BMJ Paediatrics Open

Infrared thermography in paediatrics: a narrative review of clinical use

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To cite: Owen R, Ramlakhan S. Infrared thermography in paediatrics: a narrative review of clinical use. *BMJ Paediatrics Open* 2017;**1**:e000080. doi:10.1136/bmjpo-2017-000080

► Additional material is published online only. To view please visit the journal online (http://dx.doi.org/10.1136/bmjpo-2017-000080).

Received 15 May 2017
Revised 17 August 2017
Accepted 5 September 2017

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ABSTRACT

Background Infrared thermography (IRT) has been used in adult medicine for decades, but recent improvements in quality of imaging and increasing computer processing power have allowed for a diversification of clinical applications. The specific usage of IRT in a paediatric population has not been widely explored, so this article aims to summarise the available literature in this area. IRT involves the non-contact, accurate measurement of skin surface temperature to identify temperature changes suggesting disease. IRT could well have unique applications in paediatric medicine.

Methods Electronic searches were performed independently by two authors, using the databases of MEDLINE (via Web of Science), the Cochrane Library, CINAHL (EBSCO) and Scopus, including articles published from 1990 to July 2016. The search strategy that was used aimed to include articles that covered the topics of IRT and children, including studies with participants 18 years old or younger. Articles were screened by title and abstract by two authors. Meta-analysis was not performed due to the marked heterogeneity in applications, study design and outcomes: this is a narrative summary of the available literature.

Results IRT has been shown to be an effective additional diagnostic tool in a number of different paediatric specialties, namely in fracture screening, burns assessment and neonatal monitoring. Small measurable skin temperature changes can effectively add to the clinical picture, while computer-tracking systems can be reliably used to focus investigations on particular areas of the body.

Conclusion Throughout this review of the available literature, there has been a general consensus that this non-invasive, non-irradiating and relatively inexpensive technology may well have a place in the management of paediatric patients in the future.

What is already known?

- ► Infrared thermography has applications in adult medicine, with a number of studies showing it to be an accurate method of recording skin surface temperature.
- ► Many diseases are associated with skin temperature changes that can be detected with infrared thermography.
- ► In the screening for diseases, for example, breast cancer, infrared thermography has been found to have a particularly high sensitivity when compared with current management.

What this study adds?

- ► The use of infrared thermography in children has not been widely explored, with a limited number of relevant studies.
- ► Infrared thermography has been shown to be more accurate in detecting skin temperature changes in children, compared with an adult population.

INTRODUCTION

Infrared thermography (IRT) has been used in medicine for decades, with the first medical use of the technology described in 1959 for imaging arthritic joints.[1] Infrared radiation is normally emitted by the human skin, with varying degrees of radiation being recorded from different regions of the body. Using IRT, a unique infrared 'map' of the body can be recorded and, through computer processing, can be displayed as a colour image. The clinical use of this technology derives from the changes in blood flow associated with particular diseases, which confer an alteration of the local skin temperature. Thermography has been used in a range of fields in adult medicine, but its usage in children has not been as widely explored.[2] Additionally, technological improvements have allowed patients to be imaged with greater detail and accuracy, opening up new scope for research.

MATERIALS AND METHODS

Databases and search strategy

Electronic searches were performed independently by two authors, using the databases of MEDLINE (via Web of Science), the Cochrane Library, CINAHL (EBSCO) and SCOPUS. We also searched Open Grey, Google Scholar and recent conference abstracts. The manufacturers of current IR cameras were also contacted, as were authors of recently published studies. Articles published from 1990 to July 2016 were included.

The search strategy that was used aimed to include articles that covered the topics of IRT and children, widening this search as much as possible, to include any possible synonyms (online supplementary file 1).

Study selection

After removal of duplicate articles, the authors then independently screened the search results by title and abstract. Studies were selected on the basis of specified inclusion criteria: studies must involve the use of IRT imaging technology in a clinical setting, including one or several samples of living human subjects, with subjects being under the age of 18 years. Disagreement in study inclusion or exclusion was resolved by discussion. All eligible studies were included, except those not archived online or with no available English translation of their abstract.

Resulting studies were then reviewed and included based on relevance to the topic of clinical IRT in children. Finally, the references of included studies were checked for additional studies that may have been overlooked.

The study selection is summarised in online supplementary file 2.

Meta-analysis was not performed due to the marked heterogeneity in applications, study design and outcomes: this is a narrative summary of the available literature.

