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Infrared thermography for the evaluation of adolescent and juvenile idiopathic scoliosis: A systematic review

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ABSTRACT

Introduction: Adolescent and Juvenile Idiopathic Scoliosis are a three-dimensional spine deformity characterized by a muscle alteration of the convex and concave sides of the scoliosis, which can be evaluated with different non-invasive and radiation-free methods such as infrared thermography. The objective of the present review is to assess infrared thermography as a potential method to evaluate alterations of the scoliosis.

Materials and methods: A systematic review was performed by collecting articles from PubMed, Web of Science, Scopus, and Google Scholar, published from 1990 to April 2022, on the use of infrared thermography to evaluate adolescent and juvenile idiopathic scoliosis. Relevant data were collected in tables, and the primary outcomes were discussed narratively.

Results: Of the 587 articles selected, only 5 were in line with the objective of this systematic review and were eligible for the inclusion criteria. The findings of the selected articles corroborate the applicability of infrared thermography as an objective method to assess the thermal differences of the muscles between the convex and concave sides of scoliosis. The overall quality of the research was uneven in the reference standard method and assessment of measures.

Conclusion: Infrared thermography is providing promising results to discriminate thermal differences in scoliosis evaluation, albeit there are still some concerns about considering it as a diagnostic tool for scoliosis evaluation because specific recommendations for collecting data are not met. We propose additional recommendations to existing guidelines to perform thermal acquisition to reduce errors and provide the best results to the scientific community.

1. Introduction

Adolescent and Juvenile Idiopathic Scoliosis (AJIS) are defined as a three-dimensional deformity of the spine with a multifactorial aetiology involving genetic, environmental, and lifestyle factors (Burwell et al., 2016). AJIS is characterized by a structural alteration of the spine's regions, presenting vertebrae rotated and translated in relation to normal body axes (Lee et al., 2020). The Scoliosis Research Society (SRS) suggests the diagnosis of scoliosis when there is axial rotation and the curve exceeds the 10 ° Cobb angle. Several classifications of scoliosis have been proposed; however, the International Society for Orthopaedic and Rehabilitation Treatment of Scoliosis (SOSORT) recommends three main characteristics when approaching it: Age of diagnosis, Cobb degrees, and Apex of the scoliotic curve (Negrini et al., 2018).

The clinical assessment of AJIS concerns the application of Adam's forward bending test, whose positivity is pathognomonic for scoliosis

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(Cilli et al., 2009), and the Scoliometer, which measures scoliosis' hump appearing from Adam's test (Bunnell, 1993). Radiography is the gold standard for identifying and monitoring scoliosis (Knott et al., 2014), even if it is associated with increasing awareness of the potential adverse effects of exposure to x-rays (Knott et al., 2014). The Italian Scoliosis Society suggests a two projections x-ray at the first scoliosis assessment and a subsequent x-ray at least one year later (Negrini et al., 2005). Different non-invasive and radiation-free methods have been proposed to evaluate scoliosis without harmful effects. Such methods include Moiré topography (Takasaki, 1970), rasterstereography (Marin et al., 2022; Roggio et al., 2021), 3D ultrasound imaging (Lai et al., 2021; Zheng et al., 2016), 3D scanner (Sudo et al., 2018), and infrared thermography (IRT) (Cooke et al., 1980).

