Infrared Imaging for Emergency Medical Services (EMS): Using an IR camera to identify life-threatening emergencies

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ABSTRACT

Over 150 million emergency calls are made each year in the United States (US). Different technologies have been introduced to help the Emergency Medical Systems (EMS) to correctly diagnose, monitor, and locate victims correctly to ensure the preservation of the maximum number of lives but the use of infrared imaging in this field is totally new. The purpose of this study is to describe infrared imaging features of clinical emergency and accident victims in order to verify it's useful as a quick, non-invasive and efficient manner to accurate triage information. Infrared imaging identified different features at traumatic (hypoxia, thoracic trauma, hipovolemic shock, spinal cord injury, peripheral vein access) and non-traumatic emergency (heart attack, stroke, headache, acute abdomen) that can serve as triage information and patient monitoring. In conclusion, we have presented a system that informs the risk situation of an emergency victim by different neurovascular thermal cutaneous features. Infrared imaging system efficiently chooses the order in which individuals are sent to the hospital. Infrared imaging is an effective system that also distributes limited medical resources in a manner that helps as many people as possible. At a disaster scene it could be critical for multiple victims' triage. These imaging techniques should be applied in emergency medical system. Thermography is a simple, quick and inexpensive technique. It is painless; there are no side effects and no exposure to radiation. The authors conclude that this would be a useful piece of equipment in the accident and emergency department by a trained professional.

INTRODUCTION

Over 150 million emergency calls are made each year in the United States (US). An emergency medical service exists to fulfill the basic principles of first aid, which are to preserve life, prevent further injury and promote recovery.

The possibility of public health emergencies arising in the US and in the world concerns many people in the wake of not only emergencies, like cardiac arrest and strokes, and accidents but also to recent hurricanes, tsunamis, acts of terrorism, and the threat of pandemic influenza. Though some people feel it is impossible to be prepared for unexpected events, the truth is that taking preparedness actions helps people deal with emergencies, accidents and disasters of all sorts much more effectively when they do occur. Research supports the common sense notion that getting prompt help makes surviving an emergency more likely. Different technologies has been introduced to help the Emergency Medical Systems (EMS) to correctly diagnose, monitor, and locate victims correctly to ensure the preservation of the maximum number of lives but the use of infrared imaging in this field is totally new.

The purpose of this study is to describe infrared imaging features of clinical emergency and accident victims in order to verify it's useful as a quick, non-invasive and efficient manner to accurate triage information.

MATERIALS AND METHODS

In the period between December 2007 and May 2008, eighty five cases were prospectively attended by Brazilian Emergency Medical Service – EMS with infrared imaging monitoring. This service is composed of two forces: a trauma care named Integrated System of Trauma in Emergencies Attendance (SIATE) and a clinical emergency care called Mobile Emergency Attendance Service (SAMU) at Curitiba city and Matinhos Beach, Parana State, Brazil.

Inclusion criteria were that the victims had symptoms as unconsciousness, trouble breathing or breathing in a strange way, chest pain or pressure, bleeding severely, pressure or pain in the abdomen that does not go away, vomiting or passing blood, seizures, severe headache, slurred speech, poisoned, head, neck or back injuries and possible fractures. Also the situations of fire or explosion, downed electrical wires, swiftly moving or rapidly rising water, presence of poisonous gas, vehicle collisions and victims who cannot be moved easily. All the patients were assessed by means of conventional Basic and Advanced Life and Cardiac Support and Pre-Hospital Life Support (BLS, ATLS, ACLS, and PHTLS) protocols.

The SAMU and SIATE, includes eleven advanced mobile emergency unit, staffed by doctors, paramedics and nurses, and 12 basic mobile emergency units, staffed by professionals trained in basic life support. In an attempt to organize the health services in a hierarchical manner and to guarantee the management of patient flow within the emergency care system there is a Medical Regulation Office (MRO), in a process which considered the experiences of similar systems in place in North America and Europe [7-12]. The office began to regulate the flow of emergency cases to the hospitals, with popular support, respecting the hierarchical position of each institution and the actual level of care available at the various health care centers.

Figure 1. Paramedics with FLIR BCAM SD handheld IR cameras

The doctors and paramedics were trained in a 60 hours course of Clinical Thermology and Infrared Imaging Diagnosis with emphasis in emergency and trauma. They learned to use an ultra-portable 1.2 lbs. infrared camera (BCAM SD, FLIR Systems Inc, Boston, MA, USA) with a rechargeable 7 hours Li-Ion battery operating time. The camera has a thermal sensitivity of 0.1°C and an accuracy of 0.6°C. It has an uncooled focal plane array (FPA) microbolometer infrared detector that produces an image with 120x120 pixels in the 7.5 to 13 μm spectral range. It uses a fixed 25°x25° field of view with 0.3 m minimum focus distance. The IR camera can store 1,000 images in standard radiometric JPEG format with an SD card. The IR camera also has a Laser LocatIR™ that quickly helps associate the infrared finds on the IR image with the real patient target. The emissivity was set to 0.98. The practitioners were instructed to document all the cases during the pre-hospital care.