IRT IN CHILDREN

The field of IRT in medicine is diverse and has a footing in most major specialties; however, the specific use of this technology in paediatrics is not as widely documented: this review, therefore, intends to summarise the available literature on IRT in paediatric medicine.

Skin temperature

In an assessment of skin temperature in 25 healthy children, Kolosovas-Machuca *et al* used IRT to compare the temperature patterns of various regions of the body. They reported a maximum temperature difference of 5.1°C in the y-axis of the body and 0.7°C in the x-axis. Citing a similar study into adult patients, the authors highlighted reduced variability of results in children, which could confer increased precision when applied as a diagnostic tool.[3] Symonds *et al* reported a similar conclusion, in a study of skin temperature response to cold challenge in 26 healthy participants, including adults and children. The largest temperature increase was found in the child cohort (increase of 1107%±365% in children, 33%±300% in individuals aged 13–18 years and 113%±195% in adults, following cold challenge, $p<0.05$).[4] Significantly more publications report on the use of IRT in an adult population but, as has been suggested by these two studies, IRT may have greater precision and better diagnostic outcomes in a paediatric population.

Fever screening

There is insufficient evidence for using IRT in mass population fever screening.[5] However, in paediatric patients, applying this technology to individual temperature monitoring (instead of tympanic thermometry) demonstrated more positive outcomes.

Selent *et al*[6] assessed the application of IRT in fever screening, reporting a range of sensitivity and specificity of 76.4%–83.7% and 79.4%–86.3%, respectively: standard temperature measurement reported a sensitivity of 83.9% and a specificity of 70.8%. In another study, Chan *et al*[7] reported similar results, with a sensitivity and specificity of 83% and 88% for IRT. This highlighted a benefit of the thermal systems, in that they could more accurately exclude afebrile patients, compared with traditional methods. However, Fortuna *et al*[8] criticised that IRT tended to overestimate in afebrile patients and underestimate in febrile patients, when compared with rectal temperature readings.

Although with varying consensus on its usage in temperature screening, a benefit of using IRT in the screening of young children for fever is the convenience and speed at which measurements can be taken. With further improvements in IRT technology, it may have applications in the field of emergency paediatrics for rapid high-volume screening.

Monitoring vital signs

Although vital signs are currently monitored using observations conducted at regular intervals, efforts are being made to explore technologies that would allow continuous monitoring.

Heimann *et al* showed IRT to be an effective tool in reporting fluctuations in neonatal body temperature, with a significant difference reported in preterm infants in different ambient temperatures ($p<0.05$), while a similar conclusion was reported by Anderson *et al*, in case studies of two sleeping infants.[9,10] This simple application of IRT in paediatric monitoring has been expanded in subsequent studies, in which sophisticated tracking software assists in the assessment of respiratory rate.

Abbas *et al* found IRT to be promising in neonatal respiratory monitoring, with the possibility of accurate tracking software, but results were limited by a small sample size.[11,12] This application of IRT has also been explored in studies by Al-Khalidi *et al*, Elphick *et al* and Goldman *et al*, using IRT to measure the respiratory rate of subjects, comparing results with standard methods of respiratory monitoring. Al-Khalidi *et al* reported a correlation coefficient of 0.994 between the IRT and the standard methods, while Elphick *et al* reported similar results, with a correlation coefficient of 0.578–0.999 in the paediatric cohort.[13,14] Goldman *et al* found a high Cronbach's alpha value of 0.976

(95% CI 0.992 to 0.944) between the IRT and control measurements and successfully identified individuals with respiratory disease, using the time-lag between the ribcage and abdomen (p=0.0125).[15] As these studies have suggested, there is potential for further research into non-contact, continuous respiratory monitoring with IRT.

Incorporating a similar method of neonatal monitoring, IRT has been used to screen for necrotising enterocolitis (NEC) in neonates . In a study of 13 neonates at risk of the disease, Rice *et al* found that those with NEC had a lower abdominal skin temperature (35.3±0.8°C) than those without the disease (36.6±0.9°C; $p<0.05$).[16 17] With larger studies, IRT could be incorporated in the management of this life-threatening neonatal disease.

Trauma and wound healing

Many studies have explored the potential of IRT in detecting temperature changes occurring during traumatic injury or infection.

