Original Article

Hand ischemia in patients undergoing renal replacement therapy: assessment by thermography

Isquemia de mão de pacientes em terapia renal substitutiva: avaliação por termografia

Isquemia de mano de pacientes en terapia de reemplazo renal: evaluación por termografía

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Abstract

Objective: To assess the presence of ischemia in the distal portion of the hands of the upper limbs with arteriovenous fistula (AVF) in patients undergoing renal replacement therapy (RRT) using infrared thermography.

Method: The sample consisted of 15 patients on RRT via hemodialysis using an AVF who answered a questionnaire prepared by the authors themselves with sociodemographic data, diagnosis, vital signs and data on AVF. To obtain thermograms of hands with and without AVF, a C5 infrared thermographic camera, FLIR Systems, was used, fixed 50 cm from participants' hands, favoring bilateral framing of both hands. The data obtained were organized in an Excel 2011® spreadsheet and statistically compared using the Microcal Origin 6.0 program to assess whether there was a difference between temperature averages.

Results: Regarding sociodemographic variables, males were predominant, with a mean age of 45 years, (incomplete/complete) elementary school, married and from other municipalities. Thermography demonstrated that there is a difference in temperature between hands with AVF and without AVF, with a temperature variation of 1.78°C (± SD 1.99°C), lower for hands with AVF.

Conclusion: The analysis of hand blood distribution using thermography can provide evidence on peripheral microcirculation and guide the early diagnosis and treatment of AVF-induced ischemia in individuals undergoing RRT as an innovative auxiliary diagnostic tool for complications of venous access in hemodialysis patients.

Resumo

Objetivo: Avaliar a presença de isquemia na porção distal das mãos dos membros superiores com Fistula Arteriovenosa (FAV) de pacientes em Terapia Renal Substitutiva (TRS) através da termografia por infravermelho.

Método: Amostra composta por 15 pacientes em TRS por hemodiálise por meio de FAV que responderam um questionário elaborado pelos próprios autores com as seguintes variáveis: dados sociodemográficos, diagnóstico, sinais vitais e dados sobre a FAV. Para obtenção dos termogramas das mãos com e sem FAV foi utilizado uma câmera termográfica por infravermelho C5, FLIR Systems, fixada a 50 cm das mãos dos participantes, privilegiando o enquadramento bilateral enquadrando ambas as mãos. Os dados obtidos foram organizados em planilha de Excel 2011® e comparados estatisticamente utilizando o programa Microcal Origin 6.0, para avaliar se existia diferença entre as médias de temperatura.

Resultados: Com relação as variáveis sociodemográficas, o gênero masculino foi o predominante, faixa etária com média de 45 anos, ensino fundamental (incompleto/completo), casados e provenientes de outros municípios. A termografia demonstrou que há diferença de temperatura entre as mãos com FAV e sem FAV, com variação na temperatura de 1,78°C (± DP 1,99°C), menor para as mãos com FAV.

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Conflicts of interest: nothing to declare.

Conclusão: A análise da distribuição do sangue das mãos por meio da termografia pode fornecer evidências sobre a microcirculação periférica e orientar o diagnóstico precoce e o tratamento da isquemia induzida por FAV em indivíduos em TRS, como ferramenta inovadora de diagnóstico auxiliar das complicações dos acessos venosos de pacientes em hemodiálise.

Resumen

Objetivo: Evaluar la presencia de isquemia en la parte distal de las manos de los miembros superiores con fístula arteriovenosa (FAV) de pacientes en terapia de reemplazo renal (TRR) a través de la termografía infrarroja.

Métodos: Muestra compuesta por 15 pacientes en TRR por hemodiálisis mediante FAV que respondieron un cuestionario elaborado por los propios autores con las siguientes variables: datos sociodemográficos, diagnóstico, signos vitales y datos sobre la FAV. Para obtener los termogramas de las manos con y sin FAV, se utilizó una cámara termográfica infrarroja C5, FLIR Systems, ubicada a 50 cm de las manos de los participantes, favoreciendo el encuadramiento bilateral y encuadrando ambas manos. Los datos obtenidos se organizaron en una planilla de Excel 2011® y se compararon estadísticamente con el programa Microcal Origin 6.0, para evaluar si había diferencia entre los promedios de temperatura.