IRT is a non-invasive method that provides information on body thermal changes due to different conditions such as physical activity (Hillen et al., 2020), metabolic alterations (Mi et al., 2022), rheumatic diseases (Schiavon et al., 2021), musculoskeletal disorders (Sanchis-Sánchez et al., 2014), as skin temperature change is an indicator of underlying processes (Lahiri et al., 2012). Although this procedure generally depends on the environment and surrounding conditions, several reasons promote acceptance among the medical community. IRT is a non-contact and non-invasive method that provides quick measures in a couple of minutes. Clinicians can quickly understand the pathology they are observing thanks to the color pattern of the acquisition. Additionally, this method has no adverse effects and records the natural radiation coming from the skin's surface, resulting ideal for frequent use (Švantner et al., 2021). The interest in IRT applications to recognize back disorders is constantly growing as awkward posture causes altered muscle activity, which is responsive to thermal analysis. Lasanen et al. (2018) employed IRT to discriminate muscle activity in working postures, Girasol et al. (2018) found that patients with chronic neck pain present a reduction in skin temperature at trigger points of the trapezius. However, there is still controversy about how back pain responds to IRT, as Alfieri et al. (2019) found that the temperature of the lumbar skin increased in patients with low back pain, while Roy et al. (2013) found a reduction in the paraspinal cutaneous temperature in a similar population. Except for these controversial points, IRT is effective in assessing asymmetries in temperature distribution, appearing versatile in monitoring scoliosis throughout its course. Several aspects foster the applicability of IRT in the screening, diagnosis, and follow-up of scoliosis. It may result valid in the clinical setting when scoliosis is suspected, shifting further the radiographic examination, thus avoiding unnecessary x-rays exposure to adolescents. Improper posture caused by an altered scoliotic proprioceptive stimulus (Gaudreault et al., 2005) and an asymmetric electromyography activity of the back muscles (Chwała et al., 2014) are the main aspects supporting the validity of thermography in the evaluation of scoliosis. Paraspinal muscles of the convex side are characterized by a stronger RMS electromyography than those of the concave side (Kwok et al., 2015). Specifically, Kwok et al. (2015) observed a muscle impairment in thoracic (one curve) and thoracolumbar (two curves) scoliosis, where the spine alteration affects the paraspinal muscle activity. Cooke et al. (1980) in 1980 conducted one of the first thermography studies in idiopathic scoliosis. They observed that scoliosis is the most frequent cause of thermal asymmetry of the spine in adolescents and provided a high precision of the IRT for detecting scoliosis of the dorsal spine (Cooke et al., 1980). The leading assumption underlying the use of IRT in the evaluation of scoliosis is that in muscles analyzed by means of comparison, the temperature difference between the left and right sides of the back is minimal in subjects without scoliosis. On the contrary, scoliotic people show distinct differences in back muscle thermal activity, presenting an asymmetric temperature between the considered muscles.

This systematic review aims to analyze the applicability of IRT as a diagnostic method in scoliosis evaluation in discriminating thermal differences between the right and left sides of the back.

2. Materials and Methods

2.1. Search strategy

A systematic review of the literature was conducted on April 4, 2022, in PubMed, Web of Science, Scopus, and Google Scholar. Articles dealing with the use of IRT in AJIS management were selected according to the following string: (Infrared Camera OR Thermography OR Infrared Thermography OR Thermal Camera OR IRT OR Infrared Thermal Imaging) AND (Scoliosis OR Idiopathic Scoliosis OR Adolescent Idiopathic Scoliosis). The Preferred Reporting Items for Systematic Reviews and Meta-Analysis (PRISMA) guidelines were used (Page et al., 2021). The exclusion criteria were: articles regarding surgery, animals, low back pain and neck pain, radiculopathy, other spine pathologies, injuries, physical therapy treatments. Our systematic review fulfilled the criteria of the PICO tool:

- Population: children (age 3–9) or adolescents (age 10–17);
- Intervention: assessment of scoliosis with IRT;
- Comparison: IRT compared to x-rays or scoliometer;
- Outcome: discrimination of temperature asymmetry of back the back in scoliotic patients.

2.2. Selection process

The articles were stored in EndNote 20 (EndNote 20 desktop version, Clarivate, Philadelphia, PA) (Gotschall, 2021) and duplicate papers were selected and automatically removed. The screening process and analysis were performed separately by two independent investigators. The principal investigator resolved disagreements in the selection process. The articles were first screened by title and abstract. Only articles reporting the use of IRT to evaluate scoliosis were selected for screening, considering any clinical reports, regardless of the level of evidence, published after 1990. The references of each selected article were checked to find more articles of interest. Second, the full text of the selected articles was screened, with further exclusion when no scoliosis assessment method was adopted.

2.3. Data collection

The full text of all the articles selected was read to identify meaningful information. Relevant data extracted from selected studies are: the number of patients, sample classification, age range, scoliosis evaluation protocol, type of IRT used, IRT method applied, IRT results, and conclusions.

2.4. Risk of bias and applicability assessment

The Quality Assessment of Diagnostic Accuracy Studies-2 (QUADAS-2) tool (Whiting et al., 2011) was employed to assess the risk of bias, applicability, and diagnostic accuracy of IRT in the treatment of scoliosis. It consists of four key domains: patient selection, index test, reference standard, flow, and timing. The first three domains assess both the risk of bias and applicability; flow and timing domain assesses only the risk of bias. Each domain was rated as high, low, or unclear risk of bias. Each study was evaluated for all domains, providing a single general score for all studies included in this systematic review.

