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Use of infrared thermography in medical diagnostics: a scoping review protocol

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ABSTRACT

Introduction Thermography offers a non-invasive radiation-free methodology for diagnostic imaging and temperature measurement, but the extent of the current application is unclear, as is the level of evidence for each use case. Moreover, population-based thermographic reference values for diagnostic purposes are nearly unknown. The aim of this scoping review is to identify patient populations and diseases in which thermography is applied, cataloguing of technical and environmental modalities, investigation of the existence of specific reference data and finally exploration of gaps and future tasks.

Methods and analysis PubMed, Cochrane Database of Systematic Reviews and CENTRAL, Embase, Web of Science and OpenGrey are to be searched using pretested suitable search strategies, with no language restriction, but abstracts should be available in English or German and articles should not have been published before 2000. This limited time frame is due to the rapid technological progress, which makes it necessary to exclude reports based on outdated technology. The literature found will be selected on the basis of previously defined inclusion and exclusion criteria. Subsequently, relevant data will be extracted from the included references into a predesigned table. The selection and extraction process will be conducted by two researchers independently. The report of the results will be according to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses extension for Scoping Reviews checklist. The entire review process will follow the Joanna Briggs Institute approach. The scoping review protocol is registered at the Open Science Framework.

Ethics and dissemination Ethical approval is not required for this work, but ethical medicine also obliges us to carefully consider diagnostic alternatives and compare them with current standards. The dissemination of the results will take place in a variety of ways. First and foremost through publication in an open access journal, but also through conference proceedings. In addition, this scoping review will serve to open up new research foci with regard to thermography.

Strengths and limitations of this study

- The planning and conduction of this scoping review follows the recognised standards of the Joanna Briggs Institute.
- The final results of this scoping review will be reported according to the 'Preferred Reporting Items for Systematic Reviews and Meta-Analyses extension for Scoping Reviews'.
- Given the expected volume of literature and the independence of the outcomes of this scoping review from the size of the included studies, a minimum sample size of 25 individuals per group studied was established.
- Due to the nature of a scoping review, no formal quality assessments of included studies and thus no recommendations for specific areas of application can be made.

INTRODUCTION

Thermography is described as 'a scanning technique which gives a photographic display of the temperature differences of the surface of the body'.[1] Human health is strongly correlated with body and tissue temperature, which is within a narrowly defined range in healthy individuals under standardised environmental conditions, so deviations may indicate pathological processes, physical abnormalities or defects. The infrared radiation emitted by the surface of the body allows a measurement within a specific wavelength by an infrared detector.[2] Hence, thermography was considered a promising new imaging technology in the 1970s, but subsequently disappeared due to immature technology and misinformation.[3] Thanks to the immense technical development since then, thermography today has continuously expanded its range of application and, though not as an imaging technique, has recently proven its practicability in the mass use for temperature measurements in the context of the COVID-19 pandemic.[4] However, the possible applications go far beyond the simple measurement of body temperature. Deviations in surface temperature can have many causes, such as inflammation, malignancies and infections. Here, thermography offers a non-invasive imaging option that could complement and expand the spectrum of medical imaging, even in areas that otherwise or previously could not be imaged or could only be inadequately imaged, for example, Raynaud's phenomenon, gout and arthritis.[2] Moreover, thermography could at least in part, replace or supplement radiation-based methods or those requiring a great deal of costly technical equipment or specific expertise.[2] Thermography opens up many new possibilities in preventive diagnostic and therapeutic monitoring, for example, in diabetic complications or rheumatic diseases.[5 6] The expanding capabilities of artificial intelligence, machine learning and deep learning open up unprecedented sophisticated application possibilities for technologies such as thermography, where large amounts of digital data are generated during each examination, far exceeding the capacities of any analysis by the examiner.[7]

