

Title: Accuracy of infrared thermography for perforator mapping: a systematic review and meta-analysis of diagnostic studies

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A protocol for this systematic review was registered with **PROSPERO (CRD42019154393)**

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Abstract

Introduction: Infrared thermography allows the detection of infrared radiation, which can be reliably associated with skin temperature. Modern portable thermography devices have been used to identify the location of skin perforators by detecting subtle differences in skin temperature. The aim of this study is to conduct a diagnostic accuracy systematic review to determine the specificity and sensitivity of infrared thermography.

Materials and Methods: A PRISMA-compliant systematic review and meta-analysis was conducted, scrutinising PUBMED and EMBASE databases for diagnostic studies measuring the accuracy of infrared thermography for perforator identification. Article screening, review and data gathering was conducted in parallel by two independent authors. Eligible studies were subject to a formal risk of bias was assessment using the QUADAS2 instrument.

Results: A total of 254 entries were obtained, of which 7 satisfied our pre-established inclusion criteria. These studies reported a total of 435 perforators in 133 individuals. The most commonly investigated locations were the antero-lateral thigh and abdominal wall. Reported sensitivity values ranged from 73.7% to 100%. A meta-analysis demonstrated a cumulative sensitivity of 95%. Specificity was not routinely reported. All studies presented a moderate to high risk of bias according to QUADAS2.

Discussion: Affordable infrared thermography devices are an interesting alternative to traditional preoperative investigations for perforator mapping. It is sensitive enough to reliably identify a large

proportion of perforators as “hot-spots”. However, there is limited evidence to estimate the specificity of this technology, as studies have failed to report true negative values associated with “cold-spots”.

Introduction

Infrared thermography is the technology that allows the detection of infrared radiation without the need of touching the surface of interest. Even though its clinical use was described more than half a century ago¹, the recent development of more affordable and precise infrared thermographs has captured the attention of plastic surgeons².

Normal skin temperature is variable in different anatomical regions, and one of the main determinants of skin temperature in an area is its perfusion³. Infrared thermography can, therefore, indirectly detect areas of increased perfusion or decreased perfusion by measuring subtle temperature changes⁴. All objects with temperature above absolute zero emit infrared or thermal radiation. The emissions arising from human skin tend to vary within a wavelength range of 2 to 20 micrometres, which can be detected from a distance by an infrared camera able to convert the intensity of the emitted radiation to temperature⁵. With the development of more precise hand-held or smartphone-compatible infrared thermography devices, authors have been able to use this technology to locate skin perforators arising from deeper tissues⁶.

The medical applications of infrared thermography in medicine are varied, including fever screening⁷, diagnosis of diabetic neuropathy⁸, monitoring of inflammation in rheumatic conditions⁹, among others. The utility of this application for plastic surgeons derives from the importance of perforator location for planning perforator flaps¹⁰. The raising of these flaps involves the identification and dissection of the perforator perfusing the flap that is being harvested. This allows transferring these flaps regionally or as a

free flap with its pedicle involving the perforators with or without the named vessel from which these derive¹¹.

Direct visualisation of these perforators by means of an exploratory incision is still the gold standard for locating perforators before committing to raise a perforator flap. The bedside use of a hand-held doppler can be used to look for perforators in a particular anatomical location, however, information is only useful if a perforator is actually found¹². Computed tomography (CT), magnetic resonance imaging (MRI) in and near-infrared fluorescence using indocyanine green (ICG)¹³ have been more recent additions to the reconstructive planning armamentarium, being able to accurately describe perforator anatomy¹⁴. Adequate planning can consequently reduce operative time, complications and costs¹⁵.

Unfortunately, access to CT, MRI and ICG scans can be limited in resource restrained settings, and the former involves exposing the patient to radiation. The concept of scanning for perforators on the patient's bedside using infrared thermography is appealing and several authors have advocated for this idea¹⁶. The aim of this study is to conduct a diagnostic accuracy systematic review to determine the specificity and sensitivity of this technology, compared to gold standard investigations.