Sanchis-Sánchez *et al* explored the use of IRT in ruling out fractures in paediatric trauma patients, reporting a sensitivity of 0.91 and a specificity of 0.88.[18] Similarly, Silva *et al*[19] examined the use of IRT in locating areas of trauma in 51 patients, finding that the technology matched the site of pain in 73% of locations, as well as 7 out of 11 fracture sites. Ćurković *et al* used IRT in 19 children with forearm fracture: the average temperature of the injured side was 1.17°C higher than that of the healthy side after 1 week and 0.84°C higher after 2 weeks; however, Ćurković *et al* were unable to produce statistically significant results due to the small sample size.[20] Additionally, a recent pilot study has found IRT to be successful in identifying the affected region in patients presenting with acute non-specific limp, with areas of fracture associated with the greatest temperature change, but conclusions were limited by the small sample size.

Saxena *et al* performed IRT on 483 paediatric surgical patients, over 10 years of clinical practice. In five children with partial amputation, a temperature differential of 2.5±0.3°C was observed following surgical treatment and revascularisation, which reduced to 1.8±0.3°C after 48 hours. Eighteen neonates had surgically implanted skin patches: there was an initial average temperature differential of −4.8±0.6°C following surgery, which increased to 3.4±0.5°C at 30–42 days after surgical intervention, illustrating revascularisation. Furthermore, Saxena *et al* cited a patient who underwent surgical repair of a thoracic wall abnormality, in which IRT identified a significant temperature increase of 3.7°C, associated with the formation of a sternal wound abscess. Similarly, 42 children were assessed for infection, with areas of abscess showing a temperature increase of 3.6±0.5°C and wound infections also displayed a positive temperature differential. Finally, Saxena *et al* cited a particular case involving a 2-year-old child with severe gas gangrene of an upper extremity, which required amputation: IRT was used to assess the level of amputation necessary.[21–23]

Similar to its applications in monitoring wound healing, IRT has also been used to assess burn injuries in children. In a pilot study of 13 children, Medina-Preciado *et al* reported that the average temperature of superficial dermal burns were 1.7°C higher than the contralateral side, while that of deep dermal burns was 2.3°C lower than the contralateral side ($p<0.05$). Additionally, when compared with histological results, IRT correctly identified 100% of cases of both superficial and deep burns, while clinical assessment identified 83.33% of superficial and 42.85% of deep burns.[24] This outcome was reiterated by Saxena *et al*, also reporting a 2.8±0.6°C temperature differential across superficial burns.[21]

These accounts of the surgical applications of IRT illustrate a variety of areas in which thermography can be applied to monitor revascularisation of tissue, as well as screen for signs of infection.

Haemangioma and varicocele

Similar to previous studies, IRT may be used to monitor the progression of haemangioma or varicocele, through the irregular blood flow patterns associated with their formation.

Saxena *et al* used IRT to image haemangiomas in 102 affected children: 52 patients had a rapidly progressing haemangioma, which showed a temperature differential of 1.5±0.3°C, while those that underwent complete resolution displayed a differential of <0.5°C[21]. Mohammed *et al* also reported a decrease in temperature associated with haemangioma resolution, while Garcia-Romero *et al* displayed how IRT could be used to monitor treatment response, in 10 patients with haemangioma undergoing treatment with systemic beta-blockers.[25 26]

Saxena *et al* used IRT in six boys with varicocele, reporting a positive temperature differential of 4.1±0.3°C in the affected side, which reduced significantly with surgical intervention.[21] This finding was echoed in a case study by Iwata *et al*, in which a varicocele repair in a 12-year-old boy resulted in similar temperature change in the affected side.[27]

These studies into both haemangiomas and varicoceles represent a potential way in which IRT could be incorporated to monitor treatment response in certain diseases.

Dermatology

Many skin conditions involve alterations in the relative thickness of the skin that may confer changes in temperature: a finding that may be quantified by IRT. Exploring the use of IRT in identifying children with localised scleroderma, Martini *et al* reported a sensitivity and specificity of 92% and 68%, respectively.[28] IRT found a similar correlation between disease severity and skin temperature, in another case study involving a patient with localised scleroderma, as well as a patient with psoriasis.[29 30] The skin is an accessible organ that lends itself well to imaging with IRT, and these studies illustrate how it could be applied to paediatric dermatology.

Diabetes mellitus

The effect of diabetes mellitus on skin perfusion is often only clinically evident after decades of disease. However, Zotter *et al* found that IRT identified a significant temperature difference between patients affected by diabetes and healthy controls, following cold challenge testing ($p<0.05$).[31] This study highlighted a potential advantage of IRT in diabetic screening, but a larger study is required to reinforce conclusions.

