Mass Screening for Infectious Disease Containment and Pandemic outbreaks - Misconceptions.

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ABSTRACT

IR imaging in mass screening for the containment of pandemic disease is based on detecting a febril (fever) state in individuals.
The ability to use IR affectively for this is dependent on a good understanding of the physiology and physics related to the pathology that we are trying to screen for and is not restricted to temperature measurements alone. The radiometric thermal data processed during real-time imaging must include calibrated reference sources, thermal pattern recognition and comparative analysis between individual people being screened.
A screening test should have high 'sensitivity' rather than 'specificity' and to be effective the false negative rate must be very low. To achieve this the false positive rate will be higher by necessity and so a 'secondary' level of screening can be implemented to bring the false positive rate to within a manageable level by the higher 'specificity' secondary level of screening.

Keywords: fever, mass-screening, pandemic, contagious disease, Ebola, containment.

1. INTRODUCTION

This paper discusses the physiology of fever screening, experience based operational protocols (operational problems and challenges), software assisted systems, operator / technician training and the future of IR screening as part of containment strategies for pandemic outbreaks.

2. PANDEMIC DISEASE

2.1 Pandemic diseases have occurred throughout history and will continue to cause loss of life, economic harm and varying challenges to individual countries as well as the human race in general.

The first recorded pandemic disease was in 430 BC. when typhoid fever killed a quarter of the population of Athens and led to the fall of Athenian dominance in the region.

Before modern transport and ease of intercontinental travel, pandemic outbreaks of disease was limited by natural 'containment' as the hosts of the disease either recovered after the infectious stage or died before spreading the disease.

Outbreaks of Bubonic plague, Smallpox and Black death in the medieval period accounted for up to a 50% reduction of populations during outbreaks. Pandemic outbreaks of disease have continued throughout history on a regular basis with many outbreaks in this century causing deaths in the multi millions.

2.2 There are a number of diseases (old and new) that currently have the potential to evolve into serious pandemic outbreaks that could be difficult to contain. Various viral influenzas have a long history of mutation and evolvement with the help of 'zoonoses' (cross species infection and spread by host carriers), examples include spread by birds, pigs and companion animals.

2.3 Viral hemorrhagic fever (Ebola being one type) is highly contagious, but has a relatively short incubation period and a high mortality rate which actually helps with containment.

Additional challenges present for containment when genetic mutations occur in any disease so planned strategies for containment will always be the first step for control.

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3. THERMO-PHYSIOLOGY

3.1 Thermal imaging detects skin temperature which is produced by microdermal bloodflow which in turn is controlled by the body's autonomic function responsible for core temperature control.

The temperature of the skin will be cooler than the normal core temperature of 37°C (98.6°F) in a healthy subject, but there is no normal skin temperature that can be used to detect fever as temperatures can vary greatly in relation to ambient temperature and many other factors.

Skin blood flow and the associated surface temperature is part of the body's core temperature regulatory function and responds continually in order to maintain core temperature stability.

3.2 The range of 'normal' skin temperature can be very wide, commonly between 20°C and 30°C dependent on regional climate and ambient conditions.

The skin is almost a perfect black body with close to 100% emissivity and the peak emissivity of the human body is 10 µm, also the body has a relatively low temperature range (normally within 8°C) which provides the opportunity for not only high sensitivity but also higher specificity if the detection parameters are targeted correctly, so thermal imaging has the potential for high sensitivity detection of disease.

4. MISCONCEPTIONS

4.1 Core temperature cannot be accurately evaluated by measuring skin temperature. There is no conduction of core temperature past the subcutaneous level (blood flow conducting heat).

The microdermal (skin) blood flow is a function of core temperature regulation, which is controlled from the central nervous system (sympathetic).

4.2 A febril (fever) state will not always produce elevated temperatures at the skin surface. An autonomic (sympathetic nerve) response to a pathology is necessary to affect skin temperature.

4.3 Thermal imaging does have the potential to detect developing pathology related to non symptomatic disease before inflammatory symptoms are produced.

4.4 A significant number of symptomatic fevers with elevated core temperature will produce decreased skin temperatures due to perspiration (evaporative cooling).

4.5 It is not sufficient to screen travelers with threshold alarms for hyperthermia alone, duel threshold alarms above and below the normal limits should be employed to include detection of hypothermia.