Materials and Methods

This diagnostic systematic review is compliant with the PRISMA statement¹⁷. The protocol for this study, including search strategies, inclusion and exclusion criteria (Table 1), along with screening and data gathering processes were prospectively registered in PROSPERO (CRD42019154393). Only diagnostic studies reporting the identification of perforators using infrared thermography compared with a gold standard were included in this review. Previous systematic, proof of concept and studies using this technology for flap planning, but not reporting its diagnostic accuracy were excluded.

With the aid of a senior librarian with experience in systematic reviews, a search strategy was designed using the following free search terms: “thermography”, “thermal camera”, “surgical flaps”, “free tissue flap” and “perforator flap” (Appendix 1). Searches were conducted on the 20th of April 2020, including EMBASE and MEDLINE databases. No filters or limitations were applied, including all studies in any language published to date. Abstract and conference proceedings were also considered.

Mendeley Desktop reference management software (Elsevier. London, United Kingdom) was used to find and discard duplicate publications. Independent screening of titles and abstracts was conducted by two authors (JB and LT) using the Rayyan QCRI software¹⁸ (Qatar Computing Research Institute, Qatar). Full text-review followed for eligible studies, considering the previously stated inclusion and exclusion criteria. A senior author (AJ) was designated for the resolution any arising disagreements.

The resulting list of publications was reviewed in parallel and independently by two authors (NP and PW) using a pre-established data gathering pro-forma. Information regarding patient selection, anatomical

areas, infrared thermography modalities, gold standard investigation, sensitivity and specificity were recorded. Formal risk of bias assessment was performed using the QUADAS2 instrument for diagnostic studies¹⁹. Revman 5.4 software (Cochrane Collaboration) was used for sensitivity and specificity calculations and for presenting QUADAS2 risk of bias results.

Results

A total of 254 entries were obtained from the systematic searches, of which 129 were retrieved from MEDLINE and 125 from EMBASE. Following identification of 90 duplicate items, 164 publications were reviewed further. Of these, only seven met the pre-defined inclusion criteria (Figure 1).

The definitive list of eligible studies included articles published from 2009 to date, all of which had a diagnostic accuracy design. Of these, six were published in English with a single entry was only available in Mandarin.

A total of 133 individuals were included as patients or healthy volunteers among included articles, with a median age of 44 years (range 12-70). The most investigated anatomical location was the antero-lateral thigh (n=71), followed by the abdominal wall (n=35) and the lower leg (n=18). A total of 435 perforators were identified for these cases (Table 2). Computed tomography angiography (CTA) and surgical exploration were the most commonly reported gold-standards to identify and locate perforators, however colour doppler ultrasound (CDU) and hand-held doppler ultrasound were also used, in one study each. Methodological details for each of the eligible studies, including the thermography device used and protocol are shown in Table 2²⁰⁻²⁶.

Only four studies reported specificity regarding the use of infrared thermography for identifying skin perforators, however, only the study by Pereira et al²³ included “true negative” values required for reproducing specificity calculations. Therefore, a specificity meta-analysis was not possible. All the included articles except one, by Tenorio et al²⁶, reported sensitivity measures for this diagnostic modality,

ranging from 73.7% to 100% (Figure 2). A meta-analysis for these 6 studies that reported sensitivity values demonstrated a cumulative sensitivity of 95% [Confidence Interval: 0.92-0.97]. All the studies included in this systematic review presented a moderate to high risk of bias according to the QUADAS2 instrument (Figure 3).

Discussion

Perforator flap surgery offers a reconstructive alternative which spares the functional implications of harvesting muscle or musculocutaneous flaps²⁷. The popularity of the deep inferior epigastric artery perforator (DIEP) flap for breast reconstruction²⁸ and the antero-lateral thigh (ALT) flap for head and neck and limb reconstruction²⁹ relies on the possibility of raising large flaps with long pedicles, while minimising donor site morbidity. However, raising perforator flaps can be challenging even in experienced hands, making pre-operative planning crucial³⁰.

