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An tÚdarás Um Fhaisnéis agus Cáilíocht Sláinte

Evidence summary for non-contact thermal screening as an effective means of identifying cases of COVID-19

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Key points

- Thermal screening, typically including a combination of fever screening with the self-report of exposure risk and or symptoms, has been used in infectious disease outbreaks with the aim of improving detection and reducing the time to isolation for infected individuals.
- Thermal screening is only effective in the identification of febrile symptomatic cases. However, not all cases of COVID-19 present with fever and a substantial proportion are asymptomatic (never symptomatic); approximately 25% of symptomatic cases never develop a fever. Moreover, some cases may evade detection due to mild clinical symptoms or other confounders, such as the use of antipyretic medicines. Therefore, fever screening may not identify a large proportion of potentially infectious cases.
- SARS-CoV-2 cases are infectious even if pre-symptomatic or asymptomatic, however, the duration of infectivity is still uncertain. Approximately half of all SARS-CoV-2 cases are due to pre-symptomatic transmission, with a current unknown proportion caused by asymptomatic transmission.
- For this summary, 11 primary studies, three rapid reviews and one systematic review provided evidence on the effectiveness of thermal screening for identifying cases during the COVID-19 and other respiratory virus pandemics.
- All 11 studies identified were conducted in the context of points of entry (for example, airports), with thermal screening procedures typically including a combination of fever screening and self-report of exposure risk or symptoms.
- One cross-sectional study and two epidemiological modelling studies were conducted in the context of the COVID-19 pandemic, the remaining eight studies were conducted during the Middle East Respiratory Syndrome (MERS-CoV) (n=1) and (H1N1) 2009 (n=7) pandemic.
- Evidence from the cross-sectional study conducted during the COVID-19 pandemic suggests that thermal screening is ineffective in limiting the spread of SARS-CoV-2 due to the presence of asymptomatic or pre-symptomatic cases. The two modelling studies estimated that approximately half of infected cases of SARS-CoV-2 would be identified using airport fever screening.

Key points continued:

- Seven observational studies that examined the use of thermal screening during the influenza A pandemic (H1N1) 2009 were identified. Detection rates were consistently low across all studies. Thermal screening procedures were ineffective in case identification due to the inability to discriminate between seasonal and pandemic influenza. However, limited evidence suggests that for the febrile patients detected during thermal screening, the time to isolation of cases may be reduced, thereby reducing the potential for community transmission.
- The findings of a systematic review and three rapid reviews were consistent with the primary studies, with thermal screening programmes found to be ineffective in the identification of cases of SARS-CoV, MERS-CoV, and pandemic (H1N1) 2009.
- A number of potentially beneficial effects of thermal screening at points of entry were identified in a systematic review, namely, discouraging travel of ill people, education and awareness raising, improvements in public confidence and reductions in the negative economic consequences associated with travel or trade restrictions.
- However, using thermal screening to reduce infection risk could result in a false sense of safety and it is noted to be high cost and resource intensive. Trained healthcare staff are finite resources in the context of COVID-19, and deployment to border control and health monitoring efforts has the potential to reduce the number available for other aspects of pandemic management.
- Evidence on the effectiveness of thermal screening contained within this summary was limited to points of entry; thus the applicability to other community settings is uncertain. Moreover, thermal screening was implemented as part of a composite of measures that included self-report of relevant symptoms, contact and travel history. This limits the ability to determine the effectiveness of thermal screening alone for case identification.
- Due to the high proportion of infectious cases that are asymptomatic, pre-symptomatic or have no fever, current evidence is insufficient to support the use of mass thermal screening at airports to effectively identify cases and limit the spread of COVID-19.

Evidence summary for non-contact thermal screening as an effective means of identifying cases of COVID-19

The Health Information and Quality Authority (HIQA) has developed a series of 'Evidence Summaries' to assist the Clinical Expert Advisory Group (EAG) in supporting the National Public Health Emergency Team (NPHET), as well as those developing infection prevention and control guidance in their response to COVID-19. These summaries are based on specific research questions (RQs). This evidence summary was developed to address the following research question:

> **Is non-contact thermal screening an effective means of identifying cases of COVID-19?**

Background

On 11 March 2020, the World Health Organization (WHO) declared the novel coronavirus (COVID-19) outbreak a global pandemic. As of 4 August 2020, there have been 18,142,718 and 691,013 laboratory-confirmed COVID-19 cases and deaths worldwide, respectively.(1) The most prevalent symptoms of COVID-19 are fever, cough and fatigue.(2) However, a systematic review published in June 2020 on the prevalence of symptoms in 24,410 adults diagnosed with COVID-19 reported that approximately 25% of adults who tested positive for COVID-19 never had a fever and less than 60% developed a cough. The authors concluded that the use of symptoms alone to screen for COVID-19 is likely to miss a substantial number of infected individuals.(3) Similarly, another systematic review also published in June 2020 concluded that a fever and respiratory symptoms should not be considered indicative of COVID-19 infection in children since about 50% of diagnosed COVID-19 cases in children are asymptomatic.(4)

During previous respiratory pandemics, for example, Severe Acute Respiratory Syndrome (SARS-CoV), Middle East Respiratory Syndrome (MERS-CoV) and influenza A pandemic (H1N1) 2009, mass temperature screening has been used with the aim of identifying patients with a fever and limiting the spread of the virus. Typically temperature screening has been implemented as part of a composite screening programme including questionnaire-based self-reporting of symptoms and or exposure risk in congregated settings, such as workplaces, hospitals, nursing homes, schools and points of entry (that is, airports and ports).(5) In March 2020, the WHO issued guidance on the *Management of ill travellers at Points of Entry (international airports, seaports, and ground crossings) in the context of COVID-19.*(6) This guidance covers detection of ill travellers at international points of entry, interview of ill travellers, reporting of ill travellers with suspected COVID-19 as well as isolation and referral of travellers with suspected COVID-19.(6) The guidance states that, if

temperature screening is the chosen method of screening, non-contact thermometers (handheld or thermal imaging cameras) should be used.[6]

While the Department of Health and the Department of Foreign Affairs in Ireland still advise that all non-essential overseas travel should be avoided where possible, a travel 'green list' has been developed based on the status of COVID-19 in certain locations. Individuals travelling from countries on the green list are exempt from the requirement to restrict movement, but should continue to adhere to current infection prevention and control measures. Those arriving in Ireland from locations not listed on the green list will be required to restrict their movement for 14 days after arrival in Ireland and will be required to complete a Passenger Locator Form. The green list is a dynamic list which will be reviewed and updated in accordance with changes in global virus transmission patterns. Since the original list of green list countries was developed, five countries have been removed from the travel green list. No recommendations are made in respect of thermal screening on arrival in Ireland.[7]

