Potential of Infrared Imaging in Assessing Digestive Disorders

Mahnaz Etehadtavakol, Eddie Y.K. Ng and Mohammad Hassan Emami

Abstract Thermography or infrared imaging is determined by detailed investigation of skin and cells' temperatures. It helps clinicians to detect the regions of irregular chemical and blood vessel action in body tissue. The drive of biomedical industry with consequent rapid development in other areas of biomedical imaging has also strongly influenced the destiny of thermography in biomedical practice. During past few decades, the joint efforts of biomedical engineering and medical professionals have resulted in evolution of technological progress in infrared sensor technology, image processing, organized repository of knowledge, and their overall integration into a system. All these enabled the new tools of research and use in medical thermography. Thermography is a simple, noninvasive and reproducible test that can accurately reflect the inflammatory activities, and can be used safely and repeatedly, during biological course of inflammatory bowel disease. Objective of this study is presenting the possibility of infrared imaging in assessing digestive disorders such as irritable bowel syndrome, diverticulitis and Crohn's disease.

Keywords Thermography · Digestive disorders

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E.Y.K. Ng and M. Etehadtavakol (eds.), *Application of Infrared to Biomedical Sciences*, Series in BioEngineering,
DOI 10.1007/978-981-10-3147-2_1

1 Introduction

Inflammatory bowel disease (IBD) influences chronic inflammation of all or part of the digestive section (Fig. 1). Ulcerative colitis and Crohn's disease are mainly related to IBD. Pain, severe diarrhea, weight loss, and fatigue are often prevalent in these diseases. IBD can be harmful and occasionally influences life-threatening problems. Enduring inflammation and ulcers in the innermost lining of the large intestine and rectum are caused by ulcerative colitis, which is an inflammatory bowel disease. Inflammation of the lining of the digestive section appears in Crohn's disease. However, inflammation usually influences thoroughly on involved tissues in Crohn's disease. The large intestine and the small intestine, two different parts of digestive section, or both may be affected by inflammation. Colorectal cancer is the third most typical tumor in the United States. Several factors that increase the risk of developing colorectal include eating foods rich in fat, drinking alcohol, having a low fiber, being chemical solvent exposure, and having first-degree family history. Some studies show that tumors develop from polyps in most cases. For Stage I tumor growth through the mucosa and invasion to the muscular layer of the colon or rectum, 85–95% rates and for Stage II tumor growth through the colon wall, 30–70% rates, for 5-year survival, are reported [1]. While during Stage III tumors have already spread to lymph nodes or Stage IV tumors have spread to more than one part of the body, improvement is difficult. However, by early detection of polyps and precancerous cells, we are able to increase chance of improvement. Therefore, a safe, noninvasive, reproducible, and standard adjunctively method that has potential for colon cancer early detection is appreciable. Common standard diagnostic tests to evaluate IBD involve clinical examination, laboratory tests, activity evidence as well as several imaging techniques.

The first documented practice of thermobiological signs happens to be the written works of Hippocrates at about 480 BC. Wet mud spread all over a patient to investigate the regions would dry first in order to achieve the hidden pathology of organs. Thereupon, by advanced studies and researches it has been confirmed that particular temperatures interrelated to organs of body were definitely indicative of healthy and

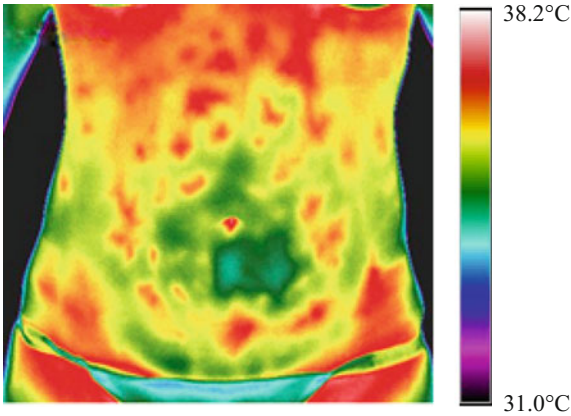

Fig. 1 Thermogram of an irritable bowel syndrome patient

unhealthy pathological mechanism [2]. The first documented use of infrared (IR) imaging in medicine was in 1956, when asymmetric hyperthermia regions and vascularity in breast thermograms were examined for breast cancer detection. Since then many discoveries have been documented [3–5]. However, thermography is not known internationally in medicine even today, mainly as a result of the inexperienced application of the method, the inadequate deep understanding of thermograms. Advances in infrared (IR) camera technologies, appropriate patient protocols, and properly calibrated thermography have led to an increased interest in the application of IR systems in the medical imaging [6]. In addition, using 3D thermal imaging to promote medical diagnosis has been considered in past two decades. In 1996, Chan et al. [7] introduced generation of 3D medical thermograms. Souza et al. [8] also used 3D thermal imaging to integrate MRI and thermographic images. In 2015, a 3D medical thermography device was introduced by Moghadam [9]. Furthermore, a patent was filed by C. Herman in Johan Hopkins University in 2015 for 3D thermal imaging for the detection of skin lesions and other natural and abnormal conditions (US 20130116573 A1). In future work, 3D thermal imaging would be useful to visualize internal organs for promoting digestive disorders diagnosis. This paper is organized as follows: Methodology is explained in "Methodology" section, eighteen case reports are presented in "Case Reports" section, results are discussed in "Results" section, and "Conclusion" section concludes the findings.