3. Results

Of the 587 articles screened, only 10 were examined in their full text. A number of 4 articles were excluded due to the inconsistency of the applied method; one article was excluded because the article was written in Korean and the results were not provided; only 5 articles were found to be eligible for inclusion in the present systematic review. The screening process is presented in Fig. 1. All articles used IRT to detect

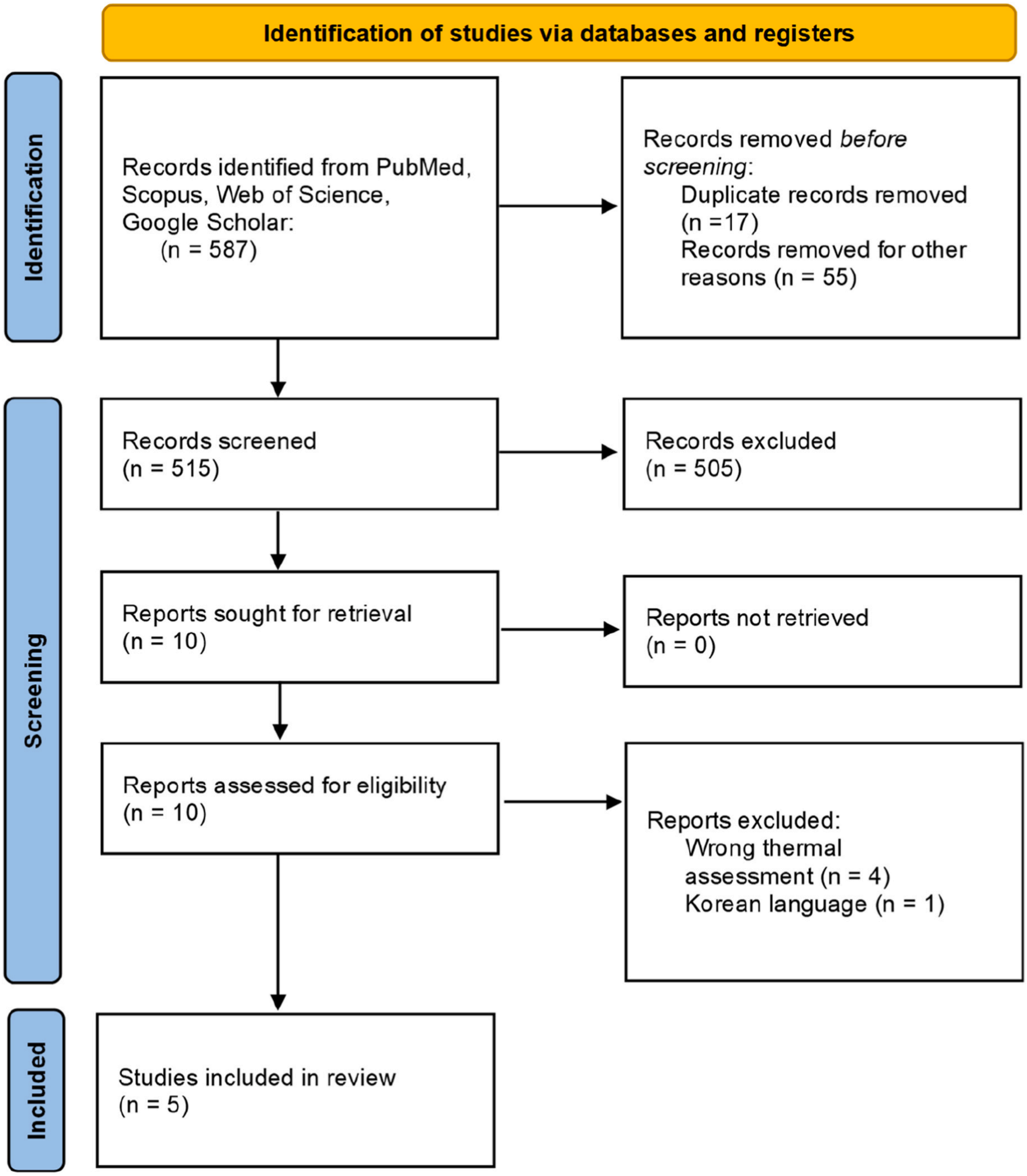

Fig. 1. PRISMA flow diagram for new systematic reviews which included searches of databases and registers only.

differences in the temperature distribution of paraspinal muscles, and one article aimed to generate a machine learning model to classify thermographic scoliosis. Three articles compared the IRT measures with x-rays and only included Cobb's angle assessment. The study includes 646 participants, 449 of them with scoliosis. The age range was 9–17, 66 were male, 146 were female, and of 434 the gender was not specified. The study characteristics are summarized in Table 1.