Conventional, clinical thermometers measure body temperature through coming into contact with skin (for example, under the arm or in the mouth); with oral thermometers being most accurate.[8] However, such thermometers may be associated with an increased risk of disease transmission due to the requirement for physical contact, and for operators to work in close proximity to those being screened. Non-contact temperature screening devices measure cutaneous (surface) body temperature and give an estimation of core body temperature. Such thermometers use infrared sensors, alleviating the need to sterilise them, thereby increasing the efficiency of mass screening of temperatures.[8] Typically, infrared thermal scanners are either stationary allowing individuals to walk through them and have their temperature recorded, or handheld; the latter may not allow the operator to maintain physical distance.[8] The aim of this summary is to review the evidence on non-contact thermal screening as a method through which to identify cases of COVID-19.

Methods

A protocol outlining the methodology for this evidence summary was developed by HIQA (available at www.hiqa.ie) and followed throughout its conduct. A systematic search of published peer-reviewed articles and non-peer-reviewed pre-prints was undertaken from 1 January 2000 up to 25 June 2020. This evidence summary considers the direct evidence of non-contact thermal screening for identifying cases of COVID-19 and other pandemic respiratory viruses. Indirect evidence from mathematical modelling studies is also included. Studies from identified systematic or rapid reviews were also screened for inclusion; the majority of which were excluded due to absence of laboratory-confirmed diagnosis of respiratory virus or use of contact thermometers (for example, oral or ear).

Results

A total of eleven studies were included in this summary.[9-19] All eleven studies were conducted[9-13, 15-17, 19] or simulated[14, 18] at points of entry (that is, airport or ports); no studies of non-contact thermal scanning in other settings, such as workplaces, hospitals, nursing homes or schools, were identified. One observational study[16] and two mathematical modelling studies[14, 18] were conducted in the context of the COVID-19 pandemic; the remaining studies were conducted during the influenza A pandemic (H1N1) 2009[9-11, 13, 15, 17, 19] (n=7) or MERS-CoV (n=1)[12] pandemics. Three studies were conducted in Japan,[10, 13, 19] two in Taiwan[11, 16] and one each in Australia,[15] China,[9] Indonesia,[12] Singapore,[17] the United Kingdom (UK)[18] and the United States of America (USA).[14] Where reported, the study population comprised adults and children. Appendix 1 provides an overview of the characteristics of studies included in this summary. In addition, one systematic review[20] and three rapid reviews[21-23] were identified and screened for relevant studies. An overview of the characteristics of these reviews is included in Appendix 2.

Evidence from studies conducted during the COVID-19 pandemic

Cases identified using thermal imaging systems with subsequent laboratory confirmation

One observational study that examined the use of non-contact thermal screening during the COVID-19 pandemic was identified.[16] Following the SARS outbreak in 2003, the Taiwan Centres for Disease Control (CDC) established infrared thermal imaging cameras in international airports. These are being used during the current COVID-19 pandemic whereby travellers with a detected fever or who self-reported respiratory symptoms must have oropharyngeal specimens (that is, the part of the throat that is at the back of the mouth) collected for COVID-19 testing and are subject to home quarantining for 14 days. No details were provided on how data on self-reported symptoms are collected.[16] All imported COVID-19 cases identified from open-access data and press releases concerning COVID-19 from Taiwan's Centres for Disease Control website from 21 January to 6 April 2020 were analysed in relation to infection characteristics, infection source, symptom presentation and route of identification.[16] Of the 373 COVID-19 cases confirmed in Taiwan between 21 January and 6 April 2020, 321 (86.1%) were imported.[16] Oropharyngeal specimens of those identified by screening were tested for COVID-19 using reverse transcription polymerase chain reaction (RT-PCR). Of the imported cases, 50.5% (n=162/321) had developed symptoms before arrival, of which 105 cases were identified by airport screening. The proportion of these identified on the basis of a fever alone was not reported. The authors did not report the total number of passengers who passed through airport screening or the number of febrile travellers

who were test negative. For those who were asymptomatic or pre-symptomatic on arrival (n=159), none were identified via airport screening (that is, had a detected fever or self-reported respiratory symptoms). Instead these cases were subsequently identified during home quarantine (39.6%), by contact tracing (28.3%) or were reported by hospitals (32.1%).[16] The authors highlighted that the reproduction number for imported cases identified via contact tracing or other identification routes was significantly higher than that of the imported cases identified through airport screening, and that early identification and isolation of cases limits transmission. The authors concluded that half the imported cases identified did not present with fever, body temperature screening at airports did not detect all cases that were symptomatic, and most cases were identified using an individuals' travel and contact history.[16]

Mathematical modelling studies

Two mathematical modelling studies that examined the use of thermal imaging during the COVID-19 pandemic were identified.[14, 18] These studies were conducted in the USA[14] and the United Kingdom (UK).[18] Gostic et al. used a previously published mathematical model, based on the natural history and epidemiology of COVID-19 and on possible combinations of departure and arrival screening policies, to determine the expected performance of different screening measures for COVID-19.[24] In summary, passengers pass through departure and arrival screening consisting of a symptom check (that is, detection of fever by thermal scanners or presence of cough) followed by self-reporting of exposure risk via questionnaires or interviews;[24] infected travellers can be detained in accordance with WHO traveller screening guidelines.[6, 25] Screened travellers fall into one of four categories: (i) symptomatic and unaware of exposure risk, (ii) aware of exposure risk and asymptomatic, (iii) symptomatic and aware of exposure risk, and (iv) asymptomatic and unaware of exposure risk. It should be noted that those in category (iv) are essentially undetectable while those in category (ii) can only be detected if they are aware of an exposure risk and willing to self-report it.[24] Using their mathematical model of screening effectiveness, and assuming adherence of all travellers with no active evasion of screening, Gostic et al. estimated that screening will detect less than half of infected travellers in a growing pandemic, and that the effectiveness of screening will increase slightly as the growth of the pandemic slows.[14] Under the most favourable assumptions (that is, one infection in twenty being asymptomatic and all travellers passing through departure and arrival screening) the median fraction of infected travellers detected is 0.34 (95% CI 0.20-0.50). Moreover, the total fraction detected is lower for programmes with only one level of screening (that is, entry or exit) and entry screening is preferable to exit screening as there is an increased possibility that symptoms may commence during travel.[14]