2 Methodology

In this paper, presented case reports were patients with different indications of IBD and colorectal cancer. Various diagnostic tests including physical examinations, different laboratory tests, and different imaging tests were performed for each case. Different tests include the microbiology testing of stool samples, C-reactive protein, calprotectin, esophagogastroduodenoscopy, multidetector computed tomography, total colonoscopy, magnetic resonance (MR) imaging of the abdomen or MR enterocolography, upper gastrointestinal (GI) endoscopy, histopathology testing, MR enterography, and terminal ileoscopy. However, thermal imaging was performed for all the cases. Details of different tests will be explained in "Case Reports" section for each case separately.

2.1 Thermal Imaging Protocol Guidelines

We briefly explain some guidelines to provide thermal images to detect probably some digestive disorders [10]:

- Imaging should be done before planning for endoscopy, to eliminate any potential influence of bowel cleansing and endoscopic mechanism.

- Imaging can be done in two interval times: before beginning the therapy and after the patient had attained the remission, as reported by clinical, laboratory and endoscopic evaluation [11].
- The imaging itself can be progressed in this way;

  i. Patients position in front of the camera, approximately at 1 m; so that the whole abdomen was captured by the camera lens.
  ii. Patients are undressed and requested to stand in front of the camera not touching there abdomen for the sake of attaining thermal equilibrium.
  iii. The process takes about 5–10 min.
  iv. Consequently to attain equilibrium the patient's abdomen is cooled with alcohol and then interval thermal image can be taken after equilibrium is attained again.
  v. Differences in thermal patterns and peak temperatures are captured.
  vi. Taken thermal images can be divided into four quadrants representing colonic segments: rectosigmoid, descending colon, transverse colon, and descending colon.
  vii. The same process of thermal imaging can be performed before beginning of therapy and consequently to achieve clinical remission of the disease.
  viii. Differences in observed thermal patterns and peak temperatures can be compared.

3 Case Reports

Case report I: In this report, a 43-year-old male patient presented to the emergency room with severe abdominal pain. Before admittance to the hospital, an esophagogastroduodenoscopy was performed that showed carcinoma on the back wall of the gastric corpus. The diagnosis of adenocarcinoma was confirmed by the pathohistological analysis. After admittance, the preoperative workup including

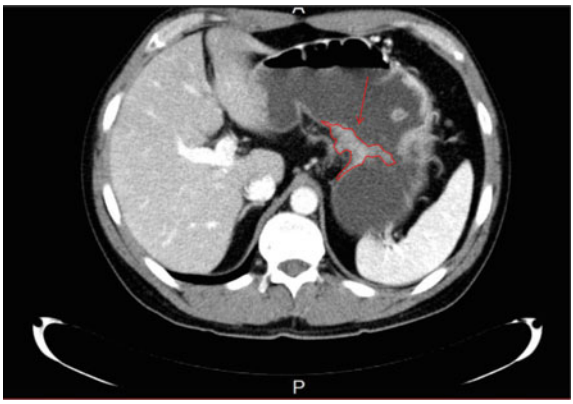

Fig. 2 MDCT showing gastric carcinoma indicated by *red part* prior operation of a 43 years male [12]

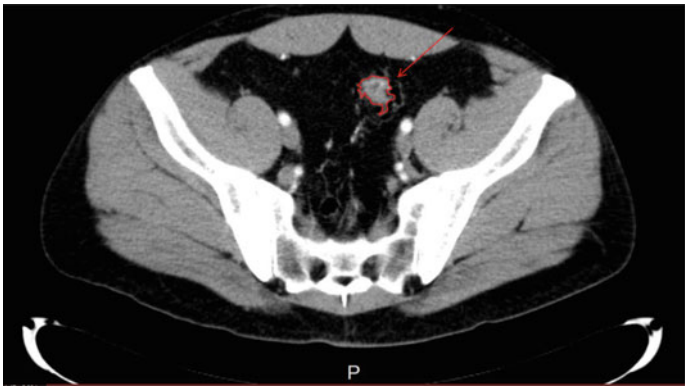

Fig. 3 Colon diverticula and opacification of the colon wall as revealed with *red part* by MDCT prior operation [12]

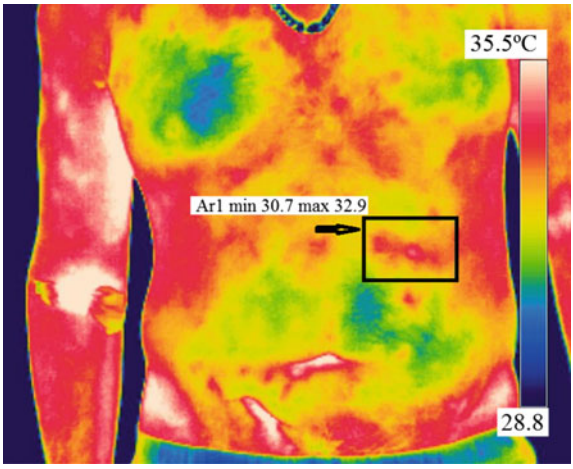

Fig. 4 Hot spot indicating inflammation as shown in thermal image of 43 years male with left UC [12]

laboratory testing and imaging methods for staging the carcinoma was performed. Laboratory testing indicated no abnormalities; however, the preformed Multidetector Computed Tomography (MDCT) indicated thickening of the gastric small curve 4 cm in diameter and a couple of affected perigastric lymph nodes. It is shown in Fig. 2.