3.1. Risk of bias and applicability assessment

The QUADAS-2 tool provided a valuable method for analyzing IRT's risk of bias and applicability in scoliosis evaluation. One study showed good quality by scoring 6 low risks in the seven key domains; two studies showed average quality by scoring 5 low risks in the seven key domains. The remaining studies did not provide sufficient information to claim good quality. All scores are reported in Table 2. Second, we analyzed the general quality of all the articles included in this systematic review. Table 3

Regarding the risk of bias (Fig. 2A), index test and reference standard are the domains achieving the higher risk of bias. Three studies have a high risk of bias in the index test domain because they already classified patients before performing IRT. Two studies have a high risk of bias for the reference standard domain because they used clinic tests that may be passible for subjectivity. In terms of concerns regarding the applicability (Fig. 2B), two studies showed high concerns regarding the IRT applicability, while two studies did not use the x-rays as a reference test.

Table 1
Characteristics of the studies.

Author, Year	Sample (M/F)	Classification	Mean age	Scoliosis evaluation	IRT system	IRT assesment	IRT results	Conclusions
Dragan et al. (2002)	403	1st, 2nd, and 3rd Gruca's curvature degree (GCD)	9–17	RX	NA	Thermal difference between the convex and concave side of the spine	Mean temperature difference: 1st GCD = 0.83°, 2nd GCD = 1°, 3rd GCD = 1.34°, CG = 0.31°	The greater the deformation between the concave and convex sides, the greater the thermal difference between the two parts of the back.
Dyszkiewicz et al. (2007)	30/60	A1 – thoracic scoliosis A2 – thoracolumbar, primary arc lumbosacral A3 – thoracolumbar scoliosis mirror-like B – control group	10–15	RX	Agema 450	Thermal differences of the left and right paravertebral muscles	A1 = 0.921 ± 0.085 A2 = 0,87 ± 0.08 A3 = 0.78 ± 0.09 B = 0.94 ± 0.11	The highest correlation of muscle activity asymmetry was present only in group A3. Groups A1 and A2 did not present it, probably due to a reached osseous stabilization.
Kwok et al. (2017)	31	Scoliotic = spine curve >10° Non-scoliotic = no spinal curve	10–13	Scoliometer and scoliosis ultrasound scan	FLIR E33	Thermal differences of the left and right Trapezius, Latissimus Dorsi, and Quadratus Lumborum muscles	Mean temperature difference: T = −0.077 ± 0.149, LD = −0.275 ± 0.203, QL = −0.300 ± 0.436	Scoliotic subjects demonstrate a statistically significant difference between the left and right sides of the regions of interest due to the higher IR emission of the convex side of the observed area.
Ka Natalie et al. (2021)	18/64	Group 0 < 20°, Group 1 20°–30°, Group 2 31°–40°, Group 3 > 40°	10–13	RX	FLIR E33	Thermal matrix of the back surface of a patient	With an accuracy >0.80 the machine learning approaches show promising potential for the use of thermography to predict the severity of scoliosis.	With an accuracy >0.80 the machine learning approaches show promising potential for the use of thermography to predict the severity of scoliosis.
Lubkowska and Gajewska (2020)	18/22	Scoliotic = spine curve >10° Non-scoliotic = no spinal curve	8–12	Adam test and scoliometer	FLIR T1030sc	Thermal differences of left and right: upper back, lower back, abdominal, frontal thigh, back thigh, frontal shank, back shank	Mean temperature difference: UB = 0.4 ± 0.1, LB = 0.2 ± 0.2, Ch = 0.1 ± 0.1, Ab = 0.1 ± 0.1, FT = 0.4 ± 0.1, BT = 0.3 ± 0.1, FS = 0.2 ± 0.1, BS = 0.5 ± 0.2	Scoliotic children present thermal asymmetry of the upper back, thigh, and back shank with a high positive correlation between spinal rotation angle and thermal asymmetry.