Computed tomography and magnetic resonance angiography (MRA) can provide a detailed description of the vascular anatomy, providing reliable information about the location of perforators and their course towards their nutrient vessel¹⁴. The routine use of these investigations has proven to result in a reduction in operative time and associated costs¹⁵. Even though CTA and MRA are accessible in high-income countries, this is not necessarily the case for the developing world³¹. Furthermore, these can be contraindicated in certain groups of patients, as contrast agents are usually required.

Hand-held doppler ultrasound devices have become an important tool for the reconstructive surgeon. These are considerably cheaper, easily portable and safe in all patient groups³². These allow the detection of perforators by scanning anatomical areas known for their high perforator density. However, their use is user-dependant and affected by other factors such as environmental noise and interference from electronic equipment in its vicinity¹².

Infrared thermography offers an alternative for mapping perforators by detecting subtle temperature differences in the skin surface⁶. Even though a correlation between thermographic “hot-spots” and underlying perforators has been proposed in previous primary studies, to our knowledge the diagnostic accuracy systematic review hereby presented has not.

A total of seven diagnostic accuracy articles were identified, of which six reported true positive and false negative values necessary for a sensitivity meta-analysis^{20–25}. Even though, four studies reported specificity values, ranging from 65.6% to 98%^{20–23}, only one contained the required true negative “cold-spots” values for reproducing these calculations²³. Therefore, no specificity meta-analysis was possible for specificity among eligible articles.

The cumulative sensitivity of infrared thermography obtained was 95%. Gold-standard measures used in the studies included in this meta-analysis included CTA and direct visualisation during surgical exploration. All of these followed a diagnostic accuracy methodology in which all participating individuals underwent a thermography scan followed by a gold-standard assessment. Research reports that did not comply with this were excluded as per our review protocol, such as studies in which the use of infrared thermography was followed immediately by hand-held doppler investigation of identified “hot-spots”³³. Even though this methodology can correlate findings between “hot-spots” with a positive or negative doppler signal, true and false positives, it is unable to detect true and false negatives, as “cold-spots” are neglected.

Our systematic review is limited by the methodological and reporting quality of the studies found. All of these presented moderate to high risk of bias as per our QUADAS2 assessment. Furthermore, none of the

articles included in this review was compliant with the STARD reporting guidelines for reporting diagnostic accuracy studies³⁴. Future systematic reviews with meta-analysis would benefit from routine reporting of index test results to determine not only the sensitivity, but also the specificity of infrared thermography for perforator detection. Due to the small number of studies eligible for this review we were unable to further investigate any significant differences between the variety of thermographic devices used and across different anatomical locations, which could ultimately affect the results obtained in the conducted meta-analysis.

It has been argued that a “dynamic” assessment by cooling the skin surface and then appreciating re-warming of “hot-spots” would increase the accuracy of this technology³⁵. Even though three out of the seven studies included in this review reported using dynamic infrared thermography^{22,24,26}, it was impossible to compare their results with static infrared thermography reports, due to variability in skin cooling and rewarming protocols.

The development of cheaper, smaller and more accessible infrared thermography devices makes this technology an interesting alternative to traditional preoperative investigations for perforator flap planning. It is sensitive enough to reliably identify a large proportion of perforators as “hot-spots”, which can later be confirmed during surgical exploration. However, it is still obscure how many perforators may be hiding under thermographic “cold-spots”, due to the lack of studies reporting true negative values. The conduction of further well designed and adequately reported diagnostic accuracy studies is required to ascertain the specificity of this technology for perforator detection.

Ethical approval

Not required.