Besides the observations in the stomach, the MDCT also revealed nonspecific opacification of the colon wall that could show an inflammatory process as it is demonstrated in Fig. 3.

There were no radiological signs of diverticulitis, besides the diverticula. However, the patient also underwent the thermal imaging as it is shown in Fig. 4. The thermal image demonstrated signs of inflammation in spots that could reflect the position of the diverticula that revealed by the MDCT.

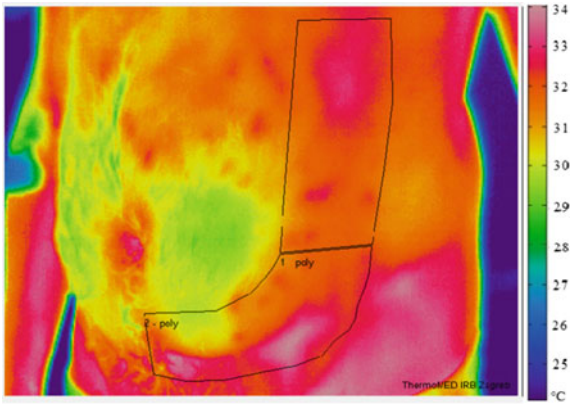

Fig. 5 Marked areas of severe inflammatory activity of 47-year male with left UC

A colonoscopy was performed to confirm and verify the diagnosis of diverticulitis (repeated). The patient was operated 5 days later. The procedure was proven. Surgical team conducted total gastrectomy with splenectomy. However, the newly diagnosed diverticulitis caused the planed adjuvant chemo-radiotherapy to be postponed. Considering that chemo-radiotherapy could provoke perforation of the inflamed diverticula and potentially be fatal for the patient [12].

Case report II: In 2013, a 47-year-old male diagnosed with left-sided ulcerative colitis (UC). He was admitted in a hospital whereas aggravation of the disease happened in September 2014. Before admittance to the hospital, the patient presented with fever, fatigue, loss of appetite, and loss of body weight, in duration of 2 weeks. The disease was characterized with abdominal cramps located in the lower left quadrant of the abdomen, and diarrhea (7–10 stools/day, mixed with mucus and blood). The laboratory tests indicated elevated leucocyte levels. Total colonoscopy suggested severe left-sided colitis with Mayo endoscopic subscore of 2 (in range 0–3). However, the patient also underwent for the thermal imaging. His abdominal thermal image is shown in Fig. 5.

Detected temperatures in quadrants were 2 °C higher than in the unaffected parts of the abdomen representing the left colon (the rectosigmoid and the descending colon). The patient was discharged clinically in better shape after 12 days of hospitalization. The plan was to take another thermogram of the patient's abdomen, upon achieving whole remission. There were no obvious signs of disease activity seven months later. Although stool frequency and consistency were normal, the patient did complain about discomfort in the lower left quadrant of the abdomen. A control thermogram was taken and surprisingly some disease activity was detected. Detected temperatures in quadrant representing the left colon were almost the same as the one taken 7 months earlier. The thermogram is shown in Fig. 6.

Two days later the patient was readmitted to the hospital with full worsening conditions. Active disease along the left part of the colon, Mayo endoscopic subscore 2 as indicated by the preformed colonoscopy [10].

Case report III: In this report, a 42-year-old female, diagnosed with UC in 2005. She consulted her gastroenterologist because of frequent bloody stools

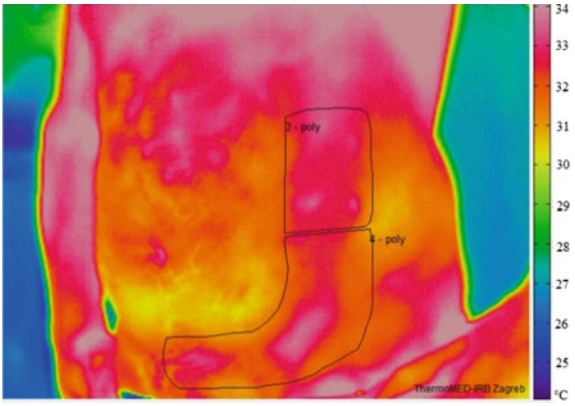

Fig. 6 Control thermogram showing some remaining disease activity after 7 months discharged from hospitalization

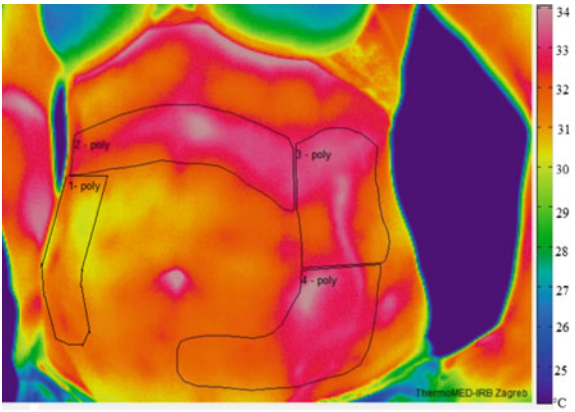

Fig. 7 Disease activity shown by the 42-year-old female patient abdomen thermogram

(7–8/day) and abdominal pain in February 2015. Active disease extending to the hepatic flexure was indicated by colonoscopy. Elevated inflammatory markers (high leukocytosis and elevated C-reactive protein) were revealed by the laboratory tests. Any infective causes were however excluded by microbiological stool analysis. A thermogram of the patient's abdomen was taken and a distinctive infrared pattern corresponding to colonoscopy findings was indicated as shown in Fig. 7.