CG: control group, GCD: gruca's curvature degree T: trapezius, LD: latissimus dorsi, QL: quadratus lumborum, UB: upper back, LB: lower back, Ch: chest, Ab: abdominal, TF: frontal thigh, TB: back thigh, SF: front shank, SB: back shank.

Table 2
Tabular presentation of QUADAS-2 study assessment.

Study	Risk of bias				Applicability concerns		
	Patient selection	*Index test*	*Reference Standard*	*Flow and Timing*	*Patient selection*	*Index test*	*Reference standard*
(Dragan et al., 2002)	↑	↑	↓	//	↑	//	↓
(Dyszkiewicz et al., 2007)	↓	↑	↓	↓	↓	↓	↓
(Kwok et al., 2017)	↓	↓	↑	↓	↓	↓	↑
(Ka Natalie et al., 2021)	↑	↑	↓	//	↑	↓	↓
(Lubkowska and Gajewska, 2020)	↓	↓	↑	↓	↓	↓	↑

↑ = high risk, ↓ = low risk, //= unclear risk

3.2. Scoliosis evaluation

The comprises of papers differ in the classification of the scoliosis of patients. Three articles classified as scoliotic patients those showing a spine curve >10°, and the three articles evaluated scoliosis with the Adam test and the scoliometer. Dragan et al. (2002) followed Gruca's classification of scoliosis (1st grade = spine curve <30°; 2nd grade = spine curve 30°–60°; 3rd grade = spine curve 60°–90°), and analyzed

Table 3
Specific recommendations for the evaluation of scoliosis with infrared thermography.

Exam procedure	Perform the forward bending test and measure the trunk rotation with a scoliometer. Then, mark with a skin pencil the spine reference points: C7, Thoracic apex, T12, L3 and S2.
Scoliosis classification	*Chronological* – age (juvenile: 3–9, adolescent: 10–17, adult: 18+) *Angular* – Cobb degrees (low: <20°, moderate: 21°–35°, moderate to severe: 36°–40°, severe: 41°–50°, severe to very severe: 51°–55°, very severe: 56°+) *Topographic* – apex (cervical: C1–C7, cervico-thoracic: C7–T1, thoracic: T1-2 disc-T11–12 disc, thoraco-lumbar: T12–L1, Lumbar: L1-2 disc)
Region of interest	Compare the thermal differences of left and right trapezius, latissimus dorsi, and quadratus lumborum.
Results presentation	Describe the thermal difference between the regions of interest and highlight the thermal asymmetry of the convex and concave sides of scoliosis.

scoliosis using x-rays. Dyszkiewicz et al. (2007) analyzed the x-rays and divided the scoliotic group based on the scoliosis situs, i.e. mirror-like thoracic, thoracolumbar, thoracolumbar. Additionally, Ka Natalie et al. (Ka Natalie et al., 2021) analyzed the x-rays to classify the patients; however, they used a personal classification that divided the patients into: group 0 = scoliosis <20°, group 1 = scoliosis 20°–30°, group 2 = scoliosis 31°–40°, Group 3 > 40°.

3.3. Infrared thermography assessment

All studies used IRT to evaluate the thermal average difference between the convex and concave paravertebral muscles. Specifically, Lubkowska et al. (Lubkowska and Gajewska, 2020) analyzed the back muscles and also the abdominal, front, and back thigh, front, and back shank. The IRT results were expressed differently by the authors. Two studies stratified the mean temperature difference (MTD) by scoliosis classification, while the other studies classified MTD according to muscle selection. Dragan et al. (2002) found a thermal difference between the convex and concave sides of MTD = 0.83 in the group with a spinal curve <30°, MTD = 1 in the group with a spinal curve of 30°–60°,