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Conflicts of interest

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References

1. Ring EFJ. The historical development of thermal imaging in medicine. *Rheumatology*. 2004;43:800-802. doi:10.1093/rheumatology/keg009
2. John HE, Niumsawatt V, Rozen WM, Whitaker IS. Clinical applications of dynamic infrared thermography in plastic surgery: a systematic review. *Gland Surg*. 2016;5(2):122-132. doi:https://dx.doi.org/10.3978/j.issn.2227-684X.2015.11.07
3. Love TJ. Thermography as an indicator of blood perfusion. *Ann N Y Acad Sci*. 1980;335(1):429-437. doi:10.1111/j.1749-6632.1980.tb50766.x
4. Bulstrode NW, Wilson GR, Inglis MS. No-touch free-flap temperature monitoring. *Br J Plast Surg*. 2002;55(2):174. <http://ovidsp.ovid.com/ovidweb.cgi?T=JS&PAGE=reference&D=med4&NEWS=N&AN=11987966>.
5. Lahiri BB, Bagavathiappan S, Jayakumar T, Philip J. Medical applications of infrared thermography: A review. *Infrared Phys Technol*. 2012;55(4):221-235. doi:10.1016/j.infrared.2012.03.007
6. Hardwicke JT, Osmani O, Skillman JM. Detection of Perforators Using Smartphone Thermal Imaging. *Plast Reconstr Surg*. 2016;137(1):39-41. doi:https://dx.doi.org/10.1097/PRS.0000000000001849
7. Tay MR, Low YL, Zhao X, Cook AR, Lee VJ. Comparison of Infrared Thermal Detection Systems for mass fever screening in a tropical healthcare setting. *Public Health*. 2015;129(11):1471-1478. doi:10.1016/j.puhe.2015.07.023
8. Bharara M, Schoess J, Armstrong DG. Coming events cast their shadows before: Detecting inflammation in the acute diabetic foot and the foot in remission. *Diabetes Metab Res Rev*. 2012;28(SUPPL. 1):15-20. doi:10.1002/dmrr.2231
9. Gatt A, Mercieca C, Borg A, et al. A comparison of thermographic characteristics of the hands and

wrists of rheumatoid arthritis patients and healthy controls. *Sci Rep.* 2019;9(1).

doi:10.1038/s41598-019-53598-0

10. Pereira N, Hallock GG. Smartphone Thermography for Lower Extremity Local Flap Perforator Mapping. *J Reconstr Microsurg.* 2020. doi:http://dx.doi.org/10.1055/s-0039-3402032
11. Morris SF, Tang M, Almutari K, Geddes C, Yang D. The anatomic basis of perforator flaps. *Clin Plast Surg.* 2010;37(4):553-570. doi:10.1016/j.cps.2010.06.006
12. Stekelenburg CM, Sonneveld PMDG, Bouman MB, et al. The hand held Doppler device for the detection of perforators in reconstructive surgery: What you hear is not always what you get. *Burns.* 2014;40(8):1702-1706. doi:10.1016/j.burns.2014.04.018
13. Cornelissen AJM, van Mulken TJM, Graupner C, et al. Near-infrared fluorescence image-guidance in plastic surgery: A systematic review. *Eur J Plast Surg.* 2018;41(3):269-278. doi:10.1007/s00238-018-1404-5
14. Masia J, Clavero JA, Larrañaga JR, Alomar X, Pons G, Serret P. Multidetector-row computed tomography in the planning of abdominal perforator flaps. *J Plast Reconstr Aesthetic Surg.* 2006;59(6):594-599. doi:10.1016/j.bjps.2005.10.024
15. O'Connor EF, Rozen WM, Chowdhry M, Band B, Ramakrishnan V V., Griffiths M. Preoperative computed tomography angiography for planning DIEP flap breast reconstruction reduces operative time and overall complications. *Gland Surg.* 2016;5(2):93-98. doi:10.3978/j.issn.2227-684X.2015.05.17
16. Weum S, Lott A, de Weerd L. Detection of Perforators Using Smartphone Thermal Imaging. *Plast Reconstr Surg.* 2016;138(5):938e-940e.
<http://ovidsp.ovid.com/ovidweb.cgi?T=JS&PAGE=reference&D=med13&NEWS=N&AN=27783018>.
17. Moher D, Liberati A, Tetzlaff J, Altman DG, Group TP. Preferred Reporting Items for Systematic