Hot spots were observed in quadrants representing the left and the transverse colon. Intensive treatment with anti-inflammatory drugs (methylprednisolone and azathioprine, in combination with mesalamine) and after four weeks, the patient entered the remission of the disease. Clinical, laboratory, and imaging examination indicated significant improvement in disease activity. Only mild abnormalities with the significant normalization in abdominal surface temperature pattern were observed when compared to the initial thermographic examination. It indicated the remission of active colitis, [10]. His remitted thermal image was presented in Fig. 8.

Temperatures in the affected quadrant were significantly lower as can be seen in Chart 1.

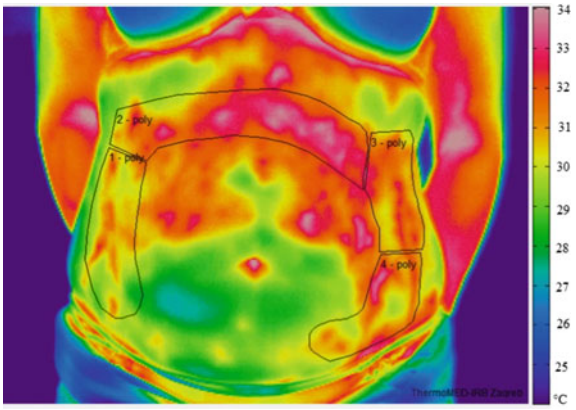

Fig. 8 Thermogram of the same patient, after 4 weeks of treatment with improvement in disease activity

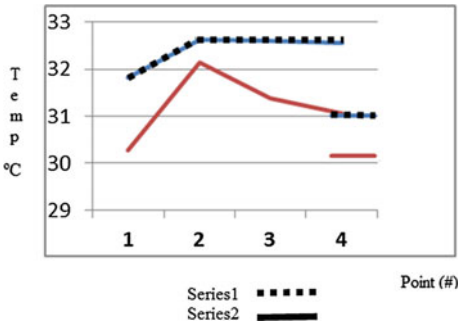

Chart 1 Temperatures before treatment (*Series1*) and after treatment (*Series2*) of case report III

Case report IV: Banic et al. [13] presented findings belonging to a 53-year-old female patient diagnosed with severe ulcerative pancolitis. The patient had been presented with fever, fatigue, loss of appetite and loss of body weight for 6 weeks before her admittance to the University Hospital of Dubrava, Croatia. The disease was characterized with abdominal cramps and diarrhea (5–10 stools/day, mixed with mucus and blood). The laboratory tests revealed anemia with elevated erythrocyte sedimentation rate and c-reactive protein (CRP) levels above normal values. The upper gastrointestinal (GI) endoscopy documented mild chronic gastritis and histopathology testing did not document the presence of *Helicobacter pylori* (*H. pylori*) infection in the stomach. The MR enterography documented no signs of Crohn's disease in the small intestines and no signs of fistulas [13].

The terminal ileoscopy indicated no signs of inflammatory involvement of the mucosa in terminal ileum. However, total colonoscopy revealed acute severe pancolitis with Mayo endoscopic subscore of 3 (in range 0–3), in each colonic segments. The initial findings of pancolitis and severe inflammatory activity of the disease were discovered through the heat patterns of thermal images taken before any treatment. Abdominal skin temperature of the patient is shown in Fig. 9 which indicates temperature abnormalities.

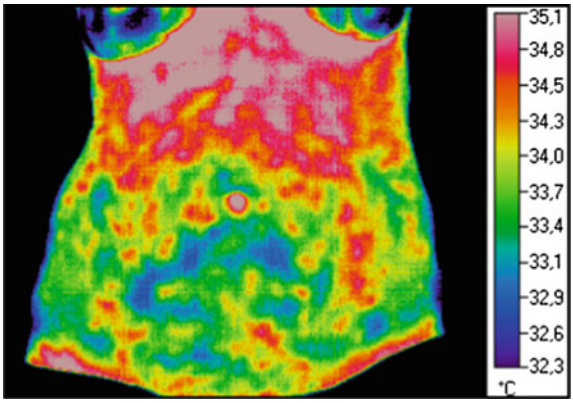

Fig. 9 A 53-year-old female patient with areas of enhanced thermal abnormalities

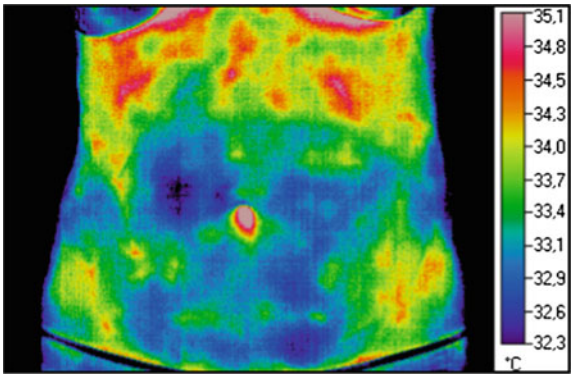

Fig. 10 Patient in Fig. 9 after 4 weeks of intensive treatment

After four weeks of intensive treatment with anti-inflammatory drugs (methylprednisolone and azathioprine, in combination with mesalamine), the patient entered the remission of the disease, documented with significant clinical, laboratory and imaging improvement in disease activity [14, 15]. The laboratory tests detected no anemia with normal values of CRP. Control examination by the means of total colonoscopy, performed 4 weeks after initial examination documented healing in each segments of colonic mucosa, expressed with Mayo endoscopic subscore of 1. This finding indicated the remission of active colitis according to the non-contact thermal image (Fig. 10) shows only mild abnormalities with the significant decrease in abdominal skin temperature compared to the first taken thermal image (Fig. 9).