4.6 Radiometric Screening for an absolute temperature threshold, with or without an internal or external temperature reference source (black body) is limited and is dependent on the skill and attention of the technician. The level of false positives produced when setting a manual threshold generally results in technicians setting the threshold higher to reduce the false positives rate. This will increase the potential for false negative findings which renders the screening ineffective.

4.7 The highest sensitivity and specificity is produced when a combination of comparative analysis of all subjects being screened is used to establish a threshold and continually calibrate that threshold along with pattern recognition and abnormal gradients.

5. DETECTION of FEVER

5.1 A subject will become febril when most contagious diseases become symptomatic.

The radiometric thermal data processed during real-time imaging must include calibrated reference sources, thermal pattern recognition and comparative analysis between individual people being screened (for dynamic and agile adjustment of threshold alarms).
A screening test should have high 'sensitivity' rather than 'specificity' and to be effective the false negative rate must be very low.

To achieve this the false positive rate will be higher by necessity and so a 'secondary' level of screening should be implemented to bring the false positive rate to within a manageable level by the higher 'specificity' secondary level of screening.

5.2 The utility and justification for using thermal imaging for the detection of fever during pandemic disease outbreaks is based on proactive and preventative strategies aimed at containment.

Thermal imaging as a fever screening tool is used as a first level mass screening test that is sensitive and accurate at identifying any individuals that exhibit abnormal thermal findings that may indicate a systemic fever.

5.3 The first level screening (primary screening) should cause little or no inconvenience or interruption of movement for the majority of people being screened.
At point of entry (POE) screening in airport environments our statistical experience has been that 2.2% (22 people in every 1,000) will generate a positive alert.
Of the 2.2% positives, secondary screening will show that 82% of these are 'false positives' for a febril state (systemic fever) and the remaining 18% (4 people in a thousand) will have a systemic fever.

In almost all cases the positive subjects are diagnosed with non pandemic diseases and infections but the important fact is that any symptomatic (and in most diseases) infectious people are identified.

The 'false positives' (individuals who are cleared at the secondary screening) are made up of local inflammatory conditions such as dental infection, sinusitis, dermatitis, hormonal dysfunction (such as hot-flush) and simple artefacts such as drinking hot drinks or recent sunburn.

5.4 The additional benefits of covering POE's with thermal fever screening for containment of infectious disease are:

1 Reassurance for other travellers and populations at risk of exposure.
2 Deterrent to individuals considering traveling with undiagnosed symptoms of fever
3 Flexibility in escalation of screening protocols due to level of risk. (level of screening)

The opportunities for deployment of screening include:

Airports and border checkpoints
Docks and ferry / cruise terminals
Points of entry / Points of exit
Hospitals
Military bases
Government buildings
Any large gatherings / conferences / meetings in public places.

Challenges / Risks
Variable Incubation periods of highly contagious virulent strains would be health risk to operators.
Protective clothing and safety protocols should be observed (WHO advisements).

6. PROTOCOLS

The design for thermal imaging to be affective for fever screening is dependent on a good understanding of the physiology and physics related to the specific pathologies that we are trying to screen for and is not restricted to temperature measurements alone. The technology must be simple and easy to install and operate as deployment is often at short notice and personnel generally will not be trained thermography technicians.

6.1 **Screening station set-up:**
The station should be set-up as close to a point of entry (POE) or entry into terminal as possible.

An area of minimal reflected infrared should be chosen. Infrared sources including all incandescent, halogen, or any other heat producing lighting should be avoided if possible, infrared producing lighting affecting results in the field of view (FOV) should be replaced with non IR producing lights or screened off from the camera FOV.

The ideal temperature for the screening area is 21°C on a physiological basis but in most cases this will not be practical or achievable.
Good results can still be achieved with any ambient temperatures between 19°C and 27°C but reliable data can be achieved in temperatures up to 35°C if temperature range of detection is reduced from 8 °C to 5 °C and the threshold alarm is reduced (inevitably producing increased false positives).

Air conditioning should not blow cold air directly onto the subjects being scanned, (if cold air can be felt on the face, air conditioning ducts should be moved or baffled to diffuse or divert the air from the persons being scanned.

A plain, non reflective background (wall or partition) should be behind the subjects for best results.