The infrared images were examined at real time during the attendance and the saved jpeg images stored were analyzed after with the program ThermaCAM QuickView which extracts the temperature value of pixels. The study, conducted after being approved by our Ethics committee, involved patients with a mean of 36 year-old (patients younger than 16 years of age were generally cared for by pediatricians) who presented traumatic and non-traumatic afflictions and were admitted to the emergency center (EC) in the areas of Internal Medicine, Surgery and Neurology.

RESULTS

TRAUMA CARE

a) Airway

If the patient's airway is blocked, oxygen cannot reach the lungs and so cannot be transported round the body in the blood. Ensuring a clear airway is the first step in treating any patient. Common problems with the airway involve blockage by the tongue or vomit. In most tissues of the body, the response to hypoxia is initial vasodilation. By widening the blood vessels, the tissue allows greater perfusion. But the extremities turn cold due to his lower metabolism, allowing the brain to withstand a much longer period of hypoxia. As Figure 2 shows, although this thoracic trauma patient had been intubated his temperature rapidly fell 2.7 °C compared to the nurse as identified by IR imaging because obstruction of his endotracheal tube by serum-bloody pulmonary secretions. The orotracheal airway was cleaned.

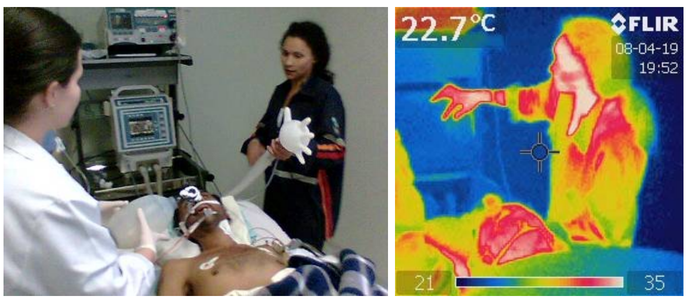

Figure 2. IR image shows intubated patient with lower temperature than nurse due to obstruction of the Endotracheal tube.

b) Breathing and Ventilation

The injuries that may acutely impair ventilation and that should be identified in the primary survey are tension pneumothorax, flail chest with pulmonary contusion, massive hemothorax and open pneumothorax. Figure 3 shows how infrared imaging helped the team to suspected of a pulmonary contusion caused by trauma at left thorax in an unconscious injured male. The red area indicates the troubled region and the spot meter points to the high temperature into the image coincident with fracture at 9th anterior left rib confirmed at ED by radiographies.

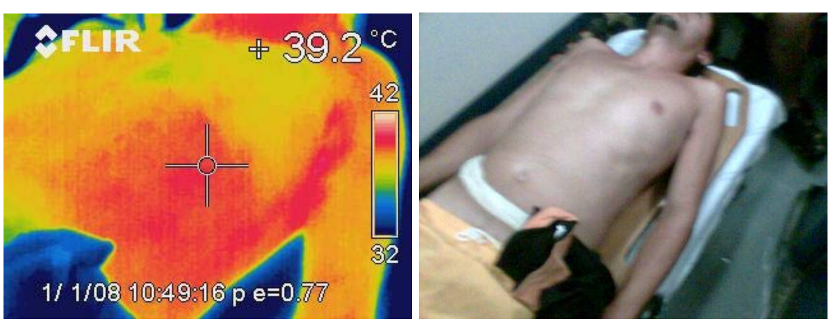

Figure 3. IR image shows abnormal warming coincident with rib fracture

In this medico-legal case an indirect infrared imaging feature of the eyes exposed the cause of death of a 34-year-old woman by a severe crush injury of the thorax, called traumatic asphyxia syndrome (Perthes). It was identified an immediate postmortem infrared peripalpebral sign caused by such compression that would give rise to a venous pressure wave transmitted to the eyes, not well visible by the team.

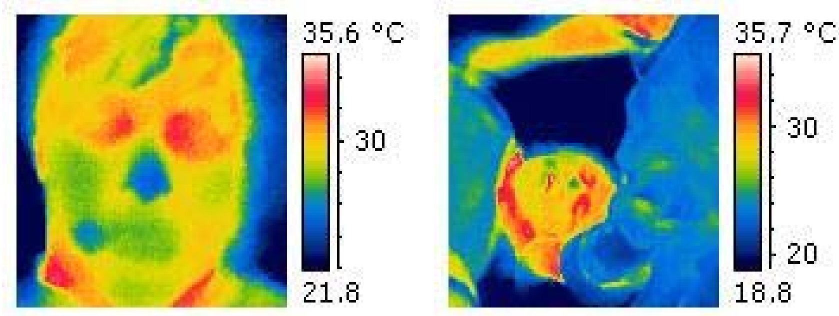

Figure 4. IR image of eyes postmortem of a severe crush injury victim

c) Circulation with hemorrhage control

Once oxygen can be delivered to the lungs by a clear airway and efficient breathing, there needs to be a circulation to deliver it to the rest of the body. This can be assessed in a number of ways, including a pulse check, ECG analysis, or capillary refill time. Other diagnostic techniques include blood pressure checks or temperature checks on peripheral areas. The extremities becomes colder because reactive vasoconstriction to preserve central blood flow to vital organs as brain, heart and kidneys.

