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# High Resolution Infrared Thermography for Monitoring Central Venous Catheters in a Pediatric Intensive Care Unit in Uruguay

## Termografía infrarroja de alta resolución para monitoreo de catéteres venosos centrales en una unidad de cuidados intensivos pediátricos en Uruguay

## Termografia infravermelha de alta resolução para monitoramento de cateteres venosos centrais em uma unidade de terapia intensiva pediátrica no Uruguai

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## Abstract

**Introduction:** vascular access is an indispensable tool for children care in the Pediatric Intensive Care Unit (PICU). Infection due to the use of central venous catheters (CVC) is the main cause of hospital-acquired infections in PICUs. Infrared imaging at the bedside has potential for semiological support when a CVC-related infection is suspected, since it is a non-invasive method that causes no adverse effects, does not require sedation, does not require moving a critically ill patient, and does not produce ionizing radiation. It has high sensitivity and specificity for providing information on the metabolism, perfusion, and inflammation of a region of interest.

**Methodology:** the high-resolution FLIR E75 sensor (FLIR Systems AB, Taby, Sweden) was used, with a thermal sensitivity of 0.03°C and 307.200 pixels- resolution IR. The measurement of the average and maximum T°C deltas ($\Delta T^{average}$, $\Delta T^{max}$) was performed. This work describes 2 clinical cases of patients in which infrared imaging was used in the follow-up of 2 confirmed CVC-related infections, where asymmetries and altered thermal dysfunctions with $\Delta T^{average}$ greater than 1°C were observed in the described cases. Both cases also presented $\Delta T^{max}$ greater than 2.0°C.

**Conclusions:** the use of infrared imaging could be promising as a semiological tool for monitoring CVC during PICU stay.

**Key words:** Thermography
Central Venous Catheters
Infections

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## Resumen

**Introducción:** los accesos vasculares constituyen una herramienta indispensable para la asistencia de los niños en una unidad de cuidados intensivos pediátricos (UCIP). La infección relacionada al uso de catéteres venosos centrales (CVC) constituye la principal causa de infección intrahospitalaria en las UCIP. La imagen infrarroja al pie de la unidad tiene potencialidad para el apoyo semiológico cuando existe presunción de infección relacionada a CVC, dado que es un método no invasivo, no genera efectos adversos, no requiere sedación, no requiere movilizar al paciente crítico y no genera radiación ionizante. Tiene alta sensibilidad y especificidad para brindar información a nivel del metabolismo, perfusión e inflamación de una región de interés.
**Metodología:** se utilizó el sensor de alta resolución FLIR E75 (FLIR Systems AB, Taby, Suecia), con una sensibilidad térmica de 0,03°C, una resolución de IR 307.200 píxeles. Se realizó la medición de los deltas de T°Caverage y máximos ($\Delta^{Taverage}$ $\Delta T^{max}$). Se describen en este trabajo dos casos clínicos de pacientes en los que se utilizó la imagen infrarroja en el seguimiento de dos infecciones confirmadas vinculadas al uso de CVC, donde se constató en los casos descritos asimetrías y disfunciones térmicas alteradas con $\Delta T^{average}$ mayor a 1°C. A su vez, ambos casos presentaron $\Delta T^{max}$ mayores a 2,0 °C.
**Conclusiones:** el uso de la imagen infrarroja podría ser promisorio como una herramienta semiológica para el seguimiento de los CVC durante la estadía en una UCIP.