The medical scientific interest in thermography is constantly growing, as can be seen from the increasing number of published articles. The number of systematic reviews on this topic is also steadily increasing. In November 2021, 39 protocols of ongoing reviews were found in the PROSPERO database with the keyword 'thermography'; investigating the use for breast cancer screening, temporomandibular disorders, diabetic foot, Raynaud's phenomenon, body or skin temperature measurement, vascular diseases, musculoskeletal injuries, breast reconstructive surgery, ischaemia in scleroderma, pulp vitality and auxiliary diagnosis in dentistry, back and neck syndromes, diagnosis of hidradenitis suppurativa, facial paralysis, diabetic complications, spinal cord injury, outcome assessment in striae treatment, burns healing, detecting tendinopathy or risk of tendon injury, osteomioarticular overload, orofacial pain, pain in Parkinson's disease, early detection of pressure ulcers, delayed-onset muscle soreness, skin temperature following total knee arthroplasty, orthopaedic and bone or joint trauma and finally thermography for the non-invasive-assessment of microvascular structure and function in cardiovascular disease.[8] This breadth of application also supports the development of the use of artificial intelligence described above, and so some specific use cases have already been developed, such as diagnosis of skin cancer and breast cancer screening.[9 10]

The number of articles published annually also shows that thermography is widely researched. A computer-assisted literature survey of publications on thermography in 2017 listed 1038 articles in Scopus and Embase, and an additional 15 notes or abstracts in 'Thermology international', the organ of five international thermography associations.[11] The medical fields to which the most publications could be attributed were surgery, physiology and endocrinology, cancer, radiology and nuclear medicine and pathology and forensic science. In 2020, the literature survey of the thermography associations focused on applications related to the COVID-19 pandemic and identified 149 articles that reported temperature measurements for fever screening or preventive measures.[4]

In some application areas, such as the contactless measurement of body temperature, thermography is already state-of-the-art. However, in many other areas, it is still considered an outsider method. For a breakthrough with regard to a broad application in the entire medical field, a comprehensive, evidence-based overview of the current state of knowledge and development is still missing. But the latter is indispensable for further development and acceptance of this examination method. Technological progress both in terms of thermographic devices and in terms of possible subsequent image processing and evaluation by artificial intelligence opens up great opportunities and possibilities for a wide-ranging use of this non-invasive methodology in the medical-diagnostic field. Therefore, a structured survey for a deeper understanding of the current meaning of thermography and the state-of-the-art is necessary to identify targeted research areas that will advance the use of this promising technology will be done.

First, we had to clarify which type of review would be most appropriate for our objective of providing a comprehensive overview of use cases of infrared thermography. Since we were not interested in an evidence synthesis of a single application area, but in compiling a more comprehensive catalogue of all current use cases, we decided on a scoping review. This decision was based on the valuable recommendations provided by the Joanna Briggs Institute (JBI) in the internet, and on the guidance of Munn *et al*.[12 13]

In the preparation of this protocol, a preliminary search was performed in PROSPERO, the Cochrane Database of Systematic Reviews, JBI Evidence Synthesis and Open Science Framework (OSF) in November 2021. Several completed or in-progress systematic reviews and some scoping reviews were found, but no comprehensive scoping review of thermography in general could be identified. In contrary to our planned scoping review, the systematic reviews we found focused on specific application areas or diseases, as did the scoping reviews that reported on specific topics, for example, neonatal care.

AIM AND OBJECTIVES

The fundamental research question of our scoping review is: 'For what health conditions and diseases is thermography used for which diagnostic purposes?'. According to the Population, Concept, Content (PCC) elements, a population without limitations to age, sex and origin, the application of thermography for diagnostic or monitoring reasons as the concept and diseases/health conditions as content were identified.

Hence, we aim to develop a comprehensive overview and mapping of the use of thermography in the medical field for healthy and sick people at the current state-of-the-art.

To comply with this, we plan to fulfil the following tasks:

1. To create a representative catalogue of all medical use cases of thermography in the diagnostic field as identified by the literature.
2. Cataloguing of the technical and environmental application modalities in the different application areas including standard procedures and protocols.
3. Detection of reference values in the normal/healthy range for use cases or body regions.
4. Exploration of potential gaps in the application or research and identification of future tasks.