These unique images were of a lateral motor vehicle accident at front passenger side. It occurred at a difficult local access but at 20 meters of distance it was possible to quickly identify by infrared imaging that the front passenger was in severe hemorrhagic shock because her surface temperature was 5 °C below the other victims inside the car. She was the first one to be attended by the EMS.

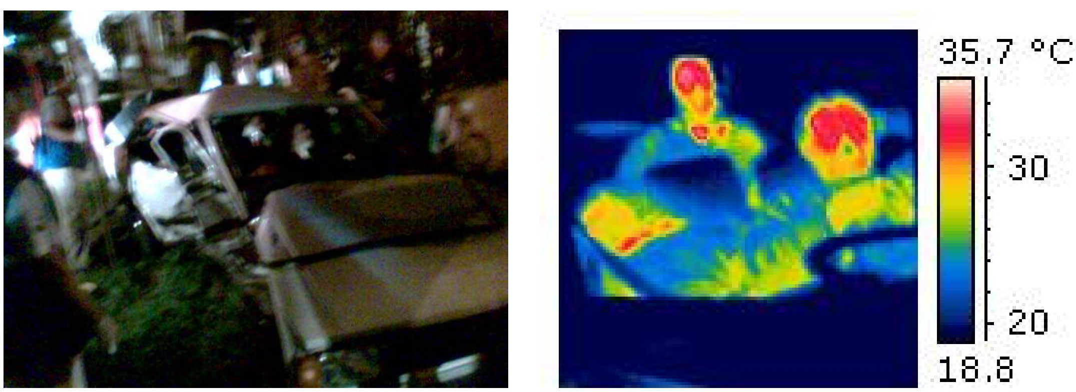

Figure 5. IR image applied to triage of traffic accident victims shows abnormal cooling of the victim on the left.

Another fascinating application revealed by IR imaging in this study was the ability to identify peripheral veins to rapidly establish intravenous access especially in children at severe hemorrhagic shock as shown in Figure 6.

Figure 6. IR image allows rapid identification of peripheral veins to gain intravenous access to child in severe hemorrhagic shock.

d) Disability: neurological status

In this phase infrared camera helped early identification of the cause of the lowering of level of consciousness as direct cerebral injury by contusion. Battle's sign, also mastoid ecchymosis, is an indication of fracture of the base of the posterior portion of the skull and may suggest underlying brain trauma. It consists of bruising immediately behind the ears. Another common bruising sign of a skull injury is raccoon eyes, the purplish discoloration around the eyes following fracture of the frontal portion of the skull base. Infrared imaging demonstrated these signs early before the bruising appears or before the patient present unconscious (ex. lucid interval of acute epidural hematoma).

e) Exposure/Environmental control

In this phase, the patient was completely undressed, usually by cutting off the garments. This helped the team to find occult lesions by infrared imaging. It is imperative to cover the patient with warm blankets to prevent hypothermia in the emergency department. Intravenous fluids should be warmed (40-42 °C) and a warm environment maintained. The IR camera was used to check the central temperature of the patient (tympanic and front head regions), intravenous fluids and the ambient. Patient privacy was maintained while exposed by closing curtains inside the ambulance unit.

f) Fractures

Trauma patients with long bone fractures induce a cascade of events which eventually lead to repair and homeostasis. This repair or wound healing involves three phases. The first phase, inflammation , is followed by tissue regeneration and tissue remodeling. The inflammatory response is primarily intended to be a local response and provides protection for the host. It is characterizes by classical clinical features such as rubor (redness), tumor (swelling), calor (heat), dolor (pain) and function laesa (loss of function).
Tissue damage surrounding the fracture will lead to disruption of blood vessels, thereby activating the coagulation cascade. Besides clot formation, coagulation induces the production of vasoactive, pro-inflammatory agents and activation of the complement cascade. Production of these mediators leads in turn to increased blood vessel permeability, local increased blood flow, induction of the expression of adhesion molecules and recruitment of cells into the site of inflammation. Of the various types of leukocytes that appear in the injured area (neutrophils, monocytes, lymphocytes, macrophages) that produce cytokines and growth factors.

Thermography was a valuable adjunct to fracture diagnosis method as an early detection of soft tissue inflammation around it. It is particularly useful for the assessment of the bone regeneration as well. There is a direct correlation between the trauma intensity (fracture grade) and thermal indices as can be seen in Figure 7, in this case of left distal femur fracture with increased local temperature.