Ulcerative colitis represents a chronic inflammatory and ulcerative disease of colonic mucosa. Clinically, ulcerative colitis is characterized by bloody diarrhea, and the diagnosis most often relies on invasive colonoscopy and macroscopically scoring of visualized inflammatory and ulcerative mucosal pattern [16–18]. Diagnostic methods currently in use, clinical (endoscopy), imaging (CT, MR) or laboratory (C-reactive protein, calprotectin) provide an insight into disease activity,

but are possibly associated with significant discomfort for the patient and/or increased risk of irradiation and potential allergic reactions on contrast agents.

Case report V: A typical irritable bowel thermogram is shown in Fig. 11. It shows diffuse (scattered throughout) hyperthermia (too much heat) in upper abdomen. The patient was having symptoms of gas, bloating, pain in abdomen [19].

Case report VI: A thermal image of a patient with parasite infection in gastrointestinal tract is demonstrated in Fig. 12. Localized areas of heat with "focal points" of hyperthermia are indicated. *H. pylori* bacteria was diagnosed on her blood test [19].

Case report VII: A sequence of thermograms for one treated irritable bowel syndrome (IBS) patient are presented in Fig. 13a–c [19]. In the first thermogram, we observe too much heat that is diffused throughout in the upper abdomen. Before the treatment the patient was complaining about gas, bloating, and pain in the abdomen. We observe that the thermograms are softer and cooler after taking alovera juice.

Case report VIII: An abdominal thermal image and its corresponding temperature histogram of a healthy female individual are presented in Fig. 14a, b. The temperature histogram has a normal distribution pattern with a peak temperature around 32 °C [1].

Case report IX: A thermal image of a female patient with active Crohn's colitis is included in Fig. 15a, b. A clear thermal pattern change is observable in the abdominal part. In addition, the histogram of the heat pattern has different distribution comparing to normal case (Fig. 14). The peak temperature is around 35 °C [1].

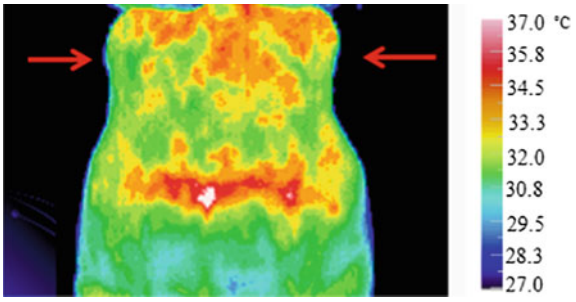

Fig. 11 An irritable bowel thermogram

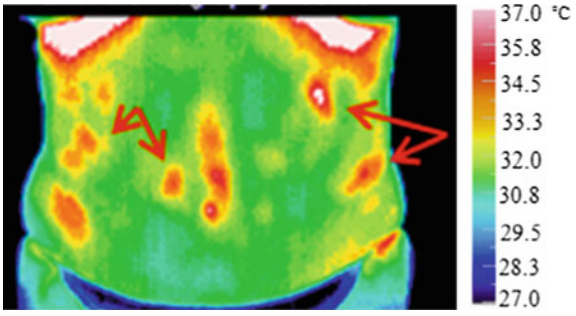

Fig. 12 A patient with parasite infection in gastrointestinal tract

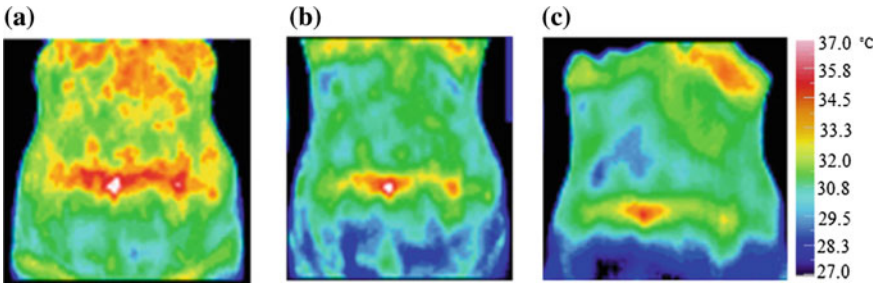

Fig. 13 IBS patient treatment with aloe vera juice. **a** Initial thermogram. **b** 5 days of taking alovera juice. **c** 13 days of taking aloe vera juice

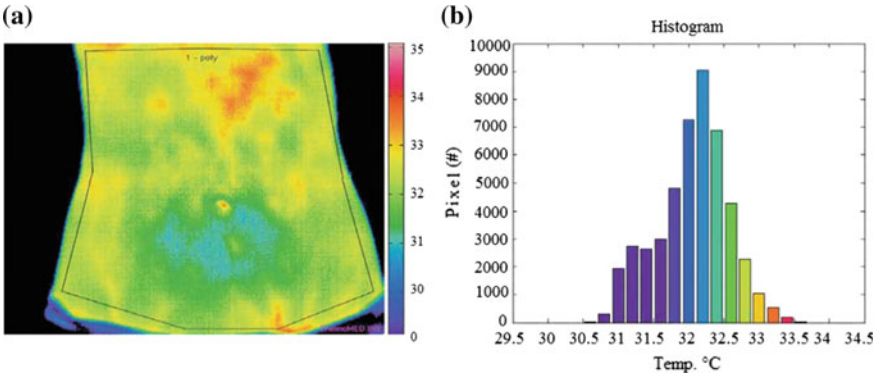

Fig. 14 A healthy female individual. **a** An abdominal thermal image. **b** Corresponding temperature histogram