Joint inflammation

There are a limited number of studies exploring the use of IRT in joint inflammation in children, even though the use of IRT in rheumatoid conditions in adults is well documented. Lasanen *et al* assessed the application of IRT in the screening of 58 children with signs of joint inflammation, reporting a statistically significant temperature increase in inflamed ankle joints, compared with controls ($p<0.05$). However, in knee joints, no such difference was shown.[32] This study suggests that the efficacy of IRT in screening for joint inflammation may be specific to the area affected, with some joints exhibiting more acute changes in temperature.

Neurology

IRT may have a variety of applications in neurology. Goetz *et al* used IRT to monitor hydrocephalus shunt patency, using cold challenge testing to assess temperature differentials, while Zurek *et al* used IRT to monitor tissue perfusion in a study involving a novel treatment for cerebral palsy.[33 34] An innovative study by Coben *et al* used IRT to record the temperature change in a specific area of the head (named 'Fpz'), lying over a region of the brain implicated in attention-deficit/hyperactivity disorder. Using the temperature differential to detect patients with disease, a sensitivity of 66% was reported and Coben *et al* suggested that IRT was superior to the limited alternative diagnostic tests for the disease.[35]

Ophthalmology

Kaercher *et al* explored IRT as a method of ophthalmic examination in 34 patients with X-linked hypohidrotic ectodermal dysplasia (XLHED). In the child cohort, IRT had a sensitivity of 66.7%, but standard methods of diagnosis reported sensitivity values of 72.7%–100%. Although representing no improvement on current practice, IRT illustrated marked temperature differences between children with XLHED and the healthy controls and was shown to be a quick and reliable tool to be used in conjunction with other methods of diagnosis.[36]

Allergy screening

Clark *et al* studied the use of IRT in detecting food intolerance, in a study of 16 children with known peanut allergy. Following administration of peanut protein via nasal spray, the active group exhibited a higher nasal temperature than the control after 20 min ($p<0.05$).[37] This result was reiterated in a previous study by the same authors, in which egg protein was found to cause a temperature change in those with egg allergy.[38] IRT may represent an improvement over alternative methods of allergy screening, with a reduced risk of adverse events associated with nasal challenge over oral challenge.

Anaesthetics

Cheema *et al* described a case report of the use of IRT in the assessment of a thoracic epidural block, in which a clearly delineated skin temperature change was found from the dermatomes of T4 to T10, indicating the epidural blockade.[39] This case study illustrates the relationship between the peripheral nervous system and skin perfusion, which has relevance in a number of clinical specialties.

RESULTS

Results from this review have been summarised in table 1.

Although a number of studies showed promising clinical applications, with sensitivity and specificity figures similar to that of accepted diagnostic tools, the quality of many included studies was relatively low, with case studies and small pilot studies providing little clinical evidence of efficacy. Conclusions drawn from this review must be considered in this context, but due to the nature of the application of IRT in a clinical environment, true diagnostic accuracy studies are uncommon.

The risk of bias and the applicability of studies was assessed using the Quality Assessment of Diagnostic Accuracy Studies Tool (QUADSA2) (table 2).

CONCLUSION

As thermal cameras have increasingly higher resolutions, the sensitivity improves and the accuracy with which diseases may be identified increases. IRT has shown to be particularly useful in an emergency setting, with applications into the assessment of both burns and fractures having the potential to change current management pathways.[18–24] Also highlighted in this review, studies into respiratory rate monitoring in neonates proved to be successful, with accurate measurement illustrated in a number of publications.[11–15] IRT can express greater accuracy in children and, in such a population, non-contact methods of investigation are well-received.[3 4] Indeed, there is a need for further research into the application of IRT in paediatrics.