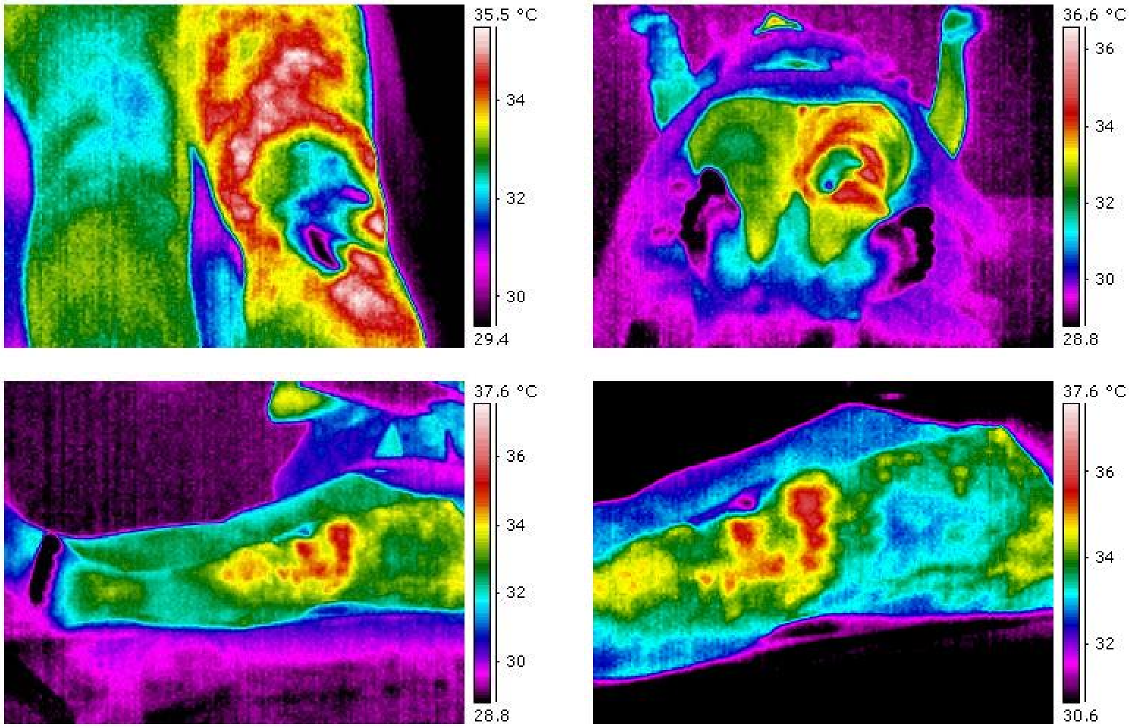

Figure 7. IR images of left distal femur fracture showing increased local temperature.

g) Spinal cord trauma

Patients with severe high level spinal cord injuries present hot lower body extremities at trauma scene due to the massive vasodilatation occurring below the level of the injury which is attributed to a quickly decreased level of sympathetic activity. High spinal cord injury impairs thermoregulation because it disconnects the thoracic cord from central thermoregulatory centers thus preventing central control of cutaneous blood flow, sweating, piloerection and shivering. Above we documented a cervical trauma caused by diving into shallow sea water. This is the major cause of spinal cord trauma. He was attended at the beach.

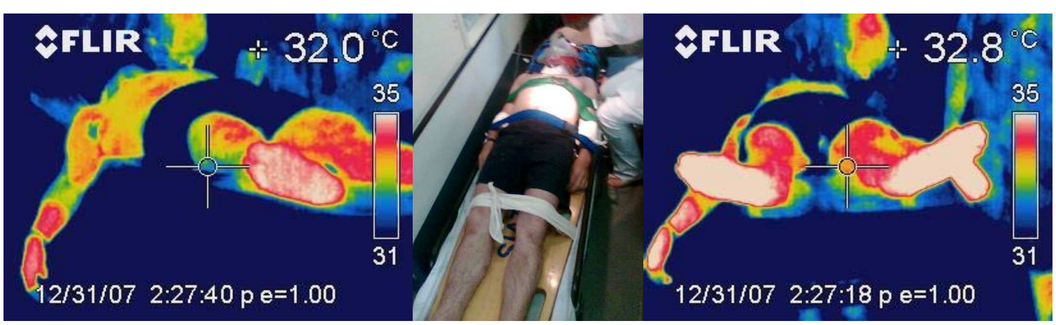

Figure 8. IR images show abnormal heating of lower extremities due to spinal cord injury.

h) Vascular trauma

Diminished or absent pulse is not a sensitive prognostic sign, as up to 25% of patients with major vascular injuries requiring repair have normal pulses distal to the injury. In this case infrared imaging helped identify foot low perfusion after tibia fracture although there was a palpable dorsal foot artery pulse as seen on the image as a hot spot at its topography. After fracture stabilization by repositioning, the flux return to normal and the foot becomes warm with a good perfusion. Because the inflammatory process of the fracture, its blood flow is greater than the non-injured contralateral foot.