The focal length from subjects to scanner should be between 2.5 m (8ft) and 5 m (16ft). Optimum distance for sensitivity and specificity is 3 m (10ft).

The IR camera should be mounted slightly above passenger head level and angled slightly down in order to bring a sufficient number of passengers into the field of view for first level mass screening (average of 10 passengers within the screen view at the choke point or optimal screening distance is recommended).
Children can be carried or stand with parent. Wheelchair passengers and females with total head covering should proceed straight to manual temperature measuring station.

6.2 **Second level screening protocols:**

Travelers undergoing second level screening (secondary imaging normally restricted to first level positives) should be advised to remove eye glasses and masks if any (for higher definition, sensitivity and specificity)
The minimum required area of the face that must be uncovered is from above the eyebrows to below the nose.
For secondary screening the passengers should look straight ahead (or at the camera) and stop briefly in a designated area.

6.3 **Travelers information and compliance:**

Travelers should be pre advised that the scan is non radiation and has no risk. This is best done at the time travellers are given a risk questionnaire (if in use) before scanning or can be posted on a notice board at the screening station).

Travelers should be controlled / managed as they approach the scanning area so they pass at a reasonable speed and density.
For any secondary screening it is beneficial for travellers to observe other passengers being scanned in order to know what to do…… better compliance.

For secondary screening a square area should be marked out on the floor which passengers can stand in to be scanned. This positions the individual or group of travellers correctly. (Coloured tape can be used but the best method is to use crowd barriers or portable gates).

A line on the floor for travellers who have been diverted from the primary mass screening to wait at should be made on the approach to the secondary scanning area so travellers are close by and ready to step into the square for scanning, saving time (make sure that the FOV does not include waiting traveller).

The travellers being scanned as a secondary test are told to remove any eye glasses or surgical masks and look straight ahead for the couple of seconds while they are being imaged.

As soon as the imaging has completed, the traveller or group of travellers can be dismissed (provided the result is within normal limits) and the next traveller or group of travellers are directed to stand in the imaging area.

A designated member of the screening team should be assigned to traveller management and compliance control.

Technician conduct: Courtesy at all times.
The process of screening should not cause concern or distress. (answer travellers questions)

6.4 **Technical set-up:**

Make sure that focus is optimum for field of view (FOV).
It is good protocol to set up and run system at least ten minutes before screening (regardless of thermal accuracy stabilization start-up time).
Set the threshold alarm to 1 °C above normal (evaluated by screening test subjects at the location to find 'normal') and test threshold alarm with a known target temperature source (cup of fluid with digital thermometer at 37 °C will suffice if an external black body source is not available)
Test threshold setting with at least 3 people as test subjects.

Set the colour scale to a visible threshold using an isotherm scale (most popular is red above the threshold and greyscale below).
There can be a wide range of normal temperature between passengers, dependant on sex, metabolism and many other factors but average skin temperatures in a comfortable ambient environment will range between 30 °C and 36 °C .

Make sure that:
Temperature 'RANGE' is set to 8 °C.
Threshold alarm is set between .5 and 1 °C of tested normal (dependant on conditions at location and sensitivity required).

Advisory: The threshold alarm will need to be closely monitored and adjusted by the operator at regular intervals if no automatic threshold calibration linked to an internal or external temperature source is used.

6.5 **Peripheral equipment:**

A digital thermometer to measure ambient temperature.
Gloves and masks for screening team as per WHO guidelines. (any passenger testing positive should immediately be asked to wear an approved (N95) mask.
A hazardous materials bin should be available for disposal of tympanic thermometer covers and any other material considered potentially infectious.
A tape measure for measuring focal distances (fine tuning is done by using images as guide).

7. LIASON WITH MEDICAL STAFF

Procedures should be in place for processing travellers that test positive for fever or have other abnormal thermal findings.
The risk level for conducting health screening that is in operation at the time will dictate the action to be taken by the thermography technician.
The technician should be aware of the protocols and procedures that are in force for handling travellers that test positive.
Documentation of each individual tested positive should be recorded, at minimum, full name and the time and date of testing as well as travel information such as flight / rail / road and where journey originated.

Travelers testing positive should be referred for clinical evaluation. Arrangements for taking the positive traveller to the clinical facility for additional testing should be in place and known to the thermography technician. Any traveller testing positive should immediately be asked to wear an approved (N95) mask.