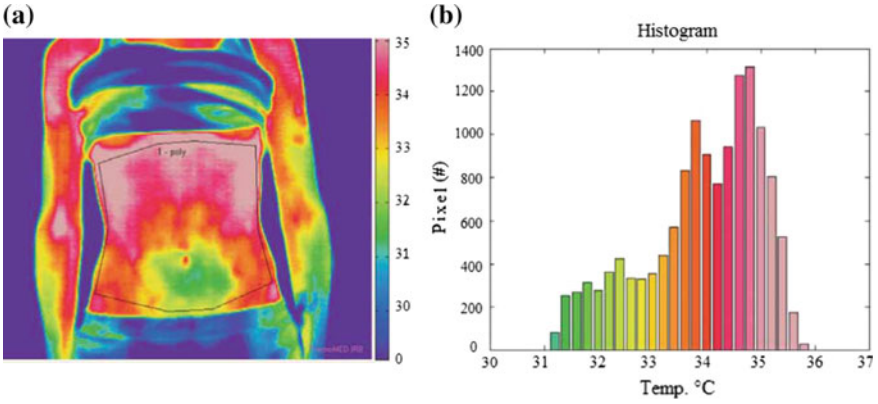

Fig. 15 A female patient with active Crohn's colitis. **a** An abdominal thermal image. **b** Corresponding temperature histogram

A thermal image of the above-mentioned female patient with active Crohn's colitis after induction of remission is demonstrated in Fig. 16. A clear thermal pattern change is evident in the abdominal part. The main peak temperature after induction of remission was 31.5 °C. However, a second less expressed peak at 32.5 °C is observed.

Case report X: A thermogram of a male patient with high-grade dysplastic polypoid lesion in left-sided ulcerative colitis is shown in Fig. 17a. A hot spot above a polypoid lesion with high-grade dysplasia is observable. Also the 3D analysis of that hot spot is demonstrated in Fig. 17b [1].

Case report XI: An abdominal thermogram of a person with hepatitis is shown in Fig. 18. After birth, the hepatic blood vessel was blocked which is shown by hot area in the abdominal thermogram. Further action was treated and the blood vessel was opened from the liver to the umbilicus [20].

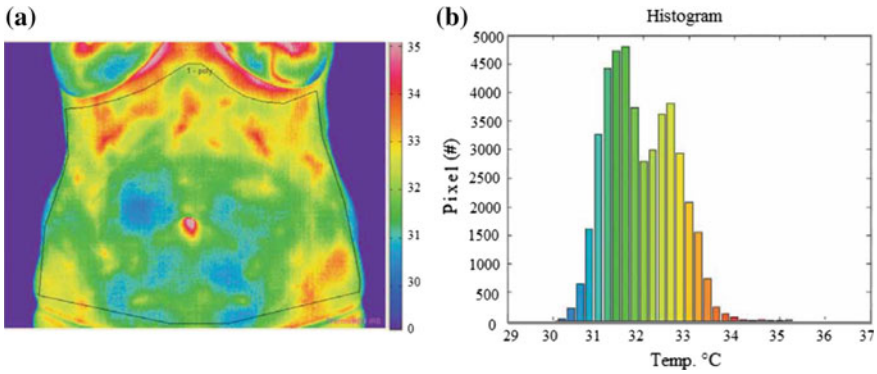

Fig. 16 **a** A thermal image of a female patient with active Crohn's colitis after induction of remission. **b** A histogram

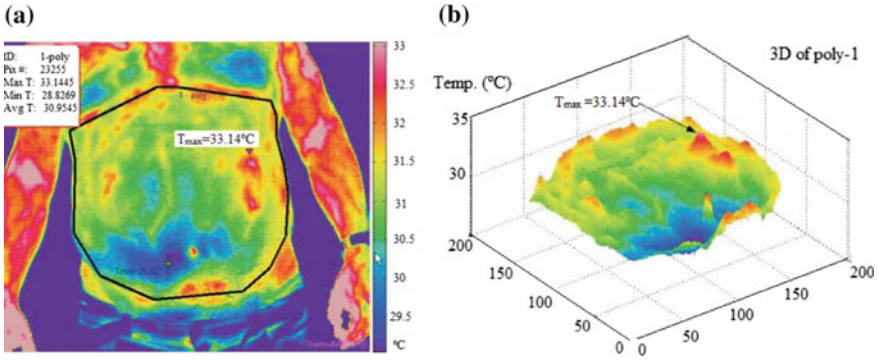

Fig. 17 **a** A thermogram of a male patient with high-grade dysplastic polypoid lesion in left-sided ulcerative colitis. **b** 3D plot of hot spots