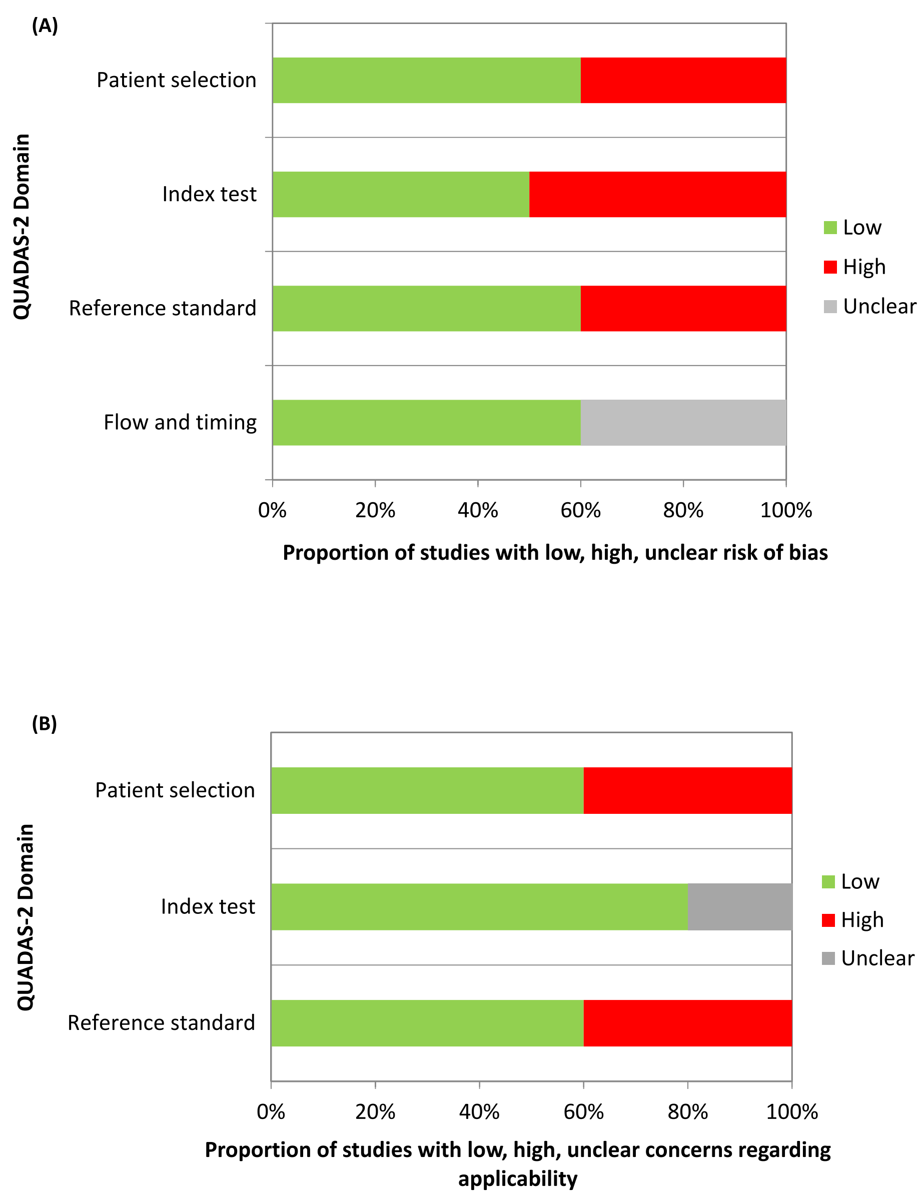

Fig. 2. Graphical representation of the QUADAS-2 results. (A) Risk of bias assessment; (B) concerns about applicability.

and MTD = 1.34 in the group with a spinal curve of 60 °–90°. Their findings suggest that the thermal difference between the convex and concave sides increases with increasing deformation between the sides. Dyszkiewicz et al. (2007) found a thermal difference of paravertebral muscles of MTD = 0.921 ± 0.085 in the group with thoracic scoliosis, MTD = 0,87 ± 0.08 in the group with thoracolumbar scoliosis, and MTD = 0.78 ± 0.09 in the group with thoracolumbar scoliosis mirror-like. The authors did not provide any tests to confirm the significance of the results; furthermore, they conclude by highlighting a correlation between muscle activity asymmetry and IRT only in the thoracolumbar scoliosis mirror-like group. Kwok et al. (2017) found a statistical difference in the three muscles considered by setting a temperature cut-off of 0.3 °C. The left and right trapezius showed an MTD = −0.077 ± 0.149 ($p = 0.048$), the latissimus dorsi showed an MTD = −0.275 ± 0.203 ($p = 0.000$), and the quadratus lumborum MTD = −0.300 ± 0.436 ($p = 0.002$). These results demonstrate a thermal difference in the muscles considered between the convex and concave sides of the back. Lubkowska et al. (Lubkowska and Gajewska, 2020) found a statistical difference only in the upper back, MTD = 0.4 ± 0.1 ($p < 0.001$), frontal thigh, MTD = 0.4 ± 0.1 ($p < 0.01$), back thigh, MTD = 0.3 ± 0.1 ($p < 0.001$), and back shank, MTD = 0.5 ± 0.2 ($p < 0.001$). Furthermore, they demonstrated a high correlation between thermal asymmetry and spine rotation angle. Ka Natalie et al. (Ka Natalie et al., 2021) analyzed the IRT measures and x-rays with several machine learning approaches. Their results pointed to an accuracy >0.80 in predicting the severity of scoliosis through IRT.