METHODS

The preparation of this protocol is based on the template of the JBI Scoping Review Working Group and the guidance from the JBI Manual for Evidence Synthesis.[14 15] The proposed scoping review will be conducted in accordance with the JBI methodology for scoping reviews.[16] It is registered in the OSF database (Registration DOI: 10.17605/OSF.IO/TSZ28).[17] The report of the results will follow the Preferred Reporting Items for Systematic Reviews and Meta-Analyses extension for Scoping Reviews (PRISMA-ScR).[18]

The projected time frame for conducting this review runs from the start of the searches in April 2022 to the completion of the report in December 2022.

Patient and public involvement

Patients and/or the public were not involved in the design, or conduct, or reporting, or dissemination plans of this research.

Search strategy

An initial limited search based on the PCC key elements, as reported above, was undertaken in PubMed, the Cochrane Library and Embase (via OVID) to identify articles on the topic. The text words contained in the titles and abstracts of relevant articles, and the index terms used to describe the articles were used to develop a preliminary full search strategy for PubMed according to the PRESS (Peer Review of Electronic Search Strategies) specifications (see online supplemental appendix A).[19] This search strategy, including all identified keywords and index terms, will be adapted for each database and/or information source to be searched. The reference list of all included sources of evidence will be screened for additional studies.

The databases to be searched include PubMed, the Cochrane Library, Embase and Web of Science. Sources of unpublished studies or grey literature to be searched include OpenGrey via Data Archiving and Networked Services, OSF and PROSPERO. Additionally, the 'Published Papers on Thermology or Temperature Measurement' list provided by Thermology International will be searched.[20]

Studies published in any language will be included but title/abstracts are to be available in English or German. The time period of publications to include will be limited to the year 2000 until current because older studies are based on outdated technology and are considered to be not relevant to the current state-of-the-art.

Eligibility criteria

Inclusion and exclusion criteria that will be applied to the titles, abstracts and articles retrieved in the systematic literature search are depicted in detail in table 1.

Source of evidence selection

Following the search, all identified citations will be collated and uploaded into RefWorks and duplicates will be removed. After a pilot test of 25 randomly selected titles/abstracts and any refinement or adjustment of the predefined inclusion and exclusion criteria, the titles and abstracts will be screened by two independent reviewers applying the finalised inclusion and exclusion criteria for the review (table 1). Positively evaluated references from the title/abstract scan are then retrieved in full text, which again are assessed in detail according to inclusion/exclusion criteria by two independent reviewers. The reasons for excluding title/abstract and full-text level references that do not meet the inclusion criteria are recorded and reported in the scoping review. All disagreements that may arise between the reviewers at any stage of the selection procedure will be resolved through discussion, or with an additional reviewer. The results of the search and the inclusion and exclusion process of all sources will be fully reported in the final scoping review and depicted in a PRISMA-ScR flow diagram.[18]

Data extraction

Data will be extracted from sources included in the scoping review by two independent researchers into a predefined data extraction table, which is developed and pretested by the reviewers. The data extracted will include specific information about the PCC elements, study methods and key findings relevant to the review objectives. The customised data extraction table, based on the JBI template,[15] will include further specific fields for type of publication, health condition, year of data collection, diagnostic purpose, author's conclusion and comment of the reviewer. A draft extraction form, which will be modified and revised as necessary during the process of extracting data from each included evidence source, is provided (online supplemental appendix B). Any modifications will be reported in detail in the final scoping review. Again, any disagreements that arise between the reviewers during the extraction process will be resolved through discussion, or with an additional reviewer. If appropriate, authors of articles will be contacted to request missing or additional data, where required.