A second mathematical model, by Quilty et al., simulated 100 COVID-19 infected passengers who planned to board a flight, thus posing a risk of transmission to a new region.[18] Using different combinations of the duration of travel, sensitivity of exit and entry screening, proportion of asymptomatic infections, incubation period (time of exposure to onset of symptoms) and time from symptom onset to hospitalisation, the authors estimated the proportion of infected travellers likely to be detected by exit and entry screening (using thermal scanners and self-reported symptoms), develop severe symptoms during travel, or go undetected.[18] Under the assumptions of the baseline analysis: (that is, a duration of travel of 12 hours, sensitivity of exit screening 86%, sensitivity of entry screening 86%, proportion of asymptomatic infections (undetectable by typical screening procedures) 17%, mean incubation period of 5.2 days and mean time from symptom onset to hospitalisation of 9.1 days) the authors estimated that 44 (95% CI: 33–56) of 100 infected travellers would be detected by exit screening, no case (95% CI: 0–3) would develop severe symptoms during travel, nine (95% CI: 2–16) additional cases would be detected by entry screening, and the remaining 46 (95% CI: 36–58) would not be detected.[18] The authors conclude that exit or entry screening at airports for initial symptoms, via thermal scanners or similar, is unlikely to prevent the passage of infected travellers into new countries or regions.[18]

Evidence from studies from other respiratory pandemics

Observational studies of cases identified with thermal imaging systems and subsequently laboratory confirmed

Seven observational studies that examined the use of thermal imaging during the influenza A pandemic (H1N1) 2009 were identified.[9-11, 13, 15, 17, 19] In May 2009, during the pandemic (H1N1) 2009, thermal scanners were installed at all airports in, and points of entry to, China. Suspected cases were defined as an influenza-like illness (temperature ≥37.5°C and at least one of the following symptoms: sore throat, cough, rhinorrhoea, nasal congestion), and either a history of travel to a country where infection had been reported in the previous seven days or those in close contact with a confirmed or suspected case in the previous seven days). No details were provided on how data on self-reported symptoms or travel history were collected. All suspected cases and close contacts of suspected or known cases were quarantined for seven days during which time pharyngeal or nasopharyngeal swabs were collected and analysed using RT-PCR.[9] By August 2009, 56 million people had been screened at points of entry to China. A total of 17,909 people were determined to have a febrile respiratory illness and 757 people were confirmed to have (H1N1) 2009; that is, 14 people per one million travellers were identified as having (H1N1) 2009.[9] Analysing national data from the first 426 hospitalised cases, the authors reported that 67.4% had a fever and 32.9% were identified at points of entry (by thermal scanners, self-reported symptoms, travel to an infected country or linked to

someone with confirmed or suspected infection).[9] The authors concluded that individuals with a normal temperature can still be infectious and entry screening using thermal scanners may reduce, but cannot eliminate transmission.[9]

In Japan, three studies[10, 13, 19] were undertaken using data collected at Narita International Airport during the pandemic (H1N1) 2009. Nishiura et al.[10] analysed two datasets. Study A comprised data collected on passengers and crew arriving from Canada, Mexico and the USA (from 28 April to 18 June 2009); this dataset was reported in two subsets, Period I (28 April to 21 May 2009) and Period II (22 May to 18 June 2009). During Period I, handheld infrared thermal scanners were used to identify potential cases. During Period II, stationary infrared thermal scanners inside the airport and self-report of acute upper respiratory symptoms, were the screening tools used to identify potential cases. Study B comprised data collected on all passengers arriving at Narita International Airport from September 2009 to January 2010. During Study B, screening was conducted using stationary infrared thermal scanners inside the airport and self-report of symptoms.[10] Sakaguchi et al. also reported findings from the Study A dataset (Period I and Period II),[19] while Fujita et al. reported findings from Period I of the Study A dataset.[13] At the time of data collection, approximately 40,000-50,000 passengers passed through this airport daily.[10] For Study A, 441,041 passengers and 30,692 crew members (arriving from Canada, Mexico and the USA) were screened on arrival. The criteria used to identify potential cases were, the presence of fever or two or more acute upper respiratory symptoms. Following screening, potential cases (n=805) had nasal swab specimens analysed by RT-PCR; 16 cases of respiratory virus were identified, of which nine were (H1N1) 2009. Five of the nine cases (55.6%) had taken anti-pyretic medication (that is, a substance used to prevent or reduce fever) prior to arrival.[10] For Study B, 9,140,435 passengers were screened on arrival from September 2009 to January 2010. The criteria used to identify potential cases were, the presence of fever, or at least one symptom, or travelling with relatives with at least one symptom. A total of 1,049 individuals were identified as potential cases, of which 930 were identified by infrared thermal scanners alone; no (H1N1) 2009 cases were identified.[10] Nishiura et al. concluded that reliance on fever alone is unlikely to be feasible as an entry screening measure since the positive predictive value (PPV) of infrared thermal scanners (37.3-68.0%) was insufficient for actively detecting febrile passengers, even when restricted to a suspected fraction of passengers (that is, those who self-report symptoms or are travelling with relatives with symptoms).[10]

Gunaratnam et al. analysed data collected (between 28 April and 18 June 2009) from airport clinics at Sydney Airport that were established to detect all cases of (H1N1) 2009. All international passengers were asked to complete a health declaration card and were screened on arrival using thermal imaging scanners with a set-point of 38°C ±2°C.[15] During this time there were 625,147 international arrivals

at Sydney Airport, 5,845 (0.93%) passengers were identified as symptomatic or febrile of which 1,296 (22.17%) were identified as requiring further assessment. Of those requiring further assessment, 11 (0.85%) were identified by thermal scanning alone. Three cases tested positive for (H1N1) 2009, giving a detection rate of 0.05 per 10,000 (95% CI, 0.02–1.14 per 10,000).[15] The authors concluded that, given the resources (cost and staff) associated with airport clinics, careful consideration should be given to implementing such screening measures as they are largely ineffective when compared with other activities such as contact tracing in the community.[15]