Resultados: Con relación a las variables sociodemográficas, el género masculino fue predominante, grupo de edad promedio de 45 años, educación primaria (incompleta/completa), casados y provenientes de otros municipios. La termografía demostró que hay diferencia de temperatura entre las manos con FAV y sin FAV, con una variación de temperatura de 1,78°C (± DP 1,99°C), menor en las manos con FAV.

Conclusión: El análisis de la distribución de la sangre de las manos por medio de termografía puede ofrecer evidencias sobre la microcirculación periférica y guiar el diagnóstico temprano y el tratamiento de la isquemia inducida por FAV en individuos en TRR, como una herramienta innovadora de diagnóstico auxiliar de las complicaciones de los accesos vasculares de pacientes en hemodiálisis.

Introduction

Chronic kidney disease (CKD) is characterized as an illness with multiple etiologies, the evolution of which is progressive and the initial symptoms are often undetected. Therefore, diagnosis occurs, most of the time, in the final stage of the disease, in which kidney functions are seriously compromised.[1]

Currently, CKD has been identified as a public health problem, due to population aging and the consequent development of chronic non-communicable diseases (NCDs). It is estimated that CKD affects between 8 and 16% of the world population,[2] with a forecast to be the 5th cause of general mortality in 2040.[3]

The pathogenesis of CKD is complex and associated with a high prevalence of risk factors. Both traditional risk factors such as Diabetes Mellitus (DM), hypertension (HTN) and dyslipidemia, and less frequent ones (inflammation, oxidative stress and endothelial dysfunction) have a major impact on patients' quality of life.[4]

The main renal replacement therapy (RRT) used during end-stage chronic kidney disease (ESCKD) treatment is hemodialysis (HD).[5] HD is a procedure where a machine performs part of the kidney functions, removing toxic waste that is harmful to health and controlling blood pressure (BP) by removing toxins present in the bloodstream.[6]

To perform RRT via HD, a venous access (VA) that allows high blood flow is essential, and temporary and/or permanent access routes can be used. Vascular access in HD represents an important step in therapy, however, it can present short- and long-term complications, such as hand ischemia.[7]

Hand ischemia, in these cases, arises when part of the cardiac output is altered from the distal vessels, resulting from the construction of an AVF, considered the gold standard access for HD.[8] The high blood flow triggered by AVF can harm limb perfusion, leading to distal ischemia, this complication can cause irreversible ischemic damage to HD patients. Its diagnosis is predominantly clinical, with signs including cold fingers, extremity cyanosis, paresthesia and/or pain and chronic ulcers.[9]

Management of this complication should involve observation and assessment of vascular access through physical examination (PE) and surveillance with periodic assessment using complementary diagnostic tests, which include Doppler ultrasound (USD) and the gold standard, which is angiography,[10] both complementary. However, for PE, specific experience is required from the examiner and, for imaging exams, a qualified operator. These, in addition to not being available in all centers, are expensive.[11]

In a scoping review,[12] it was observed that nurses are the main evaluators in detecting AVF dys-

function and highlighted the need for a more comprehensive assessment. In another study, it was observed that 55.5% of nursing professionals did not differentiate between complications related to AVF, such as low flow, thrombosis, aneurysm and hand ischemia.[13] Another study carried out in eight HD centers showed that nurses did not have enough experience to perform PE.[14]

The high work demand that direct care for HD patients entails for nurses can compromise PE accuracy in nursing assessment, hence the need for objective auxiliary technologies that can be consulted throughout the treatment. Faced with the need for adequate diagnosis and monitoring of VA used in HD, infrared video thermography (IVT) emerges, with the purpose of investigating the presence of vascular changes.[15]