4. Discussion

All the collected articles highlight the effectiveness of IRT in discriminating the thermal changes of scoliosis between the right and left sides of the back. The application of IRT has progressed during the last 30 years in instrument quality, software analysis, measurement techniques, and clinical protocols. These advances enhanced the understanding of human body temperature changes, determining more evidence for the diagnostic accuracy of IRT in different disorders (Ring and Ammer, 2012). Specifically, precise standardization is essential because different protocols can alter the results interpretation, the image processing, or the repeatability of the region of interest selection (Ring and Ammer, 2012). Furthermore, this does not allow the comparison of the data between studies, making impossible the creation of a normative data set (Petrigna et al., 2022).

The evaluation of scoliosis can be challenging due to the specific need to demonstrate the presence of rotation of the vertebrae that distinguishes it from a posture alteration that occurs without morphological changes in the spine. Actually, neither IRT can precisely diagnose changes in scoliosis, but it can be a versatile and reliable tool to detect presumable changes in the spine and then guide clinicians to specific exams only when needed. Fong et al. (2010) collected all articles on school scoliosis screening to debate the efficacy of non-invasive methods in the preventive evaluation of scoliosis. Of the 36 studies included in the meta-analysis, 23 used only the forward bending test, eight also measured the angle of rotation of the trunk, and two included Moiré topography. They found a general heterogeneity between studies, and the main finding is that the forward bending test alone is insufficient for the school scoliosis screening. School screening programs are necessary because they can detect scoliosis early, mostly when morphological changes are not yet visible: A preventive approach can determine a less invasive method when diagnosed early (Grivas et al., 2007). A study conducted in an Italian school showed a high incidence of back disorders, mainly scoliosis, performed only with clinical tests (Trovato et al., 2016). This kind of study fosters the need for a valid method to assess these disorders, such as IRT.

The articles considered in this systematic review provided exciting findings on the evaluation of scoliosis through IRT. Only Dyszkiewicz et al. (2007) showed a high quality because the authors correctly addressed all measures according to the gold standard, the classification of scoliosis, and the IRT results. Their results proved the validity of IRT only for mirror-like thoracolumbar scoliosis and not for thoracic and lumbosacral. Furthermore, the study was conducted in 2007, so the IRT measures and the respective software may be outdated compared to modern systems. The results provided by Kwok et al. (2017) and Lubkowska et al. (Lubkowska and Gajewska, 2020) are similar; they both found a significant difference between the left and right muscles of the upper back and the lower back with a mean difference of ±0.4°. Even if Kwok et al. (2017) did not employ the x-rays exam, they provided a valuable approach by screening the children firstly with the forward bending test and scoliometer. Then only those with trunk rotation >10° were evaluated with a spine ultrasound system, adding IRT detection. While they firstly screened the children and then used the IRT, Lubkowska et al. (Lubkowska and Gajewska, 2020) recruited all the patients and conducted the scoliosis evaluation with the forward bending test, scoliometer, and IRT as a whole single exam. This method likely appears to be the most suitable; however, since the IRT has not yet demonstrated its maximum reliability in assessing scoliosis, it is recommended to compare the results with the gold standard, i.e., x-rays. The findings of Dragan et al. (2002) support the validity of IRT in this field; however, they classified patients with an unconventional scale, Gruca's curvature degree, and provided results with a substantial difference between the convex and concave sides of scoliosis. We believe that their results must be interpreted with caution due to the considerable difference from the other papers included in this systematic review. Finally, we included the study of Ka Natalie et al. (Ka Natalie et al., 2021) because even if their results did not discuss the validity of IRT for scoliosis evaluation, they employed its use within machine learning methods. The main finding is that their model scored an accuracy >0.80, showing encouraging potential to predict the severity of scoliosis. Machine learning in medicine is quickly spreading because it can facilitate clinicians to anticipate the future events of a disease, drawing valid conclusions far beyond the skills of clinicians (Rajkomar et al., 2019). Out of the studies analyzed, we also considered the study by Vutan et al. (2022) using IRT to analyze muscle activation during exercises in patients with scoliosis, showing that IRT can detect asymmetric activation of the back muscles during exercises.