Data analysis and presentation

To reach the aim of giving a comprehensive overview with our scoping review, the data will be presented both in tabular form, based on the extraction table and the PCC criteria, and graphically in aggregated form. Descriptive statistics will be applied to quantify the distribution of publications across several fields of applications of

Table 1 Structured overview of inclusion and exclusion criteria according to the Population, Concept, Context approach

	Inclusion	Exclusion
Population	Human participants (all ages, all sexes).	Animal or in vitro testing.
Concept	Application of passive infrared thermographic imaging or temperature measurement for diagnosis (prevention and control), monitoring or collection of reference data/normal values.	Non-medical application, active dynamic thermography, liquid crystal thermography.
Context	Clinical, ambulatory or preclinical sites. Any health condition, disease or medical procedure correlated with: ► Changes in blood flow. ► Obstruction, destruction or formation of new blood vessels. ► Changes in skin, tissue or body temperature.	None.
Types of sources	Articles, reviews, systematic reviews, meta-analyses, scoping reviews, conference papers, grey literature (theses, dissertations, reports, etc) reporting quantitative studies with experimental or diagnostic study designs including randomised controlled trials, non-randomised controlled trials, quasi-experimental, case–control studies and analytical cross-sectional studies. Sample size in studies at least 25 per group. Any language but title and abstract available in English or German. Time period of publication 2000 – current.	Editorials, viewpoints, opinions, comments, letters, conference abstracts/reports/reviews or summaries, qualitative studies, publications from predatory journals and publishers.
Type of information	Basic description of: ► Target population. ► Site of the examination. ► Environmental and technical framework of the assessment. ► Disease, anatomical location, objective of the examination, background: preventive or screening, diagnostic, follow-up and monitoring.	Missing information.

thermography. A comprehensive narrative description and the PRISMA-ScR flow diagram will provide a detailed overview of the selection process of all included sources.

Besides the report of the overall results, each objective requires a separate compilation of results and will be reported in a narrative summary with the respectively suitable tabular and graphical data representation.

In contrast to systematic reviews, scoping reviews usually do not follow a formal process in determining the quality of the evidence as they aim to provide an overview of the evidence from a meta-level. Hence, a risk of bias assessment of the evidence included is usually not recommended.[16]

Finally, any deviation from this protocol will be reported with an explanation in the publication of the results.

Contributors DK conceptualised the review approach and provided general guidance to the research team. DK and TK developed the review questions and the review design. DK identified the framework from which TK and SB developed and tested search terms. DK and SB initially developed the data extraction framework which was then further developed by input from TK. DK initiated the first draft of the manuscript which was then followed by numerous iterations with substantial input and appraisal from TK and SB. All authors approved the final version of the manuscript.

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Competing interests None declared.

Patient and public involvement Patients and/or the public were not involved in the design, or conduct, or reporting, or dissemination plans of this research.

Patient consent for publication Not applicable.

Provenance and peer review Not commissioned; externally peer reviewed.

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Searchstrategy PubMed 29 Nov 2021

1. thermography[MeSH Terms] 7,912
2. spectrophotometry, infrared[MeSH Terms] 72,435
3. “infrared" [Text Word] AND "temperature" [Text Word] 35,509
4. "thermology"[Text Word] 21
5. “infrared camera”[Text Word] 979
6. (“contact”[Text Word] OR "infrared"[Text Word]) AND thermography[Text Word] 3,630
7. ("therm*”[Text Word] OR “infrared”[Text Word]) AND “imag*"[Text Word] 56,950
8. diagnosis/prevention and control[MeSH Terms] 26,242
9. diagnostic techniques and procedures[MeSH Terms:noexp] 3,570
10. disease progression[MeSH Terms] OR monitoring/physiologic[MeSH Terms] 382,038
11. mass screening[MeSH Terms:noexp] OR early diagnosis[MeSH Terms] 161,379
12. reference value[MeSH Terms] OR normal value*[Text Word] 148,250
13. #1 OR #2 OR #3 OR #4 OR #5 OR #6 OR #7 148,250
14. #8 OR #9 OR #10 OR #11 OR #12 744,161
15. #13 AND #14 2,815
16. #15 AND (humans[Filter]) 2,253
17. #15 AND (humans[Filter]) AND (2000/1/1:2021/11/11[pdat]) 1,624
18. #15 AND (humans[Filter]) AND (2000/1/1:2021/11/11[pdat]) AND (Clinical Study[Filter] OR Comparative Study[Filter] OR Controlled Clinical Trial[Filter] OR Evaluation Study[Filter] OR Journal Article[Filter] OR Pragmatic Clinical Trial[Filter] OR Review[Filter] OR Systematic Review[Filter] OR Technical Report[Filter]) **1,592**