Reviews and Meta-Analyses: The PRISMA Statement. *PLoS Med*. 2009;6(7):e1000097.

doi:10.1371/journal.pmed.1000097

18. Qatar Computing Research Institute. Rayyan QCRI. 2020. <https://rayyan.qcri.org/welcome>.
19. Whiting PF, Rutjes AWS, Westwood ME, et al. Quadas-2: A revised tool for the quality assessment of diagnostic accuracy studies. *Ann Intern Med*. 2011;155(8):529-536. doi:10.7326/0003-4819-155-8-201110180-00009
20. Xiao W, Li K, Kiu-Huen Ng S, et al. A Prospective Comparative Study of Color Doppler Ultrasound and Infrared Thermography in the Detection of Perforators for Anterolateral Thigh Flaps. *Ann Plast Surg*. 2020;84(5S Suppl 3):S190-S195. doi:<https://dx.doi.org/10.1097/SAP.0000000000002369>
21. Xu W-H, Lin P, Xu T-T, et al. [Application of infrared thermal imaging technology in the design of free anterolateral thigh perforator flap transplantation]. *Zhongguo Gu Shang*. 2019;32(11):1053-1057. doi:<https://dx.doi.org/10.3969/j.issn.1003-0034.2019.11.015>
22. Chen R, Huang Z-Q, Chen W-L, Ou Z-P, Li S-H, Wang J-G. Value of a smartphone-compatible thermal imaging camera in the detection of peroneal artery perforators: Comparative study with computed tomography angiography. *Head Neck*. 2019;41(5):1450-1456.
doi:<http://dx.doi.org/10.1002/hed.25581>
23. Pereira N, Valenzuela D, Mangelsdorff G, Kufeke M, Roa R. Detection of Perforators for Free Flap Planning Using Smartphone Thermal Imaging: A Concordance Study with Computed Tomographic Angiography in 120 Perforators. *Plast Reconstr Surg*. 2018;141(3):787-792.
doi:<https://dx.doi.org/10.1097/PRS.00000000000004126>
24. Weum S, Mercer JB, de Weerd L. Evaluation of dynamic infrared thermography as an alternative to CT angiography for perforator mapping in breast reconstruction: a clinical study. *BMC Med Imaging*. 2016;16(1):43. doi:<https://dx.doi.org/10.1186/s12880-016-0144-x>