**Palabras clave:** Termografía
Catéteres Venosos Centrales
Infecciones


## Resumo

**Introdução:** os acessos vasculares constituem uma ferramenta indispensável para a assistência das crianças na Unidade de Cuidados Intensivos Pediátricos (UCIP). A infecção relacionada ao uso de cateteres venosos centrais (CVC) constitui a principal causa de infecção intrahospitalar na UCIP. A imagem infravermelha na parte da unidade tem potencial para o apoio semiológico quando existe presunção de infecção relacionada ao CVC, visto que é um método não invasivo, não gera efeitos adversos, não requer sedação, não requer mobilização crítica do paciente e não gera radiação ionizante. Tem alta sensibilidade e especificidade para fornecer informações sobre o nível de metabolismo, perfusão e inflamação de uma região de interesse.
**Metodologia:** foi utilizado o sensor de alta resolução FLIR E75 (FLIR Systems AB, Taby, Suecia), com sensibilidade térmica de 0,03°C, resolução IR de 307.200 pixels. A emissão da pele foi configurada em 0,98. Foi realizada a medição dos deltas de T°C médio e máximo ($\Delta T^{média}$ $\Delta T^{máx}$). Neste paper descrevemos 2 casos clínicos de pacientes nos quais se utilizou a imagem infravermelha no acompanhamento de 2 infecções confirmadas vinculadas ao uso de CVC onde foram constatados nos casos descritos assimetrias e disfunções térmicas alteradas com $\Delta T^{média}$ maior que 1°C. Em sua vez, ambos os casos apresentaram $\Delta T^{máx}$. maiores a 2,0°C.
**Conclusões:** o uso da imagem infravermelha pode ser promovido como uma ferramenta semiológica para o acompanhamento do CVC durante a estadia na UCIP.


**Palavras chave:** Termografia
Cateteres Venosos Centrais
Infecções

## Introduction

Central venous catheter placement consists of the insertion of a biocompatible catheter into the central venous circulation for patient treatment and monitoring[1]. These vascular accesses are an essential tool for the care of children in a pediatric intensive care unit (PICU), as they allow the administration of medications, fluids, parenteral nutrition, or blood products, as well as laboratory sample collection and hemodynamic monitoring[1,2]. There are different classifications of central venous catheters. According to the access to the central circulation, if the catheter is placed in a central vein (jugular or subclavian) it is called central venous catheter (CVC); if it is placed in the femoral vein, it is referred to as a deep femoral insertion venous catheter; however, if the catheter is placed in a peripheral vein, it is known as a peripherally inserted central catheter (PICC)[3].

CVC-related infection is the main cause of hospital-acquired infection in pediatric ICUs. In a study conducted in the Pediatric Intensive Care Unit of the *Centro Hospitalario Pereira Rossell* in 2019, the incidence was 0.97 cases per 1,000 CVC days[4]. The diagnosis is initially based on clinical suspicion in the presence of local or general signs of infection, but these have low sensitivity and specificity. Therefore, microbiological techniques are required for the definitive diagnosis of catheter-related infection[5]. We refer to CVC-related sepsis based on IDSA criteria in a patient with an intravascular catheter with at least one positive blood culture for a known pathogenic microorganism. The sample is obtained through peripheral puncture, with clinical signs of systemic infection, with no other apparent source of infection, and with one of the following conditions:

- If the catheter has been removed: the culture of the catheter tip and peripheral blood both being positive for the same microorganism (by quantitative o semiquantitative technique).
- If the catheter has not been removed: a differential culture shows a higher bacterial load in the blood sample collected from the catheter lumen compared to the peripheral blood culture and both being positive for the same microorganism. The central culture is considered significantly higher than the peripheral one if the bacterial count of the detected pathogenis more than three times higher in the central blood culture or if the microorganism growth is detected (by automated blood culture system) at least 2 hours earlier in the central blood culture than in the peripheral one[5,6].

Infrared (IR) imaging at the bedside has great potential for use as a semiological clinical tool, since it is a non-invasive method that does not cause adverse effects, does not require sedation or moving the critically ill patient, and does not involve ionizing radiation[7-9]. It allows a qualitative and quantitative analysis of the thermal radiation emitted, producing a high-resolution image called a thermogram[7-10]. In the last 20 years, its use has increased exponentially, providing evidence of its contribution to various applications such as rheumatology, plastic surgery, palliative medicine, vascular pathology, diabetic foot, neoplasms, cardiology, ICU, occupational medicine, pain therapy, toxicology, and sports medicine[8-12]. It has high sensitivity and specificity for providing information on metabolism, perfusion, and inflammation in a region of interest (ROI)[10-13]. For accurate interpretation, a thorough understanding of the pathophysiology, thermodynamics, and thermokinetics of human skin is essential[10-14].