IVT has been used as an investigative method for preclinical diagnosis of blood flow and monitoring of homeostatic imbalances for several decades.[16] However, this technology was restricted to research, only in the 2000s, with more efficient computer programs and processors, which allowed obtaining higher quality images in real time,[17] that IVT emerged as a reliable tool, accurate, economical and portable, which can be used alongside patients.[16]

This technology emerges in the diagnostic area as a non-invasive method, without any physical contact, without ionizing radiation and low cost,[18] used to record body thermal patterns with the purpose of showing vasomotor responses through the skin's thermal behavior. Previous studies have attempted to clarify the thermal behavior of limbs with AVF, distal ischemia caused by Raynaud's phenomenon and changes in peripheral microcirculation.[16]

Therefore, the inclusion of this technology in the nursing area is relevant, as it can help in the management of AVF dysfunctions as it allows an analysis of evolution through the records made (thermograms).

Furthermore, the contribution of this research is in demystifying the idea that technological innovation is premised on complex and high-cost product production. The relevance lies in opening eyes to a new look at auxiliary diagnostic procedures, aiming to bring nursing closer to innovative technology production.

Therefore, to understand the thermal response of the distribution of distal blood flow in the hands, the present study assessed the presence of ischemia in the distal portion of the hands of the upper limbs with AVF in patients undergoing RRT using IVT.

Methods

The study was a descriptive, quantitative and cross-sectional research, carried out in the nephrology sector of a public hospital in western Pará.

The sample consisted of 15 patients undergoing HD through AVF, over 21 years of age, of all genders, who completed the four-hour dialysis session without complications and who expressed acceptance by signing the Informed Consent Form (ICF). Patients with severe cardiovascular disease who required surgery, with decompensated glycemic indexes, disabling neurological disease, compromised visual, auditory and cognition acuity and those who presented hemodynamic instability during the HD session were excluded from this study. For a homogeneous composition, all patients in this study were from the second shift, so there was no interference in body temperature due to the circadian cycle. Data was collected in the first half of 2022.

To characterize the sociodemographic and AV profile, an instrument created by the researchers was used, containing sociodemographic data, diagnosis, systemic blood pressure (SBP), axillary temperature and data on the AVF extracted from medical records. The clinical signs and symptoms of distal hypoperfusion of participants' hands were not assessed through PE and/or questionnaire.

To acquire hand thermograms, a C5 infrared thermographic camera was used, FLIR Systems, Oregon, USA, with thermal sensitivity lower than 70 mK, configured with emissivity=0.98, Tamb=Trefl = 24°C, relative humidity = 55%, fixed 50 cm from participants' hands. Thermogram composition favored the framing of both hands for contralateral comparison. The examination room

was air-conditioned with a controlled temperature between 22 and 24C° and relative humidity with an average of 55%, measured by a digital thermal hygrometer model 7664 from INCOTERM. In the room, heat sources were removed and the door was closed so as not to change the room temperature. Participants, after the end of HD session, were taken to the exam room by a nursing technician, where they remained under supervision with their hands exposed without any contact for 10 minutes to acclimatize before obtaining the images. The region of interest (ROI) for measuring temperature was defined as the distal position of the second toe of each hand.

The images were captured with a camera fixed in the center of a booth covered in black ethylene vinyl acetate (EVA) 50 cm from patients' hands in a room attached to the dialysis room. The hands were positioned on top of a sheet of black EVA in the shape of the hands to maintain the position and distance between them and the camera inside the cabin. The EVA sheet was changed for each patient to avoid temperature interference.

Categorical data were organized and analyzed using simple descriptive statistics (mean, standard deviation (SD), relative and absolute frequency). The FLIR Tools software was used to process the thermograms (images), defining elliptical-shaped ROIs on the distal phalanx of the second toe of both hands. Three temperatures were obtained from each ROI, totaling 45 measurements for hands with AVF and 45 for hands without AVF. The data with AVF and without AVF of participants were tabulated in an Excel® spreadsheet and statistically compared using Microcal Origin 6.0. Temperature variation of the hands with steal and those without steal of patients were initially tested for normality using the Kolmogorov-Smirnov method. Then, verifying normality, data were subjected to analysis using unpaired t-test to demonstrate the significance of temperature changes and compare the means, p-values < 0.05, considered to reject the null hypothesis that there is no difference between the means.