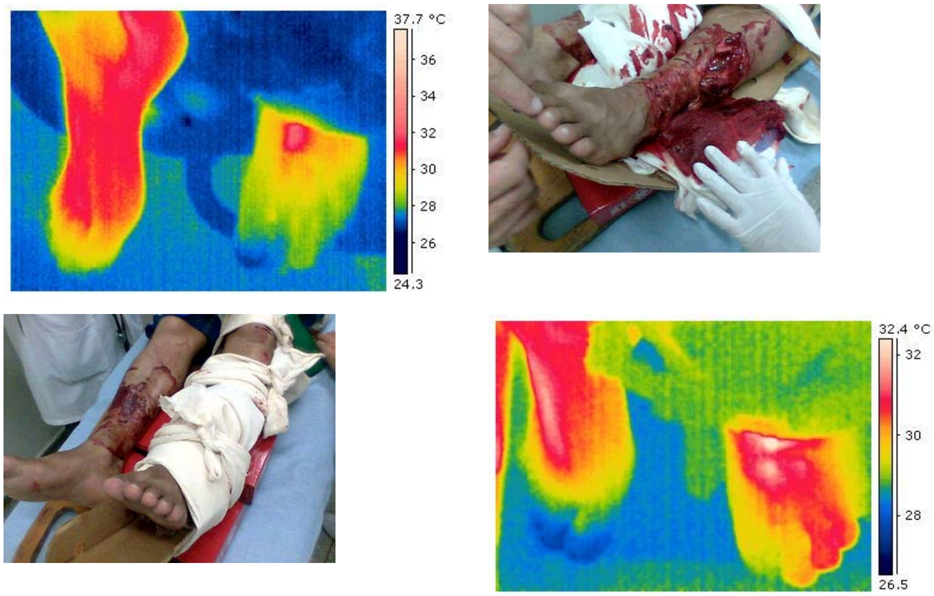

Figure 9. Top left IR image shows low blood flow to the left foot due to tibia fracture. On repositioning the fracture normal perfusion is restored and the left foot becomes warmer than the right due to inflammatory process as shown in the lower right IR image.

PEDIATRIC EMERGENCY

Hypothermia is associated with increased mortality and morbidity, with a dramatic decrease in survival at core temperatures below 34 °C. Almost two thirds of trauma patients had a core temperature of less than 36 °C. Trauma in itself, as well as bleeding with tissue hypoperfusion, alters thermoregulation and results in hypothermia. Some of the preventable factors that contribute to the high incidence of hypothermia in the trauma population are prolonged exposure in the field and administration of cold intravenous fluids. Hypothermia, together with acidosis and coagulopathy, has been identified as a component of the “lethal triad” in injured patients. Figure 10 shows monitoring by infrared imaging a hospital transference of a newborn to a pediatric intensive care. The newborn maintained his temperature during the transference.

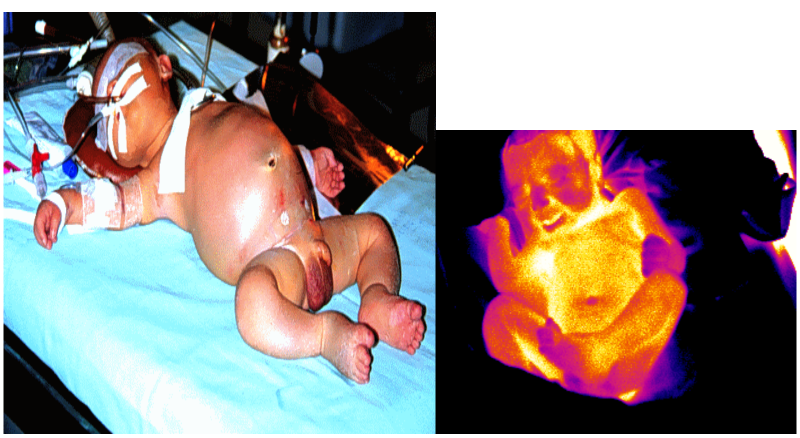

Figure 10. Normal IR image of a monitored newborn undergoing hospital transfer.

DISASTER PLANNING

A disaster occurs somewhere in the world almost daily. A recent group of disasters, starting with the September 11th terrorist attacks and continuing through the tsunami affecting countries throughout the Indian Ocean, the South Asia earthquake in Pakistan, and the 2005 Gulf Coast hurricanes have focused people's attention upon this topic.

Fewer than 10 disasters in US history have resulted in more than 1000 fatalities. The vast majority of major events have resulted in fewer than 40 fatalities. According to data from the Centers for Disease Control, the September 11th attacks caused 2819 deaths. Compared with 44,065 deaths from motor vehicle accidents in 2002, this number is small. However, the dramatic nature of disasters, with a relatively large death toll and psychological impact for a short time period can overwhelm an unprepared health and response system. Disasters are classified in natural (hurricanes, earthquakes) and technological (human-made) disasters (fires, toxic spills, nuclear mishaps). Other incidents with potential for mass casualties and disaster include war and terrorism. Since the 9/11 attacks on the World Trade Center in New York City, terrorism has become a major focus of disaster response and preparedness.

Infrared imaging can help in the triage phase. The concept of triage involves providing the most help for as many as possible. The definition of triage is "the process of prioritizing sick or injured people for treatment according to the seriousness of the condition or injury". Medical personnel are accustomed to providing extensive, definitive care to every patient. When confronted by numerous patients simultaneously in a disaster situation, it is easy to become overwhelmed, even for an experienced disaster worker. Triage must occur at multiple levels, and patients must be reassessed during every step of the process.

During a mass casualty incident, many injured people must be helped in a quick and efficient manner. A useful triage system efficiently chooses the order in which individuals are sent to the hospital. An effective system also distributes limited medical resources in a manner that helps as many people as possible. At a disaster scene, it is critical that patients are correctly diagnosed, monitored, and located to ensure the preservation of the maximum number of lives. Unfortunately, the current systems use paper triage tags that inefficiently monitor and locate patients during mass casualty situations.