Table 1 Infrared thermography in paediatrics summary table

Researchers (ref.)	Year	Study design	Participants	Key findings
Skin temperature				
Kolosovas-Machuca *et al*[3]	2011	Distribution of skin temperature in Mexican children.	25 children	Reduced physiological variability in skin temperature of children, compared with similar study in adults.
Symonds *et al*[4]	2012	Thermal imaging to assess age-related changes of skin temperature within the supraclavicular region co-locating with brown adipose tissue in healthy children.	26 patients of all ages	Child cohort had significantly greater difference in skin temperature following cold challenge, compared with adolescents and adults ($p<0.05$).
Fever screening				
Selent *et al*[6]	2013	Mass screening for fever in children a comparison of 3 infrared thermal detection systems.	855 children	Sensitivity 76.4%–83.7% and specificity of 79.4%–86.3%, across the three cameras, for detecting fever.
Chan *et al*[7]	2004	Screening for fever by remote-sensing infrared thermography camera.	176 patients of all ages	Sensitivity 83% and specificity 88%, for detecting fever by IRT.
Fortuna *et al*[8]	2010	Accuracy of non-contact infrared thermometry versus rectal thermometry in young children evaluated in the emergency department for fever.	200 children	IRT overestimated temperature in afebrile patients and underestimated temperature in febrile patients, compared with rectal thermometry ($p<0.01$).
Monitoring vital signs				
Heimann *et al*[9]	2013	Infrared thermography for detailed registration of thermoregulation in premature infants.	10 premature infants	IRT showed significant increase in head and leg skin temperature, following 90 min of neonatal skin-to-skin care ($p<0.05$).
Anderson *et al*[10]	1990	Use of thermographic imaging to study babies sleeping at home.	Five infants	IRT was used to measure skin temperature in sleeping infants, showing significant heat loss in the head and hands.
Abbas *et al*[11]	2011	Neonatal non-contact respiratory monitoring based on real-time infrared thermography.	Seven premature infants	Mean respiration rate reported as 44.92 by IRT, compared with 43.77 by ECG measurement.
Abbas *et al*[12]	2014	Intelligent neonatal monitoring based on a virtual thermal sensor.	10 neonates	Face-tracking success rate ranged from 74% ($p<0.01$) to 89% ($p<0.01$).
Al-Khalidi *et al*[13]	2015	Respiratory rate measurement in children using a thermal imaging camera.	20 children	Respiratory monitoring by IRT and standard methods had a correlation coefficient of 0.994.
Elphick *et al*[14]	2015	Thermal imaging method for measurement of respiratory rate.	50 adults, 20 children	Respiratory monitoring by IRT and standard methods had a correlation coefficient of 0.88–0.998 in adults and 0.578–0.999 in children.
Goldman *et al*[15]	2012	Nasal airflow and thoracoabdominal motion in children using infrared thermographic video processing.	17 children	Respiratory monitoring by IRT and standard methods had a correlation coefficient of 0.976. IRT successfully identified patients with respiratory disease ($p=0.0125$).

Continued

Table 1 Continued

Researchers (ref.)	Year	Study design	Participants	Key findings
Rice *et al*[16]	2010	Infrared thermal imaging (thermography) of the abdomen in extremely low birthweight infants.	13 infants	Infants with radiographic NEC had lower abdominal temperature than those without disease (p<0.05).
Knobel *et al*[17]	2011	Thermoregulation and thermography in neonatal physiology and disease.		Review of the literature, assessing feasibility of IRT for recording temperature in ELBW infants. Authors concluded future research would benefit from IRT.
Trauma and wound healing				
Sanchis-Sánchez *et al*[18]	2015	Infrared thermography is useful for ruling out fractures in paediatric emergencies.	133 children	IRT had sensitivity 91% and specificity 88% for identifying fracture.
Silva *et al*[19]	2012	Early assessment of the efficacy of digital infrared thermal imaging in pediatric extremity trauma.	51 children	IRT matched the site of pain in 73% patients and matched 7 out of 11 fracture sites.
Ćurković *et al*[20]	2015	Medical thermography (digital infrared thermal imaging) in paediatric forearm fractures – a pilot study.	19 children	IRT found average temperature of the affected arm was 1.17°C higher than the unaffected arm 1 week after injury, reducing to 0.14°C difference 1 month after injury.
Saxena *et al*[21]	2008	Infrared thermography: experience from a decade of pediatric imaging.	483 children	102 patients with haemangioma: positive temperature differential 1.5°C in rapidly progressing cases, but those that underwent complete recovery had a temperature differential of <0.5°C. Five patients with partial amputation showed temperature differential 2.5°C following surgery, reducing to 1.8°C after 48 hours. 30 patients affected by burns showed 2.8°C temperature differential following complete healing. Six patients with varicocele showed 4.1°C temperature differential in affected side. 61 patients with thoracic wall abnormalities showed temperature differential of 2.4°C across affected area. 42 patients with abscess, infection and gangrene: areas of abscess showed 3.6°C temperature differential across affected side.
Morcate *et al*[22]	1996	Post-traumatic gaseous gangrene in childhood: a case report.	One infant	Case study of 2-year-old child with gas gangrene, where IRT helped identify the area of amputation required.
Saxena *et al*[23]	1999	Thermography of *Clostridium perfringens* infection in childhood.	One infant	Same case study as Morcate *et al.* (1996).