In April 2009, Singapore implemented the containment phase of its pandemic influenza plan before (H1N1) 2009 had entered the country. During this time, thermal scanners at Changi International Airport were used to detect passengers with fever and health advisors screened for influenza-like symptoms. The total number of passengers who passed through airport screening was not reported.[17] Mukherjee et al. analysed epidemiologic and travel data for the first 152 patients hospitalised with confirmed (H1N1) 2009 between 27 April and 27 June 2009. A total of 116 of the 152 hospitalised cases were defined as being imported and travel-associated. Of the 116 imported cases, airport doctors had identified 15 (12.9%) cases; 14 of which had fever detected by thermal scanners. The remainder of the imported cases self-reported for testing or were referred by doctors in the community. Through direct interview and detailed review of cases noted, the authors reported that 25% of cases were ill before travel and boarded the flight despite symptomatic travel, while 15% became ill while traveling, suggesting that airport screening did not detect all those that were symptomatic.[17] The authors concluded that improved detection and shortened time to isolation of cases only occurs for the minority of cases detected by thermal scanners. [17]

Quarantine stations were established at international points of entry to Taiwan during the SARS-CoV outbreak in 2003 to screen and investigate travellers on the basis of, self-reported symptoms, fever detected via infrared thermal cameras, travel and contact history.[11] During the pandemic (H1N1) 2009, 1,732,455 international passengers were assessed at these quarantine stations from 27 April to 19 June 2009; 2,685 were considered to have concerning symptoms (including 1,303 passengers with fever) and 12 cases of (H1N1) 2009 were confirmed. For imported cases, airport quarantine measures were found to reduce the time interval between date of entry and date of notification (case confirmation) from 2.6 days for those notified by community physicians to 1.3 days for those screened out at international entry points.[11] The authors concluded that, while quarantine measures cannot prevent a disease from international spread (due to incubation periods and atypical presentation), they may delay the progression of the outbreak.[11]

One study that examined the use of thermal imaging during the MERS pandemic was also identified.[12] Hajj pilgrims who were returning to Indonesia through Juanda Airport between October and December 2015 were screened by a body thermal detector. In total, 28,197 pilgrims were screened and 15 pilgrims had a body temperature >38°C with respiratory symptoms (that is, a cough or sore throat). These individuals were further investigated; 12 were confirmed to have an upper respiratory tract infection, three had pneumonia and none had confirmed MERS-CoV (by RT-PCR of oropharyngeal swab samples and bacterial culture). It is unclear if fever alone warranted further investigation or if questions in relation to other symptoms were limited to those passengers with a fever detected. [12] The authors concluded that, due to the limited effectiveness of thermal scanning as a method through which to identify individuals with fever, monitoring by means of a pilgrim's self-report within ten days of arrival and involving local health authorities and public healthcare centres, may reduce the risk of missing MERS-CoV particularly for those pilgrims presenting without fever.[12]

Systematic or rapid reviews of the direct evidence on the use of non-contact thermal screening

In addition to the eleven primary studies included in this summary, one systematic review[20] and three rapid reviews[21-23] on the use of thermal screening during respiratory virus pandemics was identified. A cross-check of these published reports did not identify any additional primary studies relevant to this review. Mouchtouri et al. conducted a scoping search and a systematic literature review of published evidence on practices, guidelines, and experiences of entry and exit screening at points of entry.[20] The review identified 27 studies that investigated the use of entry and exit screening (at airports, ports and ground crossings) for detection of SARS-CoV, pandemic (H1N1) 2009 and Ebola Virus Disease (EVD); of which three studies[11, 13, 15] were relevant to this summary. The authors concluded that, while entry screening measures provide an opportunity to raise awareness and educate the public, on their own they are not effective for detecting imported cases at points of entry or borders.[20] Three rapid reviews, published in March,[23] April[21] and June[22] 2020, all concluded that evidence on the effectiveness of mass thermal imaging to identify people with COVID-19 is unfavourable; this evidence summary includes an additional seven studies[9, 11, 13, 15-17, 19] not included in the rapid reviews already published this year. See Appendix 2 for an overview of the characteristics of systematic and rapid reviews included in this summary.

Quality of included studies

Overall, cross-sectional studies scored well in terms of study design and conduct using the Joanna Briggs Institute checklist for analytical cross-sectional studies. However, the presence of confounding factors such as antipyretic medication use,

ambient air temperature or age were frequently not taken into consideration in the analysis of results. Although in this context, it is acknowledged that accounting for some confounding variables is challenging and may be associated with considerable uncertainty. The laboratory method used to confirm the diagnosis of respiratory infection was not reported in two studies.[11, 15] In addition, one study was conducted in returning Hajj pilgrims.[12] The Hajj pilgrimage has previously been associated with outbreaks of infectious diseases,[26] which may limit the applicability of the study findings to Irish settings.

For the epidemiological modelling studies, the parameter estimates used are based on preliminary or limited data sources and are associated with considerable uncertainty. However, sensitivity analysis was undertaken to identify dominant contributors. In one study, the description of the methodological approach was limited, with details of internal and external validation procedures absent.[18] The other study has not yet been formally peer-reviewed.[14]

Using the AMSTAR tool, the systematic review by Mouchtouri was rated as critically low quality, due to the absence of a number of critical domains, namely the absence of a predefined protocol, list of excluded full text studies, and an assessment of the methodological quality of included studies.[20] The methodological quality of rapid reviews was not formally assessed as a validated tool was not identified. In general, inclusion and exclusion criteria were not well defined, and details on the methods used to conduct the reviews were limited. Quality appraisal of included studies was not undertaken, making it difficult to interpret the validity and reliability of individual studies and the overall review findings.

Discussion

Overall, eleven studies, that investigated the use of non-contact thermal screening as a method through which to identify respiratory viruses in a pandemic setting, were included in this summary. All studies were conducted, or simulated, at points of entry (that is, airports) which limits the applicability of the results to community settings. Thermal screening was typically implemented as part of a multi-modal programme that also included self-reporting of relevant symptoms, contact and travel history, (although how the latter data were collected was typically poorly described). This limits the ability to determine the effectiveness of thermal screening on its own for case identification.