HEART ATTACKS

1.5 million heart attacks occur in the United States each year with 500,000 deaths. A heart attack occurs about every 20 seconds with a heart attack death about every minute. About 50% of deaths occur within one hour of the heart attack –outside a hospital. There is a only a 6% to 9% early mortality rate from heart attack for those who survive long enough to reach the hospital. Getting to the hospital quickly is the goal. Deaths from cardiovascular diseases in women exceed the total number of deaths caused by the next 16 causes. Costs related to heart attack exceed 60 billion dollars per year. Coronary heart disease is America's No. 1 killer. Stroke is No. 3 and a leading cause of serious disability.

Infrared thermography was used to measure and map precordial skin temperature in patients who suffered acute chest pain. All of them were confirmed coronary artery disease (CAD) in the hospital by angiography. The presence, mean area and degree of thermal asymmetry were significantly greater in patients with CAD compared to normal. The results demonstrate that CAD is associated with precordial thermal asymmetry. This resulted in a more fast diagnosis, conduct and transport of these emergency patients.

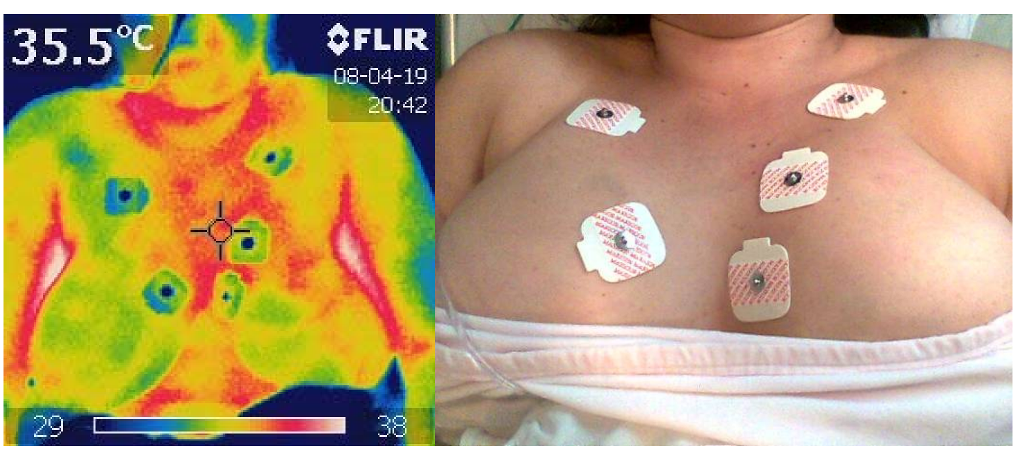

Figure 11. IR image shows asymmetry and abnormal warming in patient with coronary artery disease.

STROKES

Stroke is the third leading cause of death in America and the No.1 cause of adult disability. Many strokes are preventable and treatable with prompt medical attention. The cutaneous vessels of the medial forehead, medial canthus and supraorbital ridge are branches of the internal carotid artery. Under normal circumstances, there is a remarkable symmetry in the heat patterns from these regions. However, when the lumen of the internal carotid artery is significantly compromised, blood flow through these terminal branches is reduced and cooling of the forehead on the side of the lesion can be detected. Associated with unilateral body IR hyporadiation, as it can be see above, it confirmed the acute carotid occlusion.

Thermography had its greatest use in detecting carotid occlusive disease among a group of high-risk, asymptomatic patients. Such patients include those with hypertension, diabetes and hyperlipidemia. Thermography was helpful to the physician to better interpret early the symptoms of cerebrovascular insufficiency making a quickly triage and assistance.

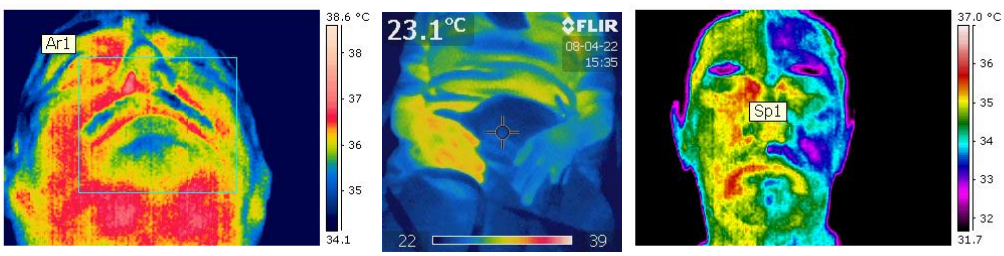

Figure 12. IR images show cerebrovascular insufficiency indicating early symptoms of carotid occlusive disease. Left is thermal asymmetry in the face, center asymmetry in arms and hands and right another facial thermal asymmetry.

MIGRAINE

"Cold patches" in the front head region (carotid territory) are associated with vascular-related headaches. The vascular "cold patch" must be included as a diagnostic aid to vascular headache. Too frequently the diagnosis of headache has been subjective and treatment has failed because some subtle secondary vascular component has been missed. For example, scalp muscle contraction headaches have been treated without success until a vascular component has been considered. With the inclusion of thermographically isolated "cold patches," these omissions can more often be avoided.