25. Chubb DP, Taylor GI, Ashton MW. True and “choke” anastomoses between perforator angiosomes: part II. dynamic thermographic identification. *Plast Reconstr Surg*. 2013;132(6):1457-1464.
doi:<http://dx.doi.org/10.1097/01.prs.0000434407.73390.82>
26. Tenorio X, Mahajan AL, Elias B, et al. Locating perforator vessels by dynamic infrared imaging and flow Doppler with no thermal cold challenge. *Ann Plast Surg*. 2011;67(2):143-146.
doi:<https://dx.doi.org/10.1097/SAP.0b013e3181ef6da3>
27. Koshima I, Yamamoto T, Narushima M, Mihara M, Iida T. Perforator Flaps and Supermicrosurgery. *Clin Plast Surg*. 2010;37(4):683-689. doi:10.1016/j.cps.2010.06.009
28. Moller L, Berner JE, Dheansa B. The reconstructive journey: description of the breast reconstruction pathway in a high-volume UK-based microsurgical centre. *J Plast Reconstr Aesthetic Surg*. 2019;72(12):1930-1935. doi:10.1016/j.bjps.2019.07.017
29. Wong CH, Wei FC. Anterolateral thigh flap. *Head Neck*. 2010;32(4):529-540.
doi:10.1002/hed.21204
30. Pratt GF, Rozen WM, Chubb D, Ashton MW, Alonso-Burgos A, Whitaker IS. Preoperative imaging for perforator flaps in reconstructive surgery: A systematic review of the evidence for current techniques. *Ann Plast Surg*. 2012;69(1):3-9. doi:10.1097/SPA.0b013e318222b7b7
31. Mclane HC, Berkowitz AL, Patenaude BN, et al. Availability, accessibility, and affordability of neurodiagnostic tests in 37 countries. *Neurology*. 2015;85(18):1614-1622.
doi:10.1212/WNL.0000000000002090
32. Yu P, Youssef A. Efficacy of the Handheld Doppler in Preoperative Identification of the Cutaneous Perforators in the Anterolateral Thigh Flap. *Plast Reconstr Surg*. 2006;118(4):928-933.
doi:10.1097/01.prs.0000232216.34854.63
33. Sheena Y, Hardwicke J, Jennison T, Titley OG. Detection of perforators using thermal imaging. *Plast*

Reconstr Surg. 2014;134(5):1603-1610. doi:<http://dx.doi.org/10.1097/PRS.0000000000000595>

34. Bossuyt PM, Reitsma JB, Bruns DE, et al. STARD 2015: an updated list of essential items for reporting diagnostic accuracy studies. *BMJ.* 2015;351:h5527.
<http://www.ncbi.nlm.nih.gov/pubmed/26511519>. Accessed January 7, 2018.
35. De Weerd L, Mercer JB, Weum S. Dynamic Infrared Thermography. *Clin Plast Surg.* 2011;38(2):277-292. doi:10.1016/j.cps.2011.03.013

Table 1: Inclusion and exclusion criteria

Inclusion criteria	Exclusion criteria
Diagnostic studies	Animal studies
Use of dynamic infrared thermography for identifying skin perforator vessels	Basic science studies
Comparison against a validated measure	Previous systematic reviews

Table 2: Included studies in systematic review

Reference	Study type	Anatomical region examined (number of patients / volunteers)	Number of perforators found	Device used	Protocol for measurements	Validated Measure	Reported Sensitivity	Reported Specificity
Xiao et al, 2020 ²⁰	Diagnostic accuracy	ALT (n=20)	53	FOTRIC® 228s	Room temperature	CDU + intraoperative visualisation	94.3%	85.7%
Xu et al, 2019 ²¹	Diagnostic accuracy	ALT (n=31)	35	Vario CAM	Room temperature	Intraoperative visualisation	100%	92.1%
Chen et al, 2019 ²²	Diagnostic accuracy	Peroneal artery perforators (n=12)	57	FLIR ONE Pro	Cooling with cold gel pack for 15 seconds	CTA + intraoperative visualisation	73.7%	65.6%
Pereira et al, 2018 ²³	Diagnostic accuracy	ALT (n=20)	117	FLIR ONE	Room temperature	CTA	100%	98%
Weum et al, 2016 ²⁴	Diagnostic accuracy	Abdomen (n=25)	108	FLIR ThermoCAM S65 HS	Fan cooling for 2 minutes	CTA + intraoperative visualisation	100%	-
Chubb et al, 2013 ²⁵	Diagnostic accuracy	Abdomen and lower extremity (n=9)	65	NEC Thermo Tracer	Cooling with water pack at 20-22 degrees Celsius for 5 minutes	CTA	94%	-
Tenorio et al 2011 ²⁶	Diagnostic accuracy	Abdomen (n=10) and peroneal artery perforators (n=6)	Average for Abdomen: 9.3 / Leg: 5.6	BioScanIR system	Room temperature	Hand-held doppler + intraoperative visualisation	-	-