Skin temperature regulation is a complex system that depends on the blood flow rate, local subcutaneous tissue structures, sympathetic nervous system activity, environmental factors, and the basal metabolic rate of the individual[15-17]. Imaging in the ICU or the emergency room is performed at the patient's bedside with a defined protocol and scientific-grade thermal sensors to obtain thermograms. These are then analyzed using validated software for human thermography by a physician trained in thermology. The objective of this study is to present two clinical cases of children with suspected CVC-related infection who were on follow-up using thermal imaging in a pediatric parenteral and enteral nutrition unit (UNEPP). The pathogenesis of the disease and clinical manifestations are analyzed, and infrared thermography is used for catheter monitoring.

## Methodology

This report is part of a larger study that includes the follow-up of CVCs during PICU hospitalization. It is an initial communication presenting two clinical cases included in the protocol, in which thermal images were recorded. The legal guardians of the patients consented to the reporting of these clinical cases, including their respective IR images. The protocol was approved by the Ethics Committee of the *Hospital Pediátrico Pereira Rossell* and was registered with the Ministry of Public Health. A high-resolution FLIR E75 sensor (FLIR Systems AB, Taby, Sweden) was used, with a thermal sensitivity of 0.03°C and a 307,200 pixels-resolution IR with UltraMax IR technology. Skin emissivity was set at 0.98. The patient underwent thermal acclimatization for 15 minutes before imaging. The room temperature was 24°C. The image acquisition protocol (UCINTERM) consistd of two thermal window approaches: one taken from 60 cm laterally and the other one from 60 cm frontally in relation to the patient unit, with the bed at a 45° angle, with safety strap, and with the patient seated. The 17-month-old patient was recorded in supine position. The 3-year and 2-month-old patient was also seated. The site of interest on the topography of the CVC was analyzed in the Pediatric Intensive Care Unit (PICU). Reference values were protocolized for the abdomen and contralateral to the ROI (R1-R2). IR recordings were performed at seven-day intervals. Image capture and storage were performed with the VisionFy 1.2.1 platform (Thermofy). Once the thermal images were captured, ROIs were processed using the circle drawing tool, with quantification of temperatures through calculation of the delta T°C (ΔTmax and ΔTaverage) of the ROIs.

High-contrast rainbow color scales were used. 3D-IR reconstructions were processed to analyze ROIs and their thermal distribution. T°C delta value scales were defined according to the protocol of the International Consensus and Guidelines on Medical Thermography 2016-2018. Delta values <0.3°C no thermal dysfunction; between 0.3°C and 0.6°C mild dysfunction; between 0.6°C and 1°C moderate dysfunction, and >1°C severe dysfunction. International standards of the TISEM and Glamorgan protocols for thermal imaging were followed.

## Clinical cases

**Case 1:** A 1-year and 5-month-old female with post-natal diagnosis of trisomy 21. The patient also presented with congenital heart disease (atrioventricular canal with pulmonary atresia) for which a Blalock-Taussig shunt was performed at 5 days of life. She has hypothyroidism, currently treated with T4, and severe malnutrition with swallowing disorder, leading to admission to the UNEPP at CHPR with a mixed feeding regimen. The placement of a non-tunneled left subclavian CVC was required to start parenteral feeding. Weekly thermographic and clinical follow-up was conducted, showing a worsening of general condition, fever, and change in acute phase reactants. Blood and catheter culture were positive for multisensitive *Staphylococcus epidermidis*. It was decided to preserve venous access and initiate intravenous treatment with vancomycin along with a local vancomycin lock. The patient showed good clinical progress, with resolution of the infection and preservation of the CVC.

**Case 2:** A 3-year and 2-month-old preschooler with chronic intestinal pseudoobstruction syndrome leading to severe chronic malnutrition. Normal developmental milestones for age. She was admitted to the UNEPP at CHPR on parenteral feeding. History of multiple hospital-acquired infections. Due to fever and change in acute phase reactants, empirical antibiotic therapy started with vancomycin and meropenem, with suspected CVC-related sepsis. Weekly thermographic follow-up was performed. During illness, fever persisted, and multidrug-resistant *Klebsiella pneumoniae* was isolated from blood culture and catheter culture. The CVC was re-moved, with subsequent clinical and thermal improvement.