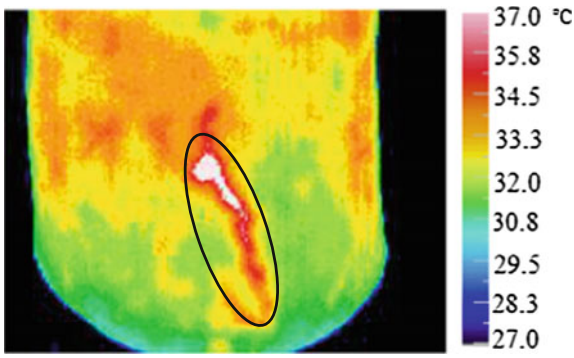

Fig. 18 A patient with hepatic blood vessel blockage [20]

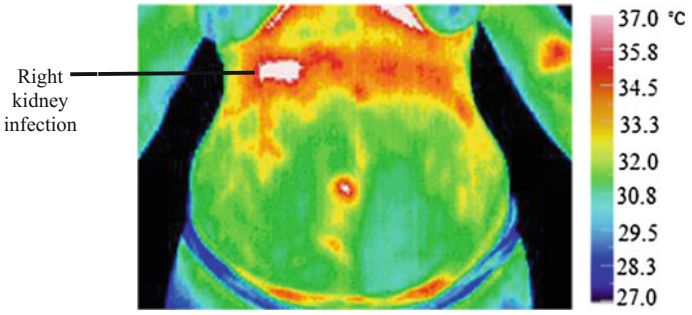

Fig. 19 Thermogram of a patient with right kidney infection confirmed with other examination

Case report XII: A thermogram of a patient complaining back pain is presented in Fig. 19. No thermal evidence was discovered in her back; however, some hyperthermia areas were observed over the right kidney through her abdomen thermogram which could address pain to the back. Besides further tests showed kidney infection as well [20].

Case report XIII: An abdomen thermogram of a female patient, depicted in Fig. 20, indicates a hyperthermia area over the hepatic flexure of the colon. Further examinations confirm diverticulitis and then suitable treatment was recommended [20].

Case report XIV: Thermography is a very useful technique for treatment monitoring of a patient. An initial abdomen thermogram of an IBS (irritable bowel syndrome) female patient is shown in Fig. 21a where the circular hyperthermia spots were indicating IBS. The patient was treated with acupuncture and Chinese herbs for 45 days. The thermogram shown in Fig. 21b was taken after the treatment. Increasing cooler and green thermal area in Fig. 21b was indicating progress in the treatment and the patient returned to a better and helthier condition [21].

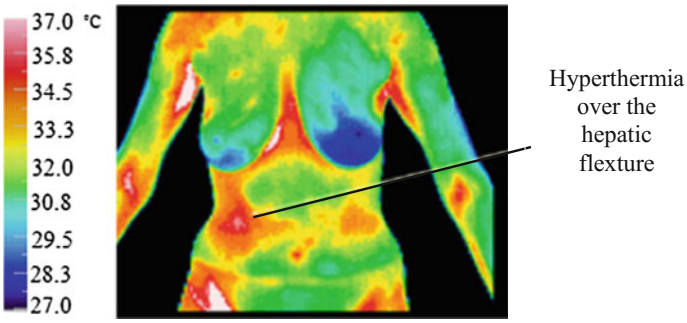

Fig. 20 Thermogram of a patient with diverticulitis [20]

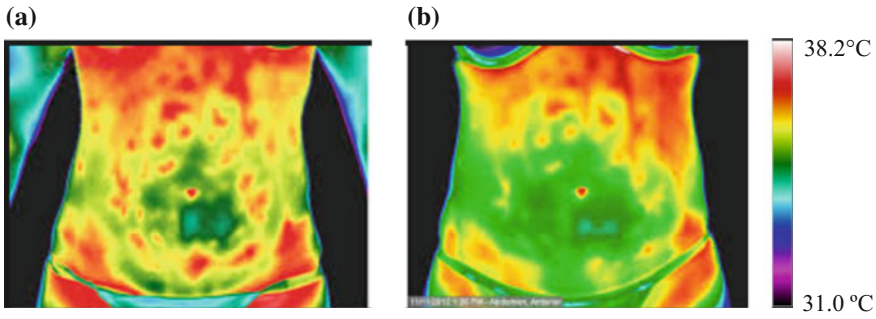

Fig. 21 Progress of an IBS patient treatment with acupuncture and Chinese herbs. **a** Before treatment. **b** After treatment

Case report XV: Fig. 22 suggests a patient with abdominal distension that happens when substances, for example gas or fluid, gather in the abdomen and generate the outward enlargement on the far side of the normal girth of the stomach and waist. Consequently, elevated abdominal pressure and volume are sensed [22].

Case report XVI: Ileocecal valve is a sphincter muscle valve that allows digested material to pass from the small intestine to the large one by opening and closing. Figure 23 demonstrates a thermogram of a patient with ileocecal valve blockage [22].

Case report XVII: One of the possible side effects of colonoscopy in rare cases is making a puncture in colon. Figure 24 shows a thermogram of a case with a punctured colon during a colonoscopy. Hot spots or hyperthermia areas are indicating inflammation or possible infection due to colon perforation [22].