It should be noted that the study is an excerpt from a PhD project in Biomedical Engineering approved by the Research Ethics Committee of the *Universidade do Estado do Pará* (UEPA), Campus XII, under Opinion 5,180,796, Certificate of Presentation for Ethical Consideration (*Certificado de Apresentação de Apreciação Ética*) 52974521.7.0000.5168.

Results

Sociodemographic characterization of patients undergoing renal replacement therapy

Table 1 shows the sociodemographic characterization of the 15 patients who were part of the sample. Males were predominant (80%), and the age range was 31-50 years (53.3%) with an average of 45 years, mixed race (100%), married (60%), with the highest incidence of education being elementary school (53.3%) and those from other municipalities (60%). Regarding the etiology of CKD, there was a higher incidence of HTN nephropathy (60%), followed by diabetic nephropathy (20%). They presented normal Body Mass Index (40%), duration of HD of 12 to 60 months (60%), second AVF (53.3%) and radiocephalic E anastomosis (46.6%).

Thermographic analysis of hands with arteriovenous fistula and without arteriovenous fistula

The information obtained by thermograms demonstrated significance levels of P<0.05 related to thermal differentiation between average temperatures of the hands of the upper limbs with AVF and without AVF (Figures 1 and 2), with a variation of 1. 78°C (± SD 1.99°C).

Discussion

Sociodemographic characterization of patients undergoing renal replacement therapy

The present study demonstrated the potential benefits of thermal imaging assessments in renal patients with arteriovenous fistulas. The technique can provide valuable clinical information about patency and therefore occlusion, vascular steal from the hand, and the likelihood of adequate blood flow for suc-

Table 1. Sociodemographic characterization of patients undergoing renal replacement therapy and etiology of chronic kidney disease

Variables	n(%)
Gender	
Male	12(80)
Female	3(20)
Age group (years)	
21-30	3(20)
31-50	8(53.3)
51-65	4(26.7)
Color	
Brown	15(100)
Marital status	
Single	4(26.7)
Married	9(60)
Divorced	2(13.3)
Education	
(Incomplete/complete) elementary school	8(53.3)
(Incomplete/complete) high school	5(33.3)
(Incomplete/complete) higher education	2(13.4)
Origin	
Municipality of Santarém	6(40)
Other municipalities	9(60)
Etiology of chronic kidney disease	
Hypertensive nephropathy	9(60)
Diabetic nephropathy	3(20)
Other causes	3(20)
Systemic blood pressure (mmhg)	
< 140x90	7(60)
>140x90	6(40)
Body Mass Index (BMI) (Kg/m²)	
Low eight <18.5	1(6.7)
Normal (18.5 to 24.9)	6(40)
Overweight (25.0 to 29.9)	5(33.3)
Degree I obesity (30.0 to 39.9)	3(20)
Duration of HD (months)	
< 12	1(6.7)
12 to 60	9(60)
61 to 130	5(33.3)
Number of AVF	
First	7(46.7)
Second	8 (53.3)
Anastomosis	
Brachiocephalic D	3(20)
Radiocephalic D	1(6.7)
Brachiocephalic E	4(26.7)
Radiocephalic E	7(46.6)