## Results

In case 1, the initial IR showed hyper-radiant areas in the selected ROIs along the path of the CVC (Figure-1 A, B, C). (Table 1 A, B).
It shows $\Delta T^{max}$ values of 3.0°C and $\Delta T^{average}$ of 2.35°C in the ROIs. (Table 1 A) (Figure 2).
The follow-up infrared imaging on day seven of the selected ROI showed a hyporadiant area along the path of the CVC compared to the initial assessment, with $\Delta T^{max}$ of 1.02°C and $\Delta T^{average}$ of 1.06°C in the ROIs, maintaining the patient's catheter. (Table 1 B).
In case 2, the initial IR shows a hyper-radiant area along the path of the CVC, asymmetrical regarding the contralateral area in the ROIs. (Figure 3 A, B, C).
The values obtained in the ROI showed a $\Delta T^{max}$ of 2.10°C and a $\Delta T^{average}$ of 2.06°C at the catheter insertion site (Table 1 C). The catheter was ultimately removed, and a new access was placed at a different site.

**Table 1.** Deltas A, B, C. Values in the regions of interest.

| | Delta | Max °C | Mín °C | Med °C |
|---|---|---|---|---|
| A | r1-r2 | 3.00 | 1.52 | 2.35 |
| B | r1-r2 | 1.02 | 0.90 | 1.06 |
| C | r1-r2 | 2.10 | 1.90 | 2.06 |

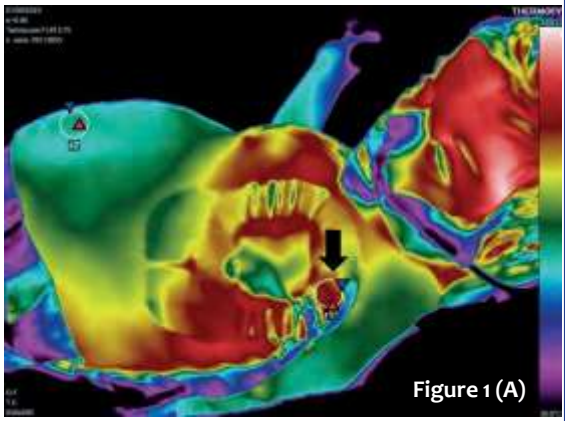
## Discussion

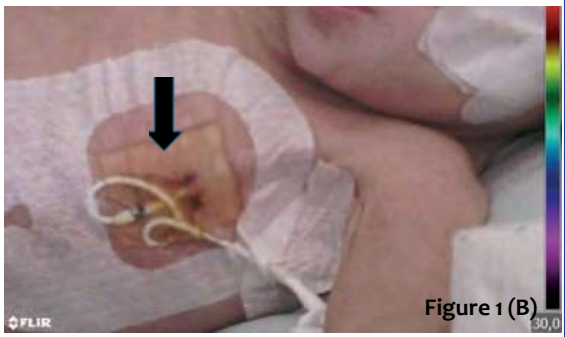
Hospital-acquired infections in the ICU lead to a marked increase in morbidity and mortality. Among hospital-acquired infections, CVC-related infections are the most prevalent and most often occur in critically ill patients[5].

For the control of CVC-related infections, several factors must be considered: the type of catheter, signs related to catheter involvement, the clinical condition of the patient, and culture results[6]. When a patient with a CVC presents suggestive signs of bacteremia, such as fever, chills, and hypotension, the protocol in the ICU is to perform a catheter culture and a peripheral blood culture at the same time. CVC-related infection is confirmed when the microorganisms from both cultures are identical in type and antibiogram, according to the criteria previously defined in the introduction[1-6].

In cases of suspected CVC-related infection, some ICUs have protocols for its removal. However, there is evidence that catheters removed in these situations often do not grow pathogens in cultures. In addition, removing CVC in pediatric patients, especially critically ill ones, and even more so in children with prolonged parenteral feeding, can pose a healthcare challenge due to the difficulty of placing a new vascular access, and each new placement worsens their

**Figure 1 (A, B, C):** Day 1.
**A:** Thermal image at 45° position with safety strap. Arrows indicate ROI (r1) selected according to the UCIN-TERM protocol.
**B:** Optical image.
**C:** 3D thermal reconstruction, showing hyper-radiant areas.