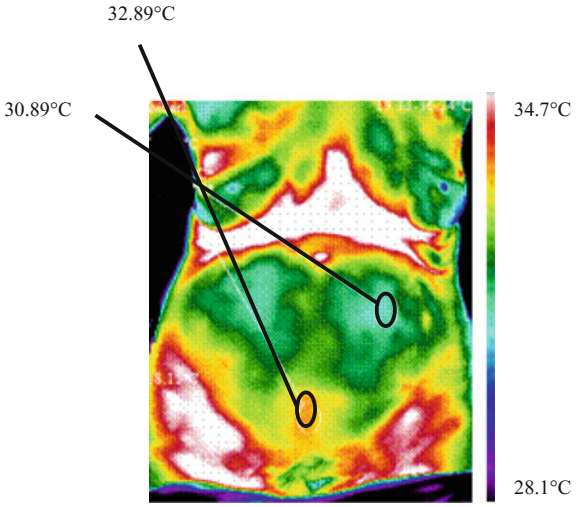

Fig. 22 A patient with abdominal distension

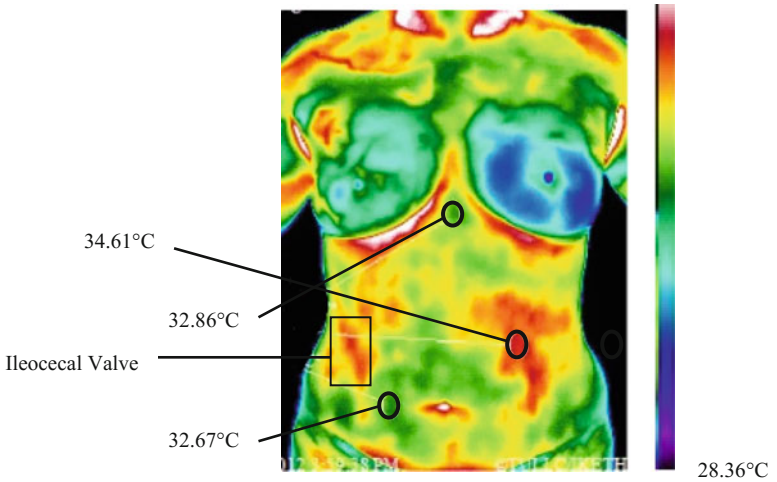

Fig. 23 Ileocecal valve blockage

Case report XVIII: In order to absorb most of the nutrients from what we eat, the intestinal track must be cleaned the dirt out. Otherwise the needed proteins, vitamins, etc., can not be absorbed by the coated intestinal walls. Figure 25 reveals an individual with belly fat and poor gut health which caused the stomach distention [22].

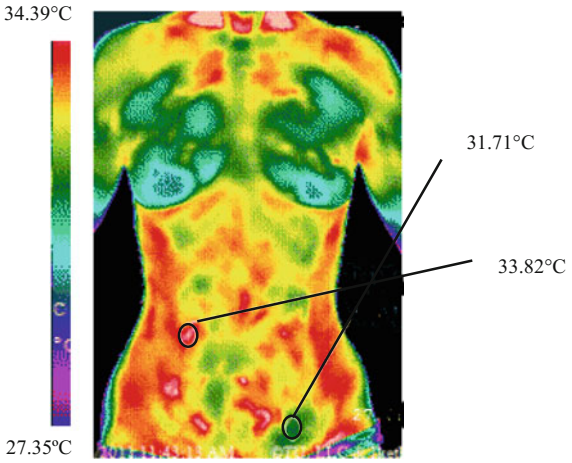

Fig. 24 Punctured colon during a colonoscopy

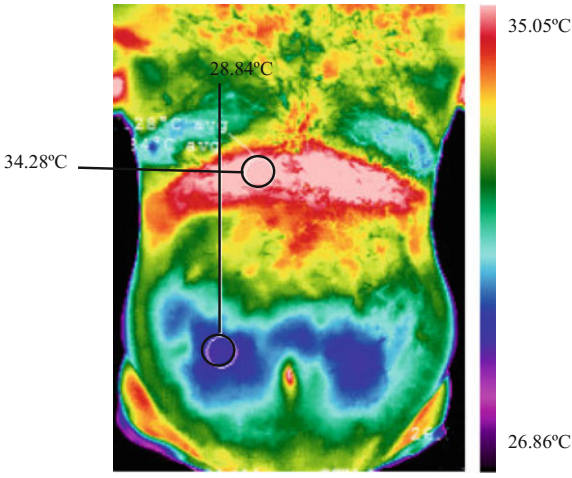

Fig. 25 An individual with extreme distension from poor intestinal health in conjunction with belly fat

4 Results

Thermography is capable of providing non-contact, in vivo diagnostic information in regard to body temperature. Also it has the possibility to map small variations in the body surface temperature and identify thermal abnormalities that accompany various physiological conditions. Being a passive technique, without external sources of radiation this technique is non-invasive and therefore intrinsically harmless.

Clear changes in thermal pattern of the abdomen of the 18 patients examined here with inflammatory bowel problems are evident. In addition, their corresponding temperature histograms have different distributions comparing to the normal cases.

5 Conclusion

Thermal imaging measures the radiation of infrared heat from human body. It presents a very early detecting system, often able to identify an abnormality process before it is distinguishable by standard diagnostic imaging techniques. On the other hand, a best application at the interface of environment and genetics is chronic inflammation which is famous to lead the development of many categories of precancerous lesions and specific diseases themselves, together with oesophageal, liver and colon inflammation.

This review has presented the potential of infrared thermography as a feasible and safe technique to be used adjunctively to evaluate patients with various manifestations of inflammatory bowel diseases. There is a need for further basic and clinical studies in order to evaluate and validate this to assess the activity and extent of intestinal inflammation and other intraabdominal inflammatory conditions.

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