In most cases the clinical professional responsible for examining travellers with potential fever will be located at or close to the secondary screening station for convenience and will make the decision regarding escalation.

8. IMAGE INTERPRETATION GUIDELINES

Interpretation of secondary scan results:
(This applies to saved images of individuals who have tested above the threshold alarm)
Only health professionals with the appropriate scope of practice should use the thermal results as an adjunct to clinical evaluation.

Images of positive findings that are going to be clinically evaluated should be saved in a standard clinical color scale with 16 contrasting colors in an 8 °C temperature range.

The majority of normal baseline face images will be in the green range with some percentage of yellow and orange, there is normally increased temperature around the medial eyes which may show as red or even white but this is localized and does not affect the average temperature significantly.

The region of the face used for statistical analysis is from below the hairline and above the eyebrow to below the nose and above the mouth.
When setting a secondary threshold it is important to keep the statistics box within the boarder of the face so only body temperature is included and not the temperature of the background behind the passenger.
If a region of interest statistical analysis is performed the average temperatures should be between 27°C and 36°C. **The maximum temperature seen in the statistics does not signify core temperature.**

Statistical analysis with an average temperature of over 36 °C should be considered suspicious and that passenger should be referred for clinical evaluation which will include objective core temperature measurement.

Pattern recognition is important, increased patterns of red or white throughout the face is suspicious. A 'mottled' appearance of the reds and whites throughout the face, particularly around the nose eyes and forehead are suspicious and justify performing statistical analysis and or proceeding to clinical evaluation.

Hypothermia can be just as suspicious as hyperthermia. A passenger who is perspiring will present as significantly cooler, normally in the blue range of colour. (this is due to evaporative cooling effect). These findings should also justify progression to clinical evaluation.

There should be minimal false positives at the secondary screening level as a febril subjects will present with an obviously different thermal signature than the majority of comparable fellow travellers.

Travellers with local pathology affecting the face generally do not produce a suspicious result as do subjects with systemic pathology.
Some local pathologies can include dental or periodontal infection, sinusitis and headache. Systemic pathologies can include autonomic dysfunction, hormonal changes, thyroid dysfunction and all other systemic diseases. (pregnancy will also cause increased core temperature of one degree).

It may be within the scope of the thermography technician to perform a tympanic temperature measurement to correlate with thermal findings that are within normal limits but if thermal findings are suspicious a normal tympanic temperature should not prevent the escalation to clinical evaluation.

9. CURENT KNOWLEDGE AND EXPERIENCE

Our current knowledge and experience of fever screening has evolved significantly since the 2002 Severe Acute Respiratory Syndrome (SARS) outbreak which was followed by a number of other pandemics such as H5N1 (Avian Flu), H1N1 (Swine Flu) and Coronavirus infections, all of which contributed to our experience based screening and operational protocols (operational problems and challenges), as well as software assisted systems and operator / technician training.

We have been given the opportunity to practice our methods of containment and response with these (so far) relatively low grade viruses but it is inevitable that we will eventually encounter new and more aggressive strains of virus that will demand more serious responses. The current Ebola outbreak with its virulent 'zaire' strain is giving healthcare professionals an opportunity to implement and adapt strategies for containment and management of serious future pandemic outbreaks which will be inevitable.

10. SUMMARY

Applying an understanding of thermal physiology is an important factor in the design and deployment of a fever screening system that will be affective in detecting disease.

Travel is the key to containment of pandemic outbreaks of disease.
We can't stop all travel to contain outbreaks otherwise the economies and infrastructures of the world would grind to a halt. We can take precautions to make travel safer and reduce the risk of spreading disease, particularly in high risk regions, and thermal imaging has shown great potential as a fast, sensitive, non-invasive way of conducting both primary mass screening as well as secondary clinical screening.

The basic infrastructure for travel security screening is already in place, having been setup as a response to global terrorism. The addition of IR thermal imaging as a 'Health Security Screening' adjunct is a natural evolvement for travel choke points such as airport security and immigration, train stations, toll booths, ship and ferry embarkation points and many other locations where people pass through to travel.

The ongoing future of IR screening as part of containment strategies for pandemic outbreaks is established but will continue to benefit and evolve from each new outbreak.

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