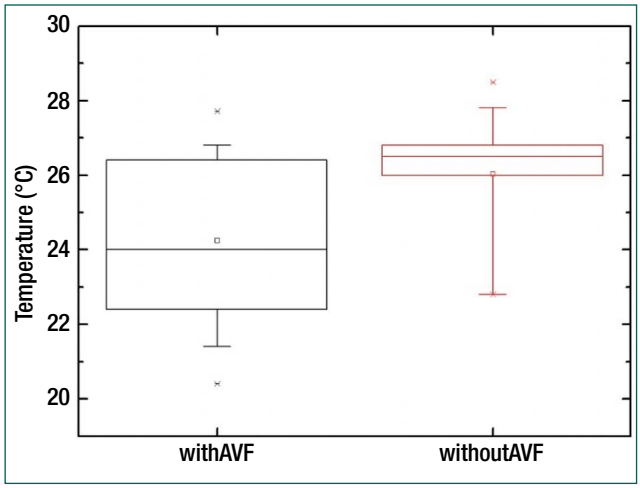

Figure 1. Variation in temperature of the hands of patients undergoing renal replacement therapy

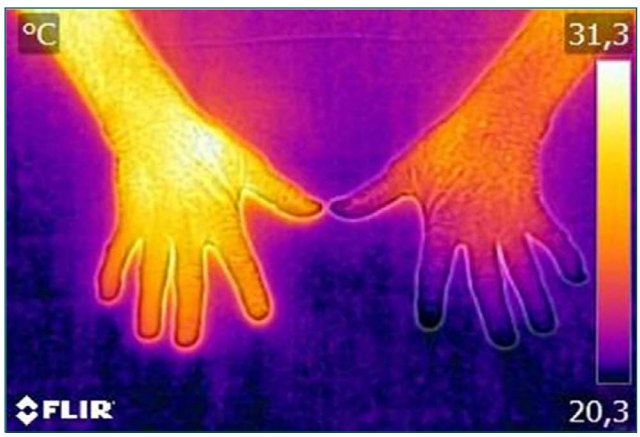

Figure 2. Hand thermogram: with arteriovenous fistula (left) and without arteriovenous fistula (right) of one of the participants in renal replacement therapy by hemodialysis

cessful HD. Furthermore, the known characteristic of bilateral thermal similarity from the right to the left side in healthy individuals was explored, with bilateral differences in maximum arm temperature providing information about fistula blood flow.

When the differences were close to zero, it was very likely that the fistula was occluded. It was also noted that if the bilateral difference in hand temperature was less than a defined threshold (i.e., -1 ÿC), then this would be consistent with vascular steal. It is clear that to detect these small physiological temperature differences with confidence, it is important that carefully considered and reliable measurement protocols are employed, ideally with thermographic measurements performed in a dedicated medical thermal imaging facility.

Of the 15 patients assessed, the male gender was predominant, with an average age of 45 years, primary education (incomplete/complete), married and from other municipalities. The sociodemographic data found corroborate studies carried out in Brazil and the northern region, where men are the most affected.[19] However, worldwide, women are the most affected,[20] unlike our findings.

It is important to highlight that this higher frequency of males was also observed at national level in the Brazilian Chronic Dialysis Survey with a predominance of 58% of these individuals.[21] The profile found showed that an important portion of people affected by CKD are in the economically active age group, increasing public spending (benefits/retirements).[22] Data from the National Health and Nutrition Examination Survey (NHANES) show that the prevalence of CKD increases with age.[23]

Regarding the low level of education found, equivalent results were observed in other studies, a factor that may contribute to non-adherence to treatment and the progression of CKD.[24] It is also observed that the majority of patients come from other municipalities close to Santarém, causing physical and financial strain for the patient who seeks treatment at another center.[25] Regarding marital status, a higher percentage was found in married patients (60%), equivalent result found in another study.[26]

Clinical profile of chronic kidney disease patients undergoing renal replacement therapy

Regarding the underlying disease, hypertensive nephropathy was the main etiology found, followed by diabetic nephropathy, similar data were found at a national level.[21] It was also observed that 20% of patients had other causes (systemic lupus erythematosus, glomerulonephritis, neoplasia and cardiovascular disease).