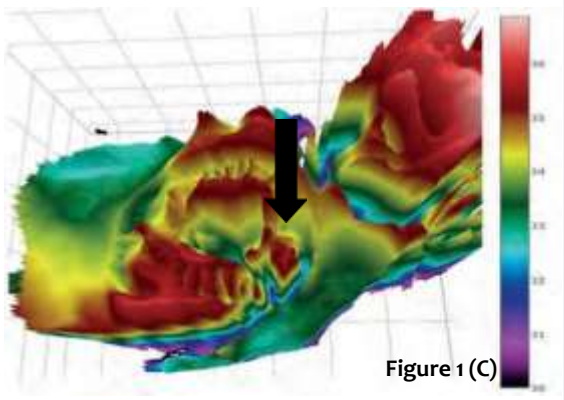
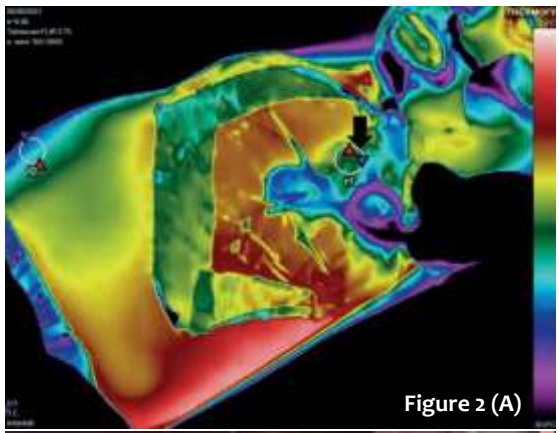
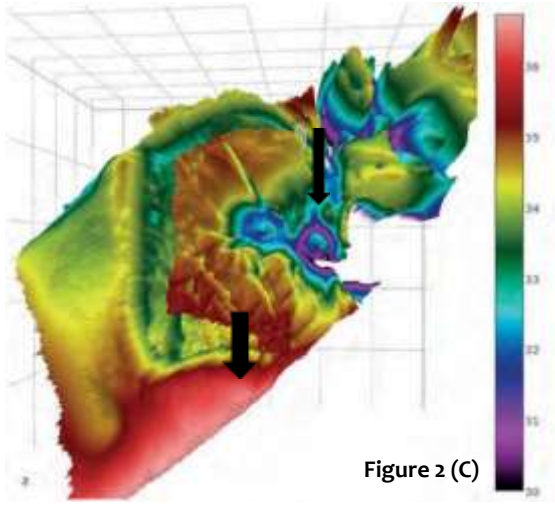




**Figure 2 (A, B, C):** Day 7.
**A:** Thermal image in 45° position with safety strap. Arrows indicate ROI (r1) selected according to the UCIN-TERM protocol.
**B:** Optical image.
**C:** 3D reconstruction, showing hypo-radiant areas. Right lateral views at 60 cm.








vital and functional prognosis. For this reason, it is necessary to have a methodology in the hospitalization unit that can help in attempting conservative management of the CVC, at least initially, when dealing with an uncomplicated catheter-related infection[3-6].

We say that a CVC-associated infection is complicated when there is persistent bacteremia: growth of the same pathogen in blood cultures >72 hours after initiation of adequate antibiotic therapy, presence of endocarditis, septic embolisms, osteomyelitis, or septic thrombophlebitis[3,4]. Internationally, in the last 20 years, multiple lines of research have been developed in the diagnosis and follow-up through thermography, using protocols that allow for reproducible studies[7-16]. It is used in the follow-up of multiple patho-

**Figure 3 (A, B, C)** Case 2:
**A:** Thermal image in 90° sitting position. In the ROIs (r1), $\Delta T^{max}$ values of 2.08°C and $\Delta T^{average}$ of 2.04°C are observed at the catheter insertion point (arrows).
**B:** 3D reconstruction, showing hyper-radiant areas (arrows).
**C:** Optical image and ROI. Frontal views at 60 cm.