Continued

Table 1 Continued

Researchers (ref.)	Year	Study design	Participants	Key findings
Medina-Preciado *et al*[24]	2013	Non-invasive determination of burn depth in children by digital infrared thermal imaging.	13 children	IRT identified 100% of superficial and deep burns, whereas clinical assessment identified 83.33% of superficial and 42.85% of deep burns.
Haemangioma and varicocele				
Garcia-Romero *et al*[25]	2014	The role of infrared thermography in evaluation of proliferative infantile hemangiomas. Results of a pilot study.	10 children	Average temperature differential across haemangioma was 2.5°F at baseline, reducing to −0.2°F after 6 months.
Mohammad *et al*[26]	2014	Infrared thermography to assess proliferation and involution of infantile hemangiomas a prospective cohort study.	42 children	Average temperature differential across haemangioma was 1.9°F at baseline, increasing to 2.5°F at 3 months, before decreasing to 0.2°F at 18.5 months.
Iwata *et al*[27]	1992	Thermography in a child with varicocele.	One child	Preoperative temperature measurements, performed with IRT, showed affected scrotum to be 4°C warmer than the unaffected side. No temperature differential was found at 39 days or 12 months postoperatively.
Dermatology				
Martini *et al*[28]	2002	Juvenile-onset localized scleroderma activity detection by infrared thermography.	40 children	IRT had sensitivity of 92% and specificity of 68% in detecting scleroderma.
Castillo-Martínez *et al*[29]	2013	Use of digital infrared imaging in the assessment of childhood psoriasis.	One child	Case study of a 9-year-old boy with psoriatic lesions. IRT found increased skin temperature in areas affected by psoriasis.
Kashiwagi *et al*[30]	2013	Thermography for evaluation of localized scleroderma treated with methotrexate and corticosteroid.	one child	Case study in a 9-year-old child with scleroderma. Skin temperature was higher around the affected skin, with IRT images showing reduced temperature following treatment but no quantitative measurements given.
Diabetes mellitus				
Zotter *et al*[31]	2003	Rewarming index of the lower leg assessed by infrared thermography in adolescents with type I diabetes mellitus.	25 adolescents	IRT found different rewarming indexes in patients with diabetes, compared with age-matched controls. The first and fifth toe and the inner ankle produced statistically significant differences, following 10 min cold challenge testing ($p<0.05$).
Joint inflammation				

Continued

Table 1 Continued

Researchers (ref.)	Year	Study design	Participants	Key findings
Lasanen *et al*[32]	2015	Thermal imaging in screening of joint inflammation and rheumatoid arthritis in children.	58 children	Surface temperature of inflamed and non-inflamed ankle joints were statistically different ($p=0.044$). No significant difference was found across inflamed and non-inflamed knee joints.
Neurology				
Goetz *et al*[33]	2005	Thermography – a valuable tool to test hydrocephalus shunt patency.	54 children	IRT identified hydrocephalus shunt patency in 88.9% of patients.
Zurek *et al*[34]	2008	Influence of mechanical hippotherapy on skin temperature responses in lower limbs in children with cerebral palsy.	16 adolescent children	IRT found no benefit in limb perfusion following intervention, in patients with cerebral palsy.
Coben *et al*[35]	2009	Sensitivity and specificity of long wave infrared imaging for attention-deficit/hyperactivity disorder.	190 patients of all ages	IRT had a sensitivity of 65.71% and a specificity of 94%, in identifying individuals with ADHD.
Ophthalmology				
Kaercher *et al*[36]	2015	Diagnosis of x-linked hypohidrotic ectodermal dysplasia by meibography and infrared thermography of the eye.	14 adults, 12 children, 8 infants	IRT had a sensitivity of 66.7% in identifying XLHED, compared with 100% and 72.7% of two best alternative methods.
Allergy screening				
Clark *et al*[37]	2007	Facial thermography is a sensitive and specific method for assessing food challenge outcome.	24 children	Positive food challenge in patients with egg allergy resulted in median nasal temperature differential 1.7°C higher than that of the control ($p<0.01$). IRT identified outcome of food challenge with 91% sensitivity and 100% specificity.
Clark *et al*[38]	2012	Thermographic imaging during nasal peanut challenge may be useful in the diagnosis of peanut allergy.	16 children	In children with peanut allergy, statistically significant mean temperature increase of 0.9°C (95% CI 0.34°C to 1.45°C) observed following nasal food challenge, compared with placebo.
Anaesthetics				
Cheema *et al*[39]	1994	Thermography: a noninvasive assessment of pediatric thoracic epidural blocks.	One child	Case study of an 8-year-old girl undergoing thoracic epidural block. IRT indicated clearly delineated temperature change of 0.9°C, from the dermatomes of T4 to T10, suggesting the region of epidural blockade.