According to the Brazilian Society of Nephrology (SBN – *Sociedade Brasileira de Nefrologia*), among the main risk factors for CKD in Brazil are HTN and DM.[27]

However, when analyzing the BP levels of patients in this study, it was possible to observe that 6 (40%) of the patients had elevated SBP and Diastolic Blood Pressure (DBP). Hypertension is quite common during HD and represents one of the greatest risk factors for the development of cardiovascular disease in CKD patients. However, the BP target for patients with CKD has not yet been established. [28] Corroborating this data, a study[29] reports that the main signs resulting from the loss of kidney function are high BP and anemia, followed by cardiovascular anemia.

Regarding duration of HD, 9 (60%) were in the range of 12 to 60 months and 5 (33.3%) in the range of 61 to 130 months of treatment, 8 (53.3%) were already on their second AVF and 7 (46.6%) were of the radiocephalic type located on the left forearm. The preference for creating AVF should always be on the upper limb and on the non-dominant side,[30] as this justifies the values found in the study, given that most people have the left upper limb as non-dominant.

AVF is the access considered the gold standard for HD. However, high-flow vascular accesses promote cardiopulmonary complications in patients on chronic HD. These complications are due to high-output heart failure and reduced systemic vascular resistance, which can lead to hypoperfusion of the hand with AVF.[31]

Cardiovascular risk increases as the glomerular filtration rate (GFR) decreases and this is directly related to the mortality of patients with CKD, such that each year on RRT, the probability of death increases.[21]

Thermographic analysis of hands with arteriovenous fistula and without arteriovenous fistula of a patient undergoing renal replacement therapy

Data on complications related to vascular access in patients undergoing RRT are scarce. Our initial experience used thermography to detect distal limb ischemia in adult dialysis patients. IVT is a reliable method and has already been scientifically validated. [32]

Patients on regular RRT depend on a well-functioning VA. However, due to increasingly prevalent comorbidities (HTN, DM, CVD), these accesses are difficult to create and are often threatened by findings such as dilations in the arteriovenous anastomosis, which can lead to low hand perfusion.

With the physiological inversion of blood flow to create AVF, ischemia symptoms tend to be compensated by distal vasodilation.[33] This is an event considered unusual, such as the one found in this study where a temperature variation =1.78°C lower was observed in hands with AVF with SD of 2.09 and mean of 23.93, compared to the limb

without AVF , which presented a SD of 1.60 and a mean of 25.34.

The temperatures between the hemispheres of the body (right X left) must be symmetrical, with a variation of up to 0.3°C in a temperature-controlled environment.[34] Asymmetries above 0.7°C can be defined as abnormal, indicating some anatomical and/or physiological change.[16]

In the present study, there was a significant difference in temperature between the assessed regions (second toe) of each hand, which can be explained by the presence of AVF in the limb with the lowest temperature. According to published data, symptomatic distal upper limb ischemia is a complication that affects approximately 2% of radiocephalic fistulas and 10% of brachiocephalic fistulas. Physiological steal can occur in 70% of radiocephalic (wrist) fistulas and in 90% of brachiocephalic (upper arm) fistulas.[35]

Hand ischemia is characterized by a reduction in blood flow and oxygen supply that reaches the periphery, where arterial blood only feeds AVF. This inadequate circulation of collateral blood in the hand is a complication that can have serious outcomes, ranging from loss of access to loss of limb function due to neurological or ischemic damage generated.[29]

Considering that the difference in average temperature at the site is caused by different rates of blood flow through the hands, and that hypoperfusion results in lower temperatures, the difference found indicates the presence of physiological steal, whose lowest values were found at the end of the limb fistulated with AVF. It is worth noting that the study has limitations such as a small sample size and did not include another diagnostic method to compare the findings, such as Doppler ultrasound.

Conclusion

Thermography can be useful in analyzing changes in blood distribution in both hands of individuals with AVF, and can help in the early diagnosis of changes in these patients' microcirculation, with the advantage of being a cheap, non-invasive test and being used close to patients, providing additional information about ischemia. Thus, the physical assessment of monitoring AVF dysfunction through the use of IVT becomes relevant as an innovative auxiliary diagnostic tool for complications caused by VA in patients undergoing RRT due to HD.