One observational study[16] and two mathematical modelling studies[14, 18] explored the use of thermal screening in the context of the COVID-19 pandemic. The observational study determined that the use of thermal screening in conjunction with self-reported symptoms was ineffective for identifying cases of COVID-19, with half of the imported cases identified not presenting with fever.[16] Both mathematical modelling studies had the same conclusion; that is, that thermal screening is unlikely

to prevent the spread of COVID-19 by infected individuals.[14, 18] Similar conclusions were drawn from the eight studies conducted in the context of other respiratory virus pandemics: influenza A pandemic (H1N1) 2009[9-11, 13, 15, 17, 19] and MERS-CoV.[12] Like the observational study conducted in the context of COVID-19, these studies assessed the use of thermal screening in conjunction with self-reported symptoms or travel and contact history; all concluded that this method of screening was ineffective as a means to identify infected cases.[9-11, 13, 15, 17, 19] Studies highlighted that cases may go undetected due to the inability of screening to detect asymptomatic or pre-symptomatic cases, the use of antipyretic agents or false negative results.[9, 10, 12, 19] Furthermore, among febrile cases, thermal imaging cannot distinguish between seasonal and pandemic influenza.[10] Finally, studies also noted that thermal screening is resource intensive.[13, 15]

This evidence summary on the effectiveness of non-contact thermal screening for detection of COVID-19 cases is predominantly based on measures implemented in response to the influenza A pandemic (H1N1) 2009.[9-11, 13, 15, 17, 19] Two studies conducted in the context of the pandemic (H1N1) 2009 reported that cases identified during airport screening had a shorter time to isolation compared with those identified through other routes (such as, contact tracing or notification by community physicians), which may reduce the potential for community transmission.[11, 17] The evidence suggests that detection by airport thermal scanners results in a shorter time to isolation for a minority of cases.

While infrared thermometers have their advantages, there are issues in relation to their accuracy, which is dependent on being operated by those with appropriate knowledge and skills. Moreover, they need to be operated within an indoor temperature controlled (±1°C) environment.[5] Other issues relate to the individual being screened. For example, comorbidities that result in circulatory problems (for example, peripheral artery disease, diabetes, obesity or Raynaud's disease), alcohol consumption and antipyretic medications (which individuals may choose not to disclose) can reduce an individual's surface body temperature, while stimulants (for example, caffeine and nicotine) and sunburn can increase an individual's surface body temperature.[5] Such factors may lead to a failure to detect febrile patients (that is, an underestimation of febrile cases), leading to a false sense of security; conversely, it may also overestimate the number of febrile patients generating unnecessary further testing, increased cost and undue stress for individuals involved.[20]

Advances in technology may help overcome some of the problems associated with thermal screening (that is, sensitivity and specificity of readings). However, detection of those who do not present with fever remains an issue. The median incubation period from exposure to symptom onset is considered to be five to six days, with a range from one to 14 days.[27] There is substantial uncertainty around

the proportion that are asymptomatic (never symptomatic) given that testing criteria for COVID-19, particularly in the early stages of the pandemic, have predominantly been on the basis of symptoms. Asymptomatic and pre-symptomatic transmission is a feature in the spread of SARS-COV-2. As the viral load of SARS-CoV-2 peaks early in the infection, (often before symptoms occur, if they occur at all), this means that an individual is infectious during these asymptomatic and pre-symptomatic periods. However, the duration of infectivity is still uncertain.[28] It has been estimated that approximately half of all SARS-CoV-2 cases are due to pre-symptomatic transmission, with a currently unknown proportion caused by asymptomatic transmission.[29] Therefore, screening based on symptoms may not identify a large proportion of potentially infectious cases. Of those that initially present with fever, it is not certain how long they remain infectious when the fever abates. Guidance from the European Centre for Disease Prevention and Control (ECDC) for discharge and ending isolation specify at least three days fever free in addition to other criteria.[27]

In terms of thermal screening, further limitations associated with human behaviour have been identified such as the use of antipyretic medication to evade detection, or failure to declare symptoms or exposure to a confirmed case. The reliance of some screening measures on self-identification of cases through documentation of exposure risk or symptoms on health questionnaires, in addition to fever screening, poses a significant challenge to the identification of cases. Some individuals may not declare symptoms or exposure risk honestly, given the associated consequences, in addition to the potential for recall bias.[20] The use of non-contact thermal screening at points of entry does have potential benefits. For example, it may discourage travel of ill people, educate the public, raise awareness, improve public confidence and reduce the negative economic consequences of trade or travel restrictions.[30, 31] Although it is noted that in the study by Mukherjee et al. during the influenza A (H1N1) pandemic, 25% of imported cases were symptomatic prior to commencing their journey. Furthermore, given the limitations of thermal screening already highlighted, its use may lead to a false sense of security; conversely, infiltration of cases missed by thermal screening may cause secondary cases and result in a loss of confidence by the public.[32]

The impact of non-contact thermal screening on resources is significant. In a study by Wilder-Smith et al. of the SARS pandemic, 442,973 passengers were screened on arrival to Changi Airport, Singapore, of which 136 were referred to hospital for SARS-CoV testing; none were diagnosed as having SARS-CoV.[33] In the context of COVID-19, resources are limited and the deployment of healthcare staff to border control and health monitoring efforts reduces capacity within other areas of pandemic management. Often, those identified as potential cases by thermal screening are likely to have symptoms unrelated to COVID-19 due to the lack of clinical specificity of thermal screening to SARS-CoV-2 infection, thus thermal

screening has the potential to increase the burden on laboratory testing. Due to cost, resource intensity and low detection rates associated with quarantine procedures (thermal screening and self-reported health assessment), the Japanese Ministry of Health, Labour and Welfare restricted screening measures to passengers arriving from the USA, Mexico and Canada, during the pandemic (H1N1) 2009.[20] Moreover, during the time period of the study by Kuo et al., the Taiwan Centres for Disease Control modified their guidance on thermal screening to only screen flights carrying ill passengers allowing reallocation of resources to healthcare or community settings.[11]

Conclusion

All studies included in this review used a combination of thermal screening and determination of symptoms by self-report questionnaire and interview or assessment. This limits the ability to determine the effectiveness of thermal screening alone for case identification. Furthermore, as all studies were conducted at points of entry (ports, airports), the applicability of the evidence to other community settings is uncertain. Thermal screening is limited to detecting febrile cases and therefore will not identify those who are symptomatic but afebrile, or those who are asymptomatic or pre-symptomatic. Factors that alter (increase or decrease) temperature act as confounders, reducing the accuracy of screening. Evidence pertaining to the use of thermal screening for respiratory infections at points of entry to identify and isolate infected cases is limited. The majority of the evidence relates to other pandemic settings (MERS and influenza A (H1N1) 2009), with uncertain applicability to COVID-19, given potential differences in the incubation periods and proportion of cases that present with fever. Low certainty evidence from a single cross-sectional study conducted during the COVID-19 pandemic suggests that thermal screening is ineffective in limiting the spread of COVID-19 due to the presence of asymptomatic or pre-symptomatic cases. Thermal screening is resource intensive and, due to a high proportion of asymptomatic or pre-symptomatic cases, results in low detection rates. Therefore, careful consideration should be given to the cost-benefit of such measures.