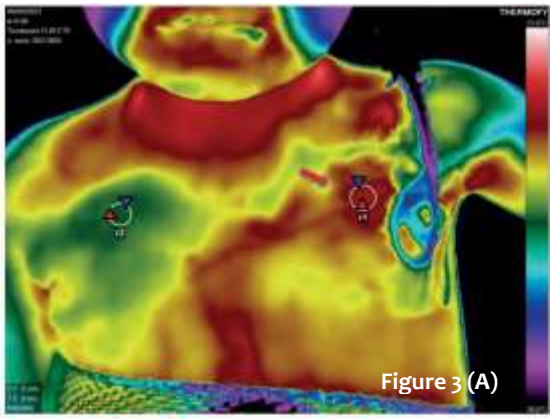


Figure 3 (A)

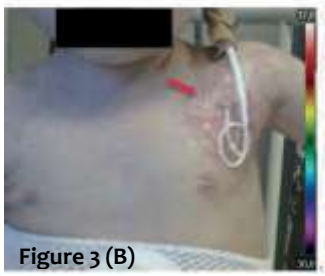


Figure 3 (B)

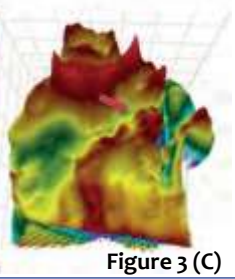


Figure 3 (C)

gies that present changes in perfusion, inflammation, and metabolism[11,13,17]. IR has been used to study diseases where the skin temperature may reflect the presence of inflammation in underlying tissues or those in which blood flow increases or decreases due to a clinical abnormality[11-14]. There are reports of the correlation between $\Delta T^{average}$ values in the ROIs and humoral infection markers[11,15,16]. The described cases presented asymmetries and altered thermal dysfunctions with $\Delta T^{average}$ higher than 1°C[10-13]. Additionally, both cases presented $\Delta T^{max}$ greater than 2.0°C[10,11,16].

In a publication that performed thermal follow-up in a patient with a bothrops bite with local swelling, on the fourth day after the bite, an increase in the $\Delta T^{average}$ of up to 3°C was observed, concomitant with an increase in systemic leukocytosis and fever, with good response after starting antibiotic treatment, showing clinical, laboratory, and thermal improvement[11]. Although we cannot extrapolate this finding to $\Delta T^{average}$ to other infectious processes, it could be indicative of processes related to systemic infections.

Another study performed a thermographic follow-up in a hospital in Valencia on children with PICC with oncologic diseases. These children have the same difficulty in placing long-term venous access as the children in the clinical cases discussed with parenteral feeding. In this group of patients, the temperature deltas were $\Delta T^{max}$ 1.5 ± 0.7°C in children with catheter-related sepsis, compared to $\Delta T^{average}$ 0.5 ± 0.2°C in children where no infection was confirmed. This difference was statistically significant, with a decrease observed once treatment was initiated[16]. The thermography team continues this project prospectively with the follow-up of patients with CVC placement during their stay in intensive care, in order to increase the number of recruited patients and thus provide significant data for statistical conclusions, as well as define possible ranges of $\Delta T^{average}$ and $\Delta T^{max}$ that may be predictive of catheter-related sepsis in our setting[14-16].

## Conclusions

IR thermography is a non-invasive study that can be useful for the follow-up and thermal semiological diagnosis of inflammatory processes in central catheters[4-6]. There are few studies in the literature on thermal follow-up of CVCs in pediatrics[14-16]. This is the first study in Uruguay with high-resolution thermal imaging in pediatrics. CVC-related infections are the main cause of hospital-acquired infections in pediatric ICUs. However, catheters removed due to suspected infection often did not show microbiological growth in cultures[4-6]. The use of a technique that does not require mobilizing the critically ill patient, complementing the physical examination and humoral parameters, together with monitoring $\Delta T^{max}$/$\Delta T^{average}$ values, combined with its low cost, shows promise. Further case series studies are needed for statistical analysis.

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**Data availability**
The dataset supporting the results of this study is NOT available in open-access repositories.

**Author's contribution**
All authors of this work contributed to the conception and critical revision and gave final approval of the version to be published.

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