Collaborations

Miranda MKV, Simplício IOB, Bezerra JS, Ferreira MS, Lima FS, Blandes AIS, Simplício ATC and Alves LP contributed to study design, data analysis and interpretation, article writing, relevant critical review of intellectual content and approval of the final version to be published.

References

1. Kalantar-Zadeh K, Jafar TH, Nitsch D, Neuen BL, Perkovic V. Doença renal crônica. Lancet. 2021;398:786–802.
2. Jha V, Garcia-Garcia G, Iseki K, Li Z, Naicker S, Plattner B, et al. Chronic kidney disease: global dimension and perspectives. Lancet. 2013;382(9888):260–72.
3. Foreman KJ, Marquez N, Dolgert A, Fukutaki K, Fullman N, McGaughey M, et al. Forecasting life expectancy, years of life lost, and all-cause and cause-specific mortality for 250 causes of death: reference and alternative scenarios for 2016-40 for 195 countries and territories. Lancet. 2018;392(10159):2052–90.
4. Schmidli J, Widmer MK. Response to 'Re. Vascular Access: Clinical Practice Guidelines of the European Society for Vascular Surgery'. Eur J Vasc Endovasc Surg. 2018;56(4):609.
5. Sousa MV, Zollner RL, Mazzali M. Renal transplant patients with preformed anti-HLA antibodies: early biopsy findings and clinical outcomes. J Bras Nefrol. 2019;42(2):201–10.
6. Lok CE, Huber TS, Lee T, Shenoy S, Yevzlin AS, Abreo K, et al.; National Kidney Foundation. 2019 Update. Am J Kidney Dis. 2020;75(4 Suppl 2):S1–164.
7. Marsh AM, Genova R, Buicko JL. Dialysis fistula. StatPearls. Treasure Island (FL): StatPearls Publishing; 2020.
8. Yeh LM, Chiu SY, Lai PC. The impact of vascular access types on hemodialysis patient long-term survival. Sci Rep. 2019;9(1):10708.
9. Joshi AS, Agrawal DP. Arteriovenous fistula takedown in hemodialysis patients: our experience of 26 cases. Kardiochir Torakochirurgia Pol. 2020 Sep;17(3):132-6.
10. Jackson VE, Hurst H, Mitra S. Structured physical assessment of arteriovenous fistulae in haemodialysis access surveillance: A missed opportunity? J Vasc Access. 2018 ;19(3):221–9.
11. Silva AB, Correia BR, Zaccaro KR, Campos JF, Souto JD, Adba YB, et al. Desenvolvimento de protótipo de chatbot para avaliação da maturação da fístula arteriovenosa. Acta Paul Enferm. 2023;36:eAPE012322.

12. Correia BR, Brandão MA, Lopes RO, Silva PC, Zaccaro KR, Benevides AB, et al. Arteriovenous fistula maturation clinical assessment for hemodialysis: a scoping review. Acta Paul Enferm. 2021;34: eAPE00232.

13. Ribeiro RD, Miranda AL, Cesarino CB, Bertolin DC, Ribeiro DF, Kusumota L. Necessidades de aprendizagem de profissionais de enfermagem na assistência aos pacientes com fístula arteriovenosa. Acta Paul Enferm. 2009;22 (Especial Nefrologia):515–8.

14. Sousa CN, Teles P, Dias VF, Apóstolo JL, Figueiredo MH, Martins MM. Physical examination of arteriovenous fistula: the influence of professional experience in the detection of complications. Hemodial Int. 2014;18(3):695–9.

15. Gavish L, Hoffer O, Rabin N, Halak M, Shkilevich S, Shayovitz Y, et al. Microcirculatory response to photobiomodulation—why some respond and others do not: a randomized controlled study. Lasers Surg Med. 2020;52(9):863–72.

16. Ring EF, Ammer K. Infrared thermal imaging in medicine. Physiol Meas. 2012;33(3):R33–46.

17. Nowicka D. Thermography improves clinical assessment in patients with systemic sclerosis treated with ozone therapy. BioMed Res Int. 2017;2017:5842723.