Current evidence is insufficient to support the use of mass thermal screening at airports to effectively identify cases and limit the spread of COVID-19.

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Appendix 1: Characteristics of studies included in this summary

Author Country Study design DOI	Population/setting/virus type/type of thermal scanning and lab test	Outcomes
Amin 2018 **Indonesia** **Cross sectional study** **DOI:** **10.1177/1757177418765634**	**Population/setting:** N =28,197 returning Hajj pilgrims through Juanda airport between Oct and Dec 2015 **Patient demographics** **Age:** 40–80 years **Sex:** 8 men, 7 women **Virus type:** MERS-CoV **Temperature detection method:** thermal body scanner Criteria: fever (>38°C) accompanied by respiratory symptoms such as cough and dyspnoea **Lab-confirmation test:** RT-PCR (oropharyngeal swab samples) and bacterial culture	**Cases identified and subsequently confirmed:** Screened at airport: 28,197 pilgrims Body temperature >38°C with respiratory symptoms: n = 15 (number of individuals with fever and no symptoms nor reported). Of those, Upper RTI: n = 12 Pneumonia: n = 3 (n = 1 with suspected MERS-CoV) Laboratory confirmed MERS-CoV: n = 0 **Conclusion:** Subsequent monitoring by means of pilgrims' self-report upon ten days of arrival involving local health authorities and public healthcare centres may reduce the risk of missing MERS-CoV, especially in those pilgrims without fever.
Cao 2009 **China** **DOI: 10.1056/NEJMoa0906612**	**Population/setting:** N = 426 persons with confirmed cases of infection who were hospitalised in May or June 2009. **Patient demographics** ***Mean age:*** 23.4 years ***Sex:*** 53.8% male **Virus type:** pandemic (H1N1) 2009 **Temperature detection method:**	**Cases identified and subsequently confirmed:** *Airport screening (all cases identified at points of entry)* Screened at points of entry: 56 million Travellers with febrile respiratory illness tested for infection: 17,909 Cases identified: 757 (14 per 1 million) *All identification routes (hospitalised patients only)* Points of entry (thermal scanner): n = 140 (32.9%)

	Thermal scanner **Lab-confirmation test:** RT-PCR PCR products were sequenced for further confirmation with the BigDye Terminator, version 3.1 Cycle Sequencing Kit (Applied Biosystems)	During quarantine: n = 86 (20.2%) Hospital: n = 200 (46.9%) **Exposure site:** Airplane: 60/148 (40.5%) Home: 25/148 (16.9%) Classroom/office: 13/148 (8.8%) Car/train/bus: 20/148 (13.5%) Restaurant: 4/148 (2.7%) **Patients presenting with fever** Total: 287/426 (67.5%) 37.3-38°C: 134/426 (31.5%) 38.1-39°C: 114/426 (26.8%) >39°C: 39/426 (9.2%) **Conclusion:** Even those with a normal temperature can still be infectious to others. Entry screening using thermometers reduces but cannot eliminate transmission.
Gostic 2020 **Modelling study** **doi: 10.1101/2020.01.28.20019224**	**Population/setting:** Traveller screening at arrival and/or departure. **Model:** The projected impact of different traveller screening programs based on the assumption that travellers can be detected due to the presence of detectable symptoms (fever or cough), or due to self-reporting of exposure risk via questionnaires or interviews. Travellers fall into 1 of 4 categories: (1) symptomatic but not aware of exposure risk, (2) aware of exposure risk but without detectable symptoms (only detectable if aware that they have been exposed and willing to self-report)	**Cases identified:** Estimated that screening will detect <50% of infected travellers in a growing epidemic, and that screening effectiveness will increase marginally as growth of the source epidemic decelerates. Under the best-case assumptions (1 infection in 20 being asymptomatic; all travellers passing through departure and arrival screening) the median fraction of infected travellers detected is only 0.34 (95% CI 0.20-0.50) The total fraction detected is lower for programmes with only 1 layer of screening, with arrival screening preferable to departure screening owing to the possibility of symptom onset during travel. **Drivers of the effectiveness of traveller screening programmes:**

	(3) symptomatic and aware that exposure may have occurred, and (4) neither symptomatic nor aware of exposure risk (fundamentally undetectable) **Patient demographics:** NR **Virus type:** SARS-CoV-2 **Temperature detection method:** Thermal scanner and exposure risk questionnaire. **Model parameters:** SARS-CoV-2-specific estimates were used for parameter estimates, but almost all have been derived from limited or preliminary data sources and remain subject to considerable uncertainty.	• Incubation period • Existence of exposure risk factors that facilitate specific and reasonably sensitive case detection by questionnaire. **Duration of the incubation period:** Screening outcomes were sensitive to the mean incubation period. For longer incubation periods, larger proportions of departing travellers would not yet be exhibiting symptoms – either at departure or arrival – which in turn reduces the probability that screening would detect these cases. **Proportion of asymptomatic cases:** Scenarios in which 5%, 25% and 50% of cases are asymptomatic were considered. At 25-50%, large fractions of the population undetectable by fever screening. **Effectiveness of exposure risk questionnaires:** Other than close contact with a known case, SARS-CoV-2 specific risk factors have not been identified. It was assumed that a minority of infected travellers would realise that they have been exposed before symptoms develop (range 5-40%). The model assumed that only 25% of travellers would self-report truthfully if aware of elevated exposure risk. **Limitations of fever screening:** Even under the most generous assumptions about the natural history of COVID-19, the presence of undetectable cases made the greatest contribution to screening failure. Correctable failures, such as missing an infected person with fever or awareness of their exposure risk, played a minor role. Adherence by travellers was assumed with no active evasion of screening. However, there are informal reports of people taking antipyretics to beat fever screening. With travel restrictions in place, individuals may also take alternative routes (e.g. road rather than air), which would in effect circumvent departure and/or arrival screening as a control measure. **Conclusions:**