ALT: antero-lateral thigh; CDU: colour doppler ultrasound; CTA: computed tomography angiography

Figure Legends

Figure 1: PRISMA flow diagram

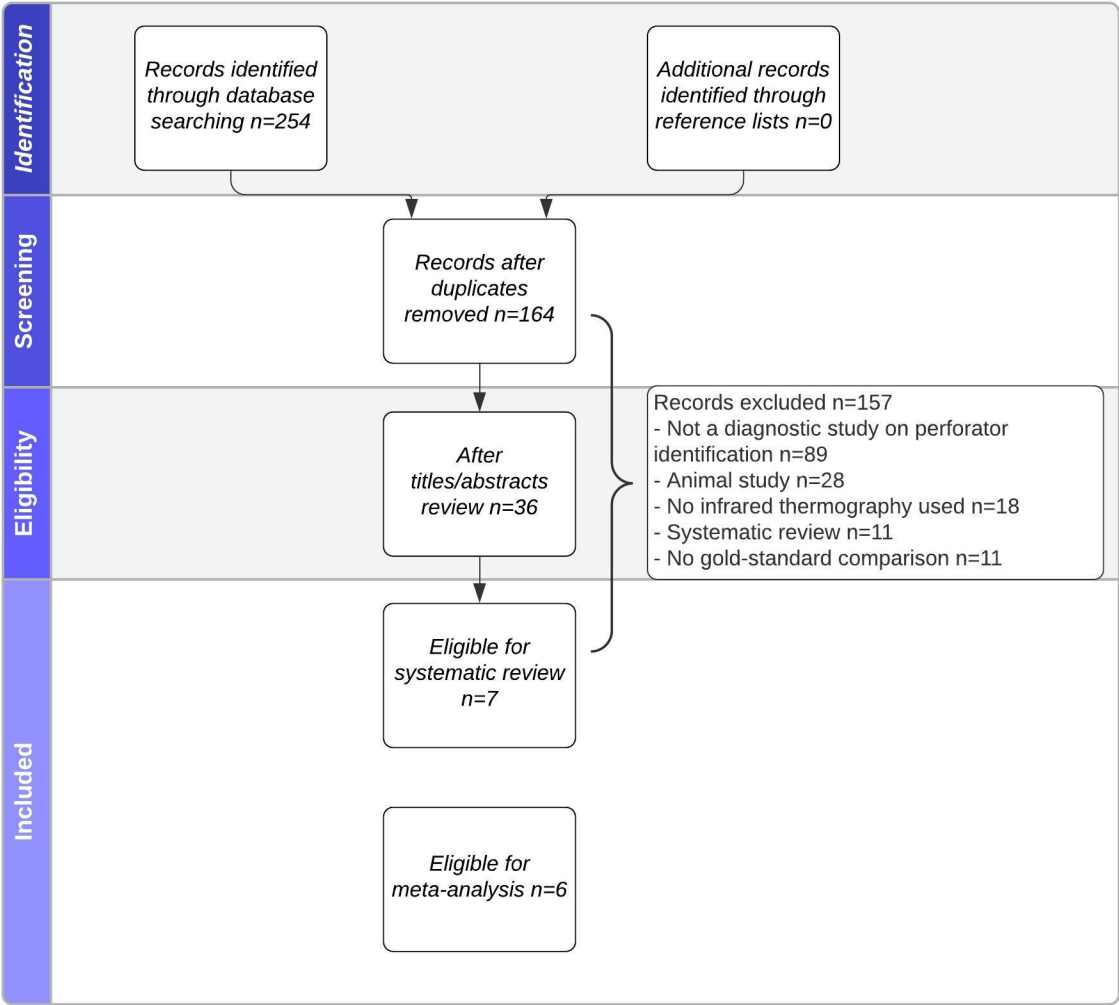


Figure 2: Sensitivity Forest Plot for studies eligible for meta-analysis