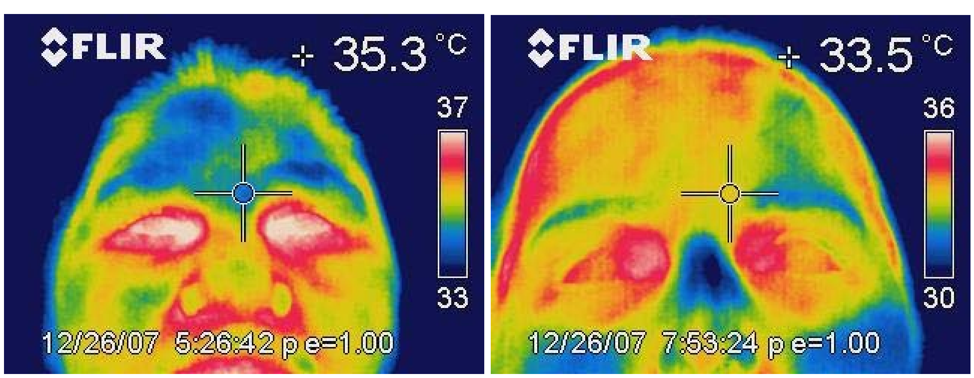

Figure 13. IR images of forehead show vascular cold patches indicating vascular headache.

ACUTE ABDOMEN

The patient with acute abdominal disease is occasionally highly problematic to the examining physician. Thermography is a useful supporting aid to classical methods of examination in the clarification of the problems of acute abdominal disease. In this case we documented a man with acute abdominal pain spread at the floor. The infrared imaging documented a high abdominal temperature, that after was identified as a peritonitis caused by a perforated appendix.

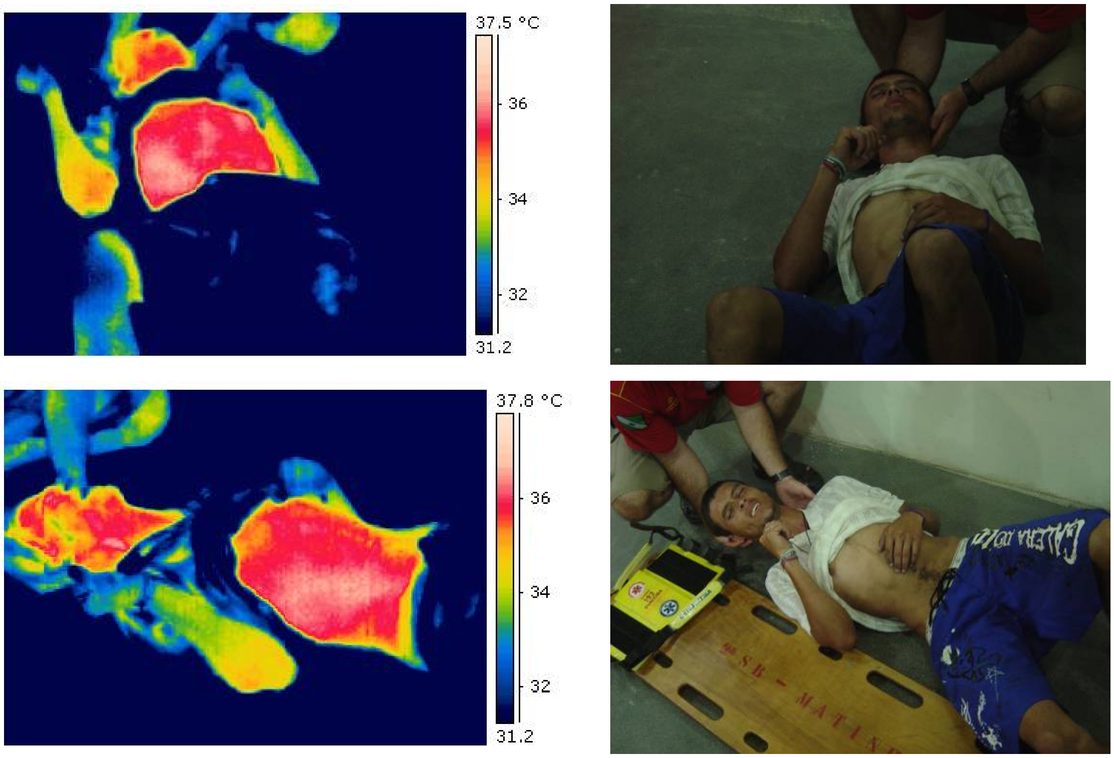

Figure 14. IR images show abnormal warming on lower right quadrant of abdomen, later found to be peritonitis caused by a perforated appendix.

DISCUSSION

Infrared imaging identified different features at traumatic and non-traumatic emergency that can serve as triage information and patient monitoring.

Several authors described this would be a useful piece of equipment in the accident and emergency department as spinal cord injury (Laird, 2006), proximal femoral fracture (Samokhin, 2004), deep venous thrombosis (Kohler, 1998), burn wound depth (Liddington, 1996), scafoid fractures (Hoise, 1987), stress fractures (Devereaux, 1984), whiplash, snake bites, cardiac arrest, stroke, headache and pneumothorax. This is the first documentation of IR imaging as a pre-hospital tool for emergency applications.