Data Extraction Table with Examples

Review Matrix on the Use of Infrared Thermographic Imaging in Medical Diagnostics: a Scoping Review

Reference & Purpose						Study Design & Participants				Content & Results							Conclusion & Comment	
RefID only for internal use	**Source** Database DOI	**Author(s) Title**	**Publication: Type Year Jounal**	**Origin: Research & Sample**	**Aims / Purpose**	**#**	**Characteristics**	**Study and Sample Design, Setting**	**Health Condition**	**Year Collected**	**Methodology** (technical and environmental) **& Device**	**(Diagnostic) Purpose** e.g. Screening	**Examination / Application**	**Comparator**	**Outcome(s)**	**Key Findings** related to review objectives	**Author's Conclusion**	**Reviewer's Comments**
		Aggarwal N, Garg M, Dwarakanathan V et al. Diagnostic accuracy of non-contact infrared thermometers and thermal scanners: a systematic review and meta-analysis.	Journal Article **2008** *J Travel Med*	Research: India, USA Sample: International (15 countries)	Investigate diagnostic accuracy of non-contact infrared thermometers and thermal scanners for the detection of fever	19 Studies in meta-analysis, 12,759 patients with 13,874 readings	Neonates, children, adults	Systematic review and Meta-analysis Studies on assessment of diagnostic accuracy of non-contact infrared thermometers and thermal scanners. Setting: inpatient, outpatient / airport, unclassified	Unclear, possible fever	2004 - 2020	Contactless infrared thermal imaging systems for temperature measurements. Handheld non-contact infrared thermometers (NCITs) and thermal scanners	Thermal screening during a pandemic	Fever measured by non-contact infrared devices	Fever measured by conventional thermometer (tympanic, axillary, rectal, oral)	NCITs sensitivity 0.781 (95%CI 0.628–0.882) and specificity 0.926 (95%CI 0.799–0.975) Thermal scanners sensitivity 0.818 (95%CI 0.758–0.866) and specificity 0.923 (95%CI 0.823–0.969)	NCITs and thermal scanners are validated instruments for mass screening of fever	Handheld NCITs and thermal scanners have a reasonable sensi-tivity and specificity in detecting fever. However,	
		Jesenšek Papež B, Palfy M, Turk, Z. Infrared Thermography Based on Artificial Intelligence for Carpal Tunnel Syndrome Diagnosis.	Journal Article **2008** *J Int Med Res*	Slovenia	Improve the diagnosis of CTS with thermography using a computer-based system employing artificial neural networks (ANN) to analyse the images	30 pathological, 26 healthy, 112 images	Adult (26-71 years, 15 females, 8 males) patients with confirmed CTS without previous surgery, volunteers (28-66 years, 8 females, 5 males) confirmed with no CTS	Observational Study Patients referred by general practitioners and specialists to the Department of Physical Medicine and Rehabilitation, Medical Centre Maribor,	Carpal tunnel syndrome (CTS)	n.a.	Neo Thermo TVS-700 camera (NEC Avio Infrared Technologies, Tokyo, Japan) resolution 320 × 240 pixels, standard distance 80 cm, ambient temperature 23±1 °C; relative humidity 56±8%). Software application based on ANN	Computer aided diagnosis of carpal tunnel syndrome	Dorsal and palmar thermographic imaging of CTS confirmed by electro-myography	Dorsal and palmar thermographic imaging of no CTS confirmed by electro-myography	The classification success rate for the dorsal side of the hand was in mean 80.6%. Palmar segments had no beneficial influence on the outcome	CTS with computer aided thermographic diagnostic is a promising field for further research	Relatively high success rates give rise to optimism, especially when there is still plenty of scope for method improvement	Temperature of each individual segment normalized according to the mean temperature of the whole hand facilitates inter-individual comparisons. Computer aided diagnosis can be resource efficient.