		Arrival screening could delay the introduction of cases if the infection is not yet present or reduce the initial rate of spread in a country. However, it is crucial to also have measures in place to identify cases missed at arrival screening. The cost-benefit trade-off for any screening policy should be assessed in light of past experiences, where few or no infected travellers have been detected by such programmes.
Gunaratnam 2014 **Australia** **Cross-sectional study** **DOI: 10.5694/mja13.10832**	**Population/setting:** Two clinics at Sydney Airport, staffed by nurses from the local area health service, with public health support from the NSW Ministry of Health (28 Apr 2009 and 18 Jun 2009) **Patient demographics:** ***Sex:*** NR ***Age:*** NR **Virus type:** pandemic (H1N1) 2009 **Temperature detection method:** Thermal imaging scanners with a set point of 38°C ± 2°C health declaration card **Lab-confirmation test:** laboratory testing of nose and throat swabs	**Cases identified:** Total arrivals: 625,147 passengers Symptomatic or febrile: 5,845 (0.93%) Indicated for further assessment: 1,296 passengers (22.17%) • Identified by self-report: 1,144 passengers (88.27%). • Thermal scanners: 11 passengers (0.85%) • Other: 35 passengers (2.70%) Pandemic (H1N1) 2009 case definition met: 83 (6.40%) Confirmed cases: 3 cases (detection rate of 0.05 per 10,000 (95% CI, 0.02–1.14 per 10,000)). **Missed cases:** 45 people with overseas acquired pandemic (H1N1) 2009 in NSW who would have probably passed through the airport during this time. **Other identification routes during this period (n = 557 confirmed cases):** Emergency departments: 290 (52.1%) General practices: 135 (24.2%) Airport: 3 (0.5%) **Conclusions:** The small number of passengers detected by thermal scanners is also consistent with published estimates of the sensitivity of non-contact infrared

		thermal image scanners, and the high proportion of influenza infections that are likely to be asymptomatic. Given the costs associated with staffing airport clinics, careful consideration should be given to deploying resources to airports for largely ineffective screening measures, compared with other activities such as contact tracing in the community.
Kuo 2009 **Taiwan** **Cross-sectional study**	**Population/setting:** On-board quarantine procedure on flights from epidemic affected areas, such as Mexico, USA, and Canada, before passengers can leave their seats. **Patient demographics:** ***Sex:*** NR ***Age:*** NR **Virus type:** pandemic (H1N1) 2009 **Temperature detection method:** Infrared thermal camera systems and self-report **Lab-confirmation test:** laboratory-confirmed (test not specified)	**Cases identified:** Quarantine examination: 1,732,455 passengers. Identified for further clinical examination: 2,685 with suspicious symptoms, including 1,303 with fever. Of 1,303 passengers with fever, 184 sent to hospitals for further diagnosis and treatment, 12 cases laboratory-confirmed with novel pandemic (H1N1) 2009 infection. **Borderline cases advised to seek medical advice:** 9 cases were identified as febrile by infrared fever cameras at international entry points, but were not transferred to hospital for further diagnosis (probably due to atypical or subclinical symptoms, or their travel destinations were not among affected areas at that time). **All identification routes of imported cases (n = 59):** • Quarantine fever screening: 21 cases (35.6%) (n = 12 referred by quarantine officers/physicians; n = 9 advised by quarantine officers to seek medical treatment immediately after returning home) • Follow-up of contacts of cases identified by quarantine fever screening: 11 cases (18.6%) • Physician notification: 22 cases (37.3%) • Follow-up of contacts of cases notified by physicians: 5 cases (8.5%) **Time to notification:** Average time intervals between the date of entry and the date of notification:

		• 1.3 days for the 9 cases screened out at international entry points • 2.6 days for the 22 cases notified by community physicians. **Breakdown of passenger numbers per day (average):** Total: 32,082.5 passengers entered through international ports; Suspicious symptoms: 49.7 passengers Fever: 24.1 passengers Suspect cases: 3.4 transferred to hospitals per day. Average rate of passengers with fever symptoms per thousand passengers per day: 0.75 passengers. **Modifications to screening procedures:** The policy of on-board quarantine was modified to apply to only airplanes reporting ill passengers onboard as the original policy exhausted a large amount of manpower and resources in countries following this policy (such as Japan, China, and Hong Kong). **Conclusions:** Quarantine procedures cannot completely prevent a disease from international spread because of factors like incubation periods and atypical symptoms, however, in the early stages of a global epidemic quarantine measures can effectively delay the occurrence of a large-scale community outbreak.
Liu 2020 **Taiwan** **Cross sectional study** **DOI: 10.3390/ijerph17093311**	**Population/setting:** N = 321 imported cases of COVID-19 (from 21 Jan to 6 Apr 2020)* **Patient demographics:** ***Sex:*** 53.0% female. ***Age:*** 4–88 years; 20–29 years = 7.4%,	**Cases identified:** Mode of identification of imported cases: • Airport screening (thermal scanner and self-reported symptoms): n = 105 (32.7%) • Home quarantine: n = 89 (27.7%) • Contact tracing: n = 52 (16.2%) • Sought medical attention and were reported by the hospitals: n = 75 (23.4%)

	30–39 years = 23.7% **Virus type:** SARS-CoV-2 **Temperature detection method:** Infrared thermal imaging cameras **Lab-confirmation test:** RT-PCR *Some duplication of cases as some cases travelled to multiple countries during their incubation period.	Of the cases who were asymptomatic on arrival, none were identified during airport screening (39.6% home quarantine; 28.3% contact tracing; 32.1% reported by hospitals). **Other:** *Reproduction number of the 321 imported cases, stratified by route of identification:* Airport screening (thermal scanner and self-reported symptoms): 0 locally acquired cases (R=0) Home quarantine: 4 locally acquired cases (R=0.04 (95% CI 0.00–0.09) Contact tracing: 8 locally acquired cases (R=0.15 (95% CI 0.00–0.30) Hospital notification: 7 locally acquired cases (R=0.09 (95% CI 0.02–0.17) *Symptom presentation* Airport screening (thermal scanner and self-reported symptoms): 64.8% of the cases who had developed symptoms before arrival were identified in airport screening. *Days from arrival to disease confirmation (Mean (95% CI))* Airport screening (thermal scanner and self-reported symptoms): 2.6 (2.4–2.7) Home quarantine: 7.4 (6.5-8.3) Home quarantine: 9.7(8.2-11.3) Hospital notification: 7.8 (6.7–9.0) **Conclusion:** Body temperature screening at the airport did not detect all cases. Airport screening is only effective in the identification of symptomatic cases. Cases may evade detection because they had taken antipyretic drugs, did not honestly declare their symptoms, or their symptoms were mild or not involving the respiratory tract. Cases identified by thermal scanner during airport screening had the shortest time from arrival to disease confirmation. Early identification and isolation of cases limits transmission.