The main finding of this study highlights the IRT application to evaluate the thermal asymmetry of scoliosis by discriminating the abnormal thermal pattern of the back. However, the comprised articles reveal the absence of a collectively agreed methodology to assess scoliosis with IRT. We support the research approach of Kwok et al. (2017) since they affirmed that the convex side of scoliosis presents an increased temperature than the concave side, currently representing a milestone of the application of IRT in the diagnosis of scoliosis. Nevertheless, their study should be repeated employing the x-rays as reference standard.

Although different authors have already provided detailed guidelines for the applicability of IRT for clinical thermal images (Ammer and Ring, 2019) and sports sciences (Moreira et al., 2017), we observed the absence of specific recommendations through this systematic review for the collection of thermal images in scoliotic patients. Standardized acquisition can reduce systematic errors and increase the quality of acquisition (Ammer and Ring, 2012; Petrigna et al., 2022). In addition to established protocols for the environment and camera or subject positioning, we suggest several recommendations when analyzing scoliosis. For the exam procedure, forward bending test and scoliometer, can increase the classification accuracy; furthermore, by marking the spine reference point, the selection of the region of interest can be located more accurately. It is essential to divide the sample into specific classes for age, Cobb degrees, and apex of the vertebrae of scoliosis, strictly following the SOSORT classification of scoliosis (Negrini et al., 2018). Finally, it is mandatory to adequately report the results highlighting which side of the scoliosis presents the higher temperature (Table 3) . We raise this issue as the included articles of this systematic review used different classifications, which caused the inability to compare the results correctly. Although the findings provided interesting results for IRT application with scoliosis, further studies should compare thermal acquisition with current methods.

Due to the lack of standard criteria for IRT classification of scoliotic patients, currently we suggest comparing the results with x-rays to make exact measurements. If researchers follow these recommendations, we expect to increase the IRT accuracy massively, avoid as much as possible exposition to x-rays, and provide sufficient data to allow machine learning methods to recognize scoliosis just by thermal acquisitions. Future studies should investigate the correlation between cobb angles and thermal differences to establish a plausible dependence of muscular thermal response to spinal alterations. Then, IRT could be compared or associated with existing non-invasive methods to enhance the analysis of musculoskeletal alterations.

5. Conclusions

This systematic review showed the applicability of IRT to diagnose scoliosis by measuring the thermal activity of the back muscles. The results support the effectiveness of this method in pointing out the temperature asymmetry between the right and left sides of the back. Although exhaustive guidelines support its applicability in human body analysis, we proposed few recommendations to enhance its strength in the evaluation of scoliosis in order to provide precise results and thus guide research toward the complete validity of this method. Future studies should clearly define the correlation with the gold standard for scoliosis diagnosis and further investigate the applicability with the non-invasive methods that already exist.

Author contributions

Federico Roggio: Conceptualization, Methodology, Software, Validation, Resources, Data Curation, Writing - Original Draft, Visualization. **Luca Petrigna**: Conceptualization, Validation, Resources, Data Curation, Writing - Original Draft. **Veronica Filetti**: Data Curation, Writing - Original Draft, Visualization. **Ermanno Vitale**: Methodology, Writing - Original Draft. **Venerando Rapisarda**: Validation, Investigation, Supervision. **Giuseppe Musumeci**: Conceptualization, Methodology, Validation, Resources, Writing - Original Draft, Visualization, Supervision, Project administration, Funding acquisition.

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Declaration of competing interest

The authors declare no conflict of interest.

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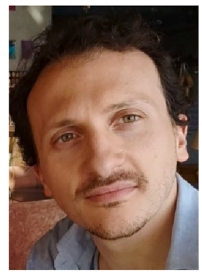

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