The thermal sensitivity and quality engineering of the FLIR IR camera used in this study allows application in an uncontrolled thermal environment, permitting prompt diagnosis and medical management. It was possible to see smaller temperature differences and consequently get sharper diagnostic images. The uncooled FPA detector produces highly sensitive thermal images that allow its use at outside emergency care by physicians and paramedics. It didn't interfere with the professional triage and treatment of the victims with life-threatening conditions due to its low weight, size and ergonomic design.

Infrared imaging is a simple and quick technique that inclusively can be used at night and other situations where visibility is poor. It is painless, passive and non-contact. There are no side effects and no exposure to radiation. The degree of false positive and false negative results is proportional to the experience of the operator and his knowledge of infrared physics, familiarity with the instrumentation and knowledge of the anatomy and physiology of the area being examined. In this study it was not possible to evaluate this because the insufficient statistical number of same cases and controls.

With a life-threatening emergency, the survival of a victim often depends on both professional medical help and the care of people around can provide. People will have to use their best judgment, based on knowledge of their surroundings, knowledge gained from the first aid & safety courses, and other training they may have received to make the decision to attend as showed in this paper, the training in Clinical Thermology and Infrared Imaging Diagnosis in emergency and trauma care.

When a new technology is introduced into the emergency response arena, it is important to note its limitations as well as its capabilities. Due to the chaotic nature of emergencies, our system faces the difficulty of operating in situations that challenge instrumentation designed for use in the controlled environment or clinical situations. Interpreting infrared images becomes more difficult in the presence of artifacts and confounding effects caused by bad weather days, ambient heat loss, heavily clothed, damp and soaked individuals that can introduce error to the inexperienced and untrained user.

CONCLUSION

In conclusion, we have presented a system that informs the risk situation of an emergency victim by different neurovascular thermal cutaneous features.

Infrared imaging can efficiently prioritize the order in which individuals are sent to the hospital. Infrared imaging is an effective system that also distributes limited medical resources in a manner that helps as many people as possible. At a disaster scene it could be critical for multiple victims' triage. These infrared imaging techniques should be applied in emergency medical systems.

Thermography is a simple, quick and inexpensive technique. It is painless, there are no side effects and no exposure to radiation. The authors conclude that this would be a useful piece of equipment in the accident and emergency department by a trained professional.

REFERENCES

1. Llewellyn CH. The role of telemedicine in disaster medicine. J Med Syst 1995, 19:29-34.
2. Garshnek V, Hassell LH, Davis HQ. Telemedicine: breaking the distance barrier in health care delivery. AIAA Student J 1997, 35(1):2-8.
3. Reid FDA, Cook DG, Majeed A. Explaining variation in admission rates between general practices: cross sectional study. BMJ 1999, 319:98-103.
4. Rosenberg AL, Hofer TP, Hayward RA, Strachan C, Watts CM, Bartlett RH. Admission source predicts surgical CIU outcomes: implications for tertiary referral centers. Anesthesiology 2000, 3A:B7.
5. Norwood S, Fernandez L, England J. The early effects of implementing American College of Surgeons Level II criteria on transfer and survival rates at a rurally based community hospital. J Trauma 1995, 39:240-245.
6. Calman K. Developing emergency services in the community. The final report. London: NHS Executive; 1997.
7. Laird AS, Carrive P, Waite PME. Cardiovascular and temperature changes in spinal cord injured rats at rest and during autonomic dysreflexia. J Physiol. 2006 1; 577(Pt 2): 539–548.
8. Samokhin AV. Diagnostic evaluation of patients during treatment of fractures in the proximal region of the femur. Lik Sprava. 2004 Mar;(2):42-6.
9. Kohler A, Hoffmann R, Platz A, Bino M. Diagnostic value of duplex ultrasound and liquid crystal contact thermography in preclinical detection of deep vein thrombosis after proximal femur fractures. Arch Orthop Trauma Surg. 1998;117(1-2):39-42.
10. Liddington MI, Shakespeare PG. Timing of the thermographic assessment of burns. Burns. 1996;22:26–28.
11. Hosie KB, Wardrope J, Crosby AC, Ferguson DG. Liquid crystal thermography in the diagnosis of scaphoid fractures. Arch Emerg Med. 1987 June; 4(2): 117–120.

12. Devereaux MD, Parr GR, Lackinan SM. The diagnosis of stress fractures in athletes. JAMA 1984, 252, 531-3.
13. Lawson W, BenEliyahu D, Meinken L, Chernilas J, Novotny H, Cohn P, Dervan J.Infrared thermography in the detection and management of coronary artery disease. Am J Cardiol. 1993 Oct 15;72(12):894-6.

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Dr. Brioschi is President of the recently formed Pan American Thermology Society, a fusion of Brazilian Thermology Society and American Association of Thermology. In the future, this association will be joining all new medical thermology societies of America. For more information on the Pan American Thermology Society visit their website at *www.termologia.org* .