18. Astasio-Picado A, Escamilla Martínez E, Martínez Nova A, Sánchez Rodríguez R, Gómez–Martín B. Thermal map of the diabetic foot using infrared thermography. Infrared Phys Technol. 2018;93:59–62.

19. Thomé FS, Sesso RC, Lopes AA, Lugon JR, Martins CT. Brazilian chronic dialysis survey 2017. J Bras Nefrol. 2019;41(2):208–14.

20. Hill NR, Fatoba ST, Oke JL, Hirst JA, O'callaghan CA, Lasserson DS, et al. Global prevalence of chronic kidney disease – a systematic review and meta-analysis. PLoS One. 2016;11(7):e0158765.

21. Teixeira FI, Lopes ML, Silva GA, Santos RF. Survival of hemodialysis patients at a university hospital. J Bras Nefrol. 2015;37(1):64–71.

22. Coutinho BS, Neves TS, Lobato TS, et al. O uso do acesso venoso na hemodiálise: repercussões na saúde. Saúde (Santa Maria), 2021;47(1).

23. Johansen KL, Chertow GM, Gilbertson DT, Ishani A, Israni A, Ku E, et al. US Renal Data System 2022 Annual Data Report: Epidemiology of Kidney Disease in the United States. Am J Kidney Dis. 2023;81(3 Suppl1):A8–11.

24. Santos KK, Lucas TC, Glória JC, et al. Epidemiological profile of chronic renal patients in treatment. Rev. enferm. UFPE. 2018;12(9):2293–300.

25. Evaristo LS, Pantoja CA, Gonçalves MC, et al. Complicações durante as sessões de hemodiálise. Av Enferm. 2020;38(3):316–24.

26. Mello MV, Menezes KS, Pires KK, Angelo M. Panorama da doença renal terminal em um estado da Amazônia brasileira. REME Rev Min Enfermagem. 2017;21:e-994.

27. Neves PD, Sesso RC, Thomé FS, Lugon JR, Nasicmento MM. Brazilian Dialysis Census: analysis of data from the 2009-2018 decade. J Bras Nefrol. 2020;42(2):191–200.

28. Cha RH, Lee H, Lee JP, Kim YS, Kim SG. The influence of blood pressure patterns on renal outcomes in patients with chronic kidney disease: the long-term follow up result of the APrODiTe-2 study. Medicine (Baltimore). 2020;99(8):e19209.

29. Santos BP, Oliveira VA, Soares MC, et al. Chronic kidney disease: relation of patients with hemodialysis. ABCS Health Sciences. 2017;42(1):8-14.

30. Neves Júnior MA, Melo RC, Almeida CC, Fernandes AR, Petnys A, Iwasaki ML, et al. Avaliação da perviedade precoce das fístulas arteriovenosas para hemodiálise. J Vasc Bras. 2011;10(2):105–9.

31. Sequeira A, Tan TW. Complications of a high-flow access and its management. Semin Dial. 2015;28(5):533–43.

32. Jones BF. A reappraisal of the use of infrared thermal image analysis in medicine. IEEE Trans Med Imaging. 1998;17(6):1019–27.

33. Yu SH, Cook PR, Canty TG, McGinn RF, Taft PM, Hye RJ. Hemodialysis-related steal syndrome: predictive factors and response to treatment with the distal revascularization-interval ligation procedure. Ann Vasc Surg. 2008;22(2):210–4.

34. Dimitrijevic IM, Kocic MN, Lazovic MP, Mancic DD, Marinkovic OK, Zlatanovic DS. Correlation of thermal deficit with clinical parameters and functional status in patients with unilateral lumbosacral radiculopathy. Hong Kong Med J. 2016;22(4):320–6.

35. Zamani P, Kaufman J, Kinlay S. Ischemic steal syndrome following arm arteriovenous fistula for hemodialysis. Vasc Med. 2009;14(4):371–6.