03/2023). The researcher would also like to thank Lavalette Hospital Malang City.

REFERENCE

Akalu, Y., &; Birhan, A. (2020). Peripheral Arterial Disease and Its Associated Factors among Type 2 Diabetes Mellitus Patients at Debre Tabor General Hospital, Northwest Ethiopia. Journal of Diabetes Research, 2020. https://doi.org/10.1155/2020/9419413

Altoijry, A., AlGhofili, H., Alanazi, S. N., AlHindawi, D. A., AlAkeel, N. S., Julaidan, B. S., AlHamzah, M., &; Altuwaijri, T. (2021). Diabetic foot and peripheral arterial disease single centre experience. Saudi Medical Journal, 42(1), 49–55. https://doi.org/10.15537/SMJ.2021.1.25640

Antônio de Carvalho Abreu, J., de Oliveira, R. A., &; Martin, A. A. (2022). Correlation between ankle-brachial index and thermography measurements in patients with peripheral arterial disease. Vascular, 30(1), 88–96. https://doi.org/10.1177/1708538121996573

Azhar, A., Basheer, M., Abdelgawad, M. S., Roshdi, H., &; Kamel, M. F. (2023). Prevalence of Peripheral Arterial Disease in Diabetic Foot Ulcer Patients and its Impact in Limb Salvage. International Journal of Lower Extremity Wounds, 22(3), 518–523. https://doi.org/10.1177/15347346211027063

Banik, P. C., Barua, L., Moniruzzaman, M., Mondal, R., Zaman, F., &; Ali, L. (2020). Risk of diabetic foot ulcer and its associated factors among Bangladeshi subjects: A multicentric cross-sectional study. BMJ Open, 10(2), 1–10. https://doi.org/10.1136/bmjopen-2019-034058

Carabott, M., Formosa, C., Mizzi, A., Papanas, N., &; Gatt, A. (2021). Thermographic Characteristics of the Diabetic Foot with Peripheral Arterial Disease Using the Angiosome

Concept. Experimental and Clinical Endocrinology and Diabetes, 129(2), 93–98. https://doi.org/10.1055/a-0838-5209

Carlos Padierna, L., Fabián Amador-Medina, L., Olivia Murillo-Ortiz, B., &; Villaseñor-Mora, C. (2020). Classification method of peripheral arterial disease in patients with type 2 diabetes mellitus by infrared thermography and machine learning. Infrared Physics and Technology, 111(September). https://doi.org/10.1016/j.infrared.2020.103531

Chatchawan, U., Narkto, P., Damri, T., & Yamauchi, J. (2018). An exploration of the relationship between foot skin temperature and blood flow in type 2 diabetes mellitus patients: a cross-sectional study. Journal of Physical Therapy Science, 30(11), 1359–1363. https://doi.org/10.1589/jpts.30.1359

Chun, D. Il, Kim, S., Kim, J., Yang, H. J., Kim, J. H., Cho, J. H., Yi, Y., Kim, W. J., &; Won, S. H. (2019). Epidemiology and burden of diabetic foot ulcer and peripheral arterial disease in Korea. Journal of Clinical Medicine, 8(5), 1–8. https://doi.org/10.3390/jcm8050748

Crepaldi, A., Caruso, L., Piva, G., Traina, L., Gasbarro, V., Manfredini, R., Lamberti, N., Rinaldo, N., Manfredini, F., &; Lopez-Soto, P. J. (2023). Foot Temperature by Infrared Thermography in Patients with Peripheral Artery Disease before and after Structured Home-Based Exercise: A Gender-Based Observational Study. Journal of Personalized Medicine, 13(9), 1–13. https://doi.org/10.3390/jpm13091312

Gatt, A., Cassar, K., Falzon, O., Ellul, C., Camilleri, K. P., Gauci, J., Mizzi, S., Mizzi, A., Sturgeon, C., Chockalingam, N., &; Formosa, C. (2018). The identification of higher forefoot temperatures associated with peripheral arterial disease in type 2 diabetes mellitus as detected by thermography. Primary Care Diabetes, 12(4), 312–318. https://doi.org/10.1016/j.pcd.2018.01.001

Ilo, A., Romsi, P., &; Mäkelä, J. (2019). Infrared Thermography and Vascular Disorders in Diabetic Feet. Journal of Diabetes Science and Technology, 14(1), 28–36. https://doi.org/10.1177/1932296819871270

Ilo, A., Romsi, P., &; Mäkelä, J. (2020). Infrared Thermography as a Diagnostic Tool for Peripheral Artery Disease. Advances in Skin and Wound Care, 33(9), 482–488. https://doi.org/10.1097/01.ASW.0000694156.62834.8b

McGinigle, K. L., &; Minc, S. D. (2021). Disparities in amputation in patients with peripheral arterial disease. Surgery (United States), 169(6), 1290–1294. https://doi.org/10.1016/j.surg.2021.01.025

Normahani, P., Mustafa, C., Standfield, N. J., Duguid, C., Fox, M., &; Jaffer, U. (2018). Management of peripheral arterial disease in diabetes: A national survey of podiatry practice in the United Kingdom. Journal of Foot and Ankle Research, 11(1), 1–12. https://doi.org/10.1186/s13047-018-0270-5

Noumegni, S. R., Demir, A., Grangereau, T., &; Bressollette, L. (2021). Prevalence of Peripheral Artery Disease of the Lower Limbs in Patients with Diabetic Foot Ulcers: A Literature Review Journal of Diabetic Complications and Research Open Access. Scholarena, 1(1). www.scholarena.com

Tresierra-Ayala, M. Á., &; García Rojas, A. (2017). Association between peripheral arterial disease and diabetic foot ulcers in patients with diabetes mellitus type 2. Medicina Universitaria, 19(76), 123–126. https://doi.org/10.1016/j.rmu.2017.07.002

Zenunaj, G., Lamberti, N., Manfredini, F., Traina, L., Acciarri, P., Bisogno, F., Scian, S., Serra, R., Abatangelo, G., &; Gasbarro, V. (2021). Infrared thermography as a diagnostic tool for the assessment of patients with symptomatic peripheral arterial disease undergoing infrafemoral endovascular revascularisations. Diagnostics, 11(9).

https://doi.org/10.3390/diagnostics11091701
Zou, J., Zhang, W., Chen, X., Su, W., &; Yu, D. (2022). Data mining reveals the association between diabetic foot ulcer and peripheral artery disease. Frontiers in Public Health, 10. https://doi.org/10.3389/fpubh.2022.963426