IRT, infrared thermography; NEC, necrotising enterocolitis; ELBW, extremely low birth weight.

 Owen R, Ramlakhan S. *BMJ Paediatrics Open* 2017;**1**:e000080. doi:10.1136/bmjpo-2017-000080

Table 2 Infrared thermography in paediatrics—QUADSA2 assessment of risk of bias and applicability

	Domain 1 Patient selection		Domain 2 Index tests		Domain 3 Reference standard		Domain 4 Flow and timing
Study (ref.)	Risk of bias	Concerns regarding applicability	Risk of bias	Concerns regarding applicability	Risk of bias	Concerns regarding applicability	Risk of bias
Kolosovas-Machuca and González[3]	Low	Low	Unclear	Low	N/A	N/A	Low
Symonds *et al*[4]	Low	Low	Low	Low	Low	Low	Low
Selent *et al*[6]	Unclear	Low	Unclear	Low	Low	Low	Unclear
Chan *et al*[7]	Low	Low	Low	Low	Low	Low	Low
Fortuna *et al*[8]	Low	Low	Low	Low	Low	Low	Low
Heimann *et al*[9]	Unclear	Low	Unclear	Low	Low	Low	Unclear
Anderson *et al*[10]	Unclear	Low	High	Unclear	N/A	N/A	Unclear
Abbas *et al*[11]	Low	Low	Low	Low	Low	Low	Low
Abbas and Leonhardt[12]	Low	Low	Low	Low	Low	Low	Low
Al-Khalidi *et al*[13]	Low	Low	Low	Low	Low	Low	Low
Elphick *et al*[14]	Unclear	Unclear	Low	Low	Low	Low	Low
Goldman[15]	Low	Low	Low	Low	Low	Low	Low
Rice *et al*[16]	Unclear	Low	Low	Low	N/A	N/A	Low
Knobel *et al*[17]	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Sanchis-Sánchez *et al*[18]	Low	Low	Low	Low	Low	Low	Low
Silva *et al*[19]	Low	Low	Low	Low	Low	Low	Low
Ćurković *et al*[20]	Low	Low	Unclear	Low	Low	Low	Low
Saxena and Willital[21]	Unclear	Low	Low	Low	Low	Low	Low
Morcate *et al*[22]	Case study						
Saxena *et al*[23]	Case study						
Medina-Preciado *et al*[24]	Low	Low	Low	Low	Low	Low	Low
Garcia-Romero *et al*[25]	Low	Low	Low	Low	N/A	N/A	Low
Mohammed *et al*[26]	Low	Low	Low	Low	N/A	N/A	Low
Iwata *et al*[27]	Case study						
Martini *et al*[28]	Unclear	Low	High	Low	Low	Low	Low
Castillo-Martínez *et al*[29]	Case study						
Kashiwagi *et al*[30]	Case study						
Zotter *et al*[31]	Unclear	Low	Low	Low	Low	Low	Low
Lasanen *et al*[32]	Low	Low	Low	Low	Low	Low	Low
Goetz *et al*[33]	Low	Low	Unclear	Low	N/A	N/A	Low
Zurek *et al*[34]	Unclear	Low	Unclear	Unclear	Unclear	Unclear	Low
Coben and Myers[35]	Low	Low	Unclear	Low	Low	Low	Low
Kaercher *et al*[36]	Unclear	Low	Low	Low	Low	Low	Low
Clark *et al*[37]	Low	Low	Low	Low	Low	Low	Low
Clark *et al*[38]	Low	Low	Low	Low	Low	Low	Low
Cheema *et al*[39]	Case study						

Competing interests None declared.

Provenance and peer review Not commissioned; externally peer reviewed.

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