Mukherjee 2010 **Singapore** **Cross-sectional study** **DOI: 10.3201/eid1601.091376**	**Population / setting:** First 116 case-patients admitted to Tan Tock Seng Hospital (TTSH), Singapore, with travel-associated infection. An imported, travel-associated case was defined as having occurred in a person with recent travel outside Singapore who had arrived in Singapore during the containment period and had illness onset within 10 days of arrival. **Patient demographics:** **Age (years):** <19: n = 18 (15.5%) 20-29: n = 63 (54.3%) 30-39: n = 13 (11.2%) 40-49: n = 14 (12.1%) ≥50: n = 8 (6.9%) **Sex:** n = 59 (50.9%) males **Virus type:** pandemic (H1N1) 2009 **Temperature detection method:** thermal scanners **Lab-confirmation test:** real-time RT–PCR performed on respiratory samples (sputum or combined nasal and throat swab specimens)	**Cases identified and subsequently confirmed:** Referral from clinical examination at airport: n = 15 (12.9%) Of those, detection by thermal scanners at airport: 14/15 Self-report to screening centre at TTSH: n =51 (44%) Referred by doctors in the community: n = 50 (43%) **Time to isolation:** Cases referred to TTSH by airport doctors had a shorter time to isolation (0.76 days) than self-referred patients or those referred by other sources (1.6–1.9 days). **Onset of symptoms:** Before embarkation: n = 29 (25%) During travel: n = 17 (14.7%) After disembarkation: n = 70 (60.3%) >30% of case-patients from all flights >3 hours had symptom onset before arrival, but overall, only 12% of all case-patients were detected by thermal scanners, suggesting that thermal scanners detected 40% of those symptomatic patients. **Conclusion:** Improving detection and shortening the time to isolation of sick persons is the rationale for using airport thermal scanners. The data shows that for the minority of cases detected by airport thermal scanners, detection does result in a hospital referral by an airport doctor and shorter time to isolation.
Dataset collected from Narita International Airport, Japan during the 2009 pandemic		
Nishiura 2011 **Analysis of two datasets:** **Study A dataset 28 Apr – 18 Jun 2009**	**Population/setting:** Narita International Airport, Japan during the 2009 pandemic. *Study A dataset*	**Cases identified and subsequently confirmed:** *Study A dataset (n = 16)* Passengers screened: 441,041 (and 30,692 crew members) Total number identified with fever n = 17

Study B dataset Sep 2009 – Jan 2010. **DOI: 10.1186/1471-2334-11-111**	Confirmed influenza cases (n = 16) whose diagnosis took place at the airport (28 Apr to 18 Jun 2009) *Study B dataset* A selected and suspected fraction of passengers (self-reported or detected by an infrared thermal scanner; n = 1,049) screened from Sept 2009 to Jan 2010. **Patient demographics:** *Study A dataset* **Age (mean (SD)):** 30.5 (16.4) years **Sex:** n = 9 cases (56.3%) **Medication:** 5/9 (55.6%) were under antipyretic medications upon arrival *Study B dataset* **Age (mean (SD)):** 30.3 (18.5) **Sex:** n= 653 males (62.7%) **Virus type**: pandemic (H1N1) 2009 **Temperature detection method:** infrared thermal scanners TVS-500 infrared thermal scanners (NEC/AVIO Infrared Technologies Co. Ltd., Tokyo, Japan) Fever (38.0°C) **Lab-confirmation test:** RT-PCR	H1N1-2009 n = 9 identified during airport screening Other H1 n =3 H3 n=4 Type B virus n = 1 *Study B dataset (n = 1,049)* Passengers screened: 9,140,435 Self-reported some symptoms: n = 285 (27.2%) Infrared thermal scanner: n =930 (88.7%) Self-reporting individuals with positive screening results: n = 185 cases (64.9% of all self-reporting individuals) **Conclusion:** The PPV of infrared thermal scanners ranged from 37.3-68.0% and was determined insufficient for actively detecting febrile passengers, even when restricted to a suspected fraction of passengers. Potentially more useful in other settings (e.g. screening of fever in a setting with a far greater prevalence of hyperthermia). Given the additional presence of confounding factors and unrestricted medications among passengers, the reliance on fever alone is unlikely to be feasible as an entry screening measure against influenza.
Sakaguchi 2012 **Analysis of Study A dataset divided into two subsets:**	**Population / setting:** All passengers arriving on direct flights into Narita Airport in Japan	**Cases identified:** *Airport screening* Total n = 9/151 cases

Period I – 28 Apr – 21 May **Period II – 22 May – 18 Jun** **DOI: 10.1371/journal.pone.0031289**	n = 9 infected individuals identified by entry screening **Patient demographics:** **Sex:** 8 male, 2 female **Age:** 5 years n =1 10-19 years n =5 20-29 years n =1 30-39 years n =1 40-49 years = 2 **Virus type:** pandemic (H1N1) 2009 **Temperature detection method:** Infrared thermal scanner (e.g., TVS-500EX, NEC Avio Infrared Technologies Co., Ltd., Tokyo, Japan) **Additional screening measures:** Self-reported health declaration form including: • presence or absence of any symptoms, • history of contact with infected individuals, • destinations in Japan during the first 10 days after entry. Any individuals that declared ILI symptoms on the health declaration forms collected, underwent medical examination, and were subsequently indicated for the rapid influenza diagnostic test, if necessary. **Lab-confirmation test:** RT-PCR	Period 1 Total passengers: n = 206,037 Passengers indicated for diagnostic testing: n = 561 Cases identified: Influenza type-A positive n = 6. Of these, pandemic (H1N1) 2009 n =4; seasonal influenza (H1 and H3) n = 2. Period 2 Total passengers: n = 265,696 Passengers indicated for diagnostic test: n = 244 Cases identified: Influenza type-A positive n = 10. Of these, pandemic (H1N1) 2009 n =5; H3 n = 3; seasonal influenza n = 2. *Community containment measures* n = 141/151 cases **Cases missed:** 24 individuals with symptoms upon entry were missed at entry screening, but were identified by enhanced surveillance afterwards. **Outbreak prevention:** 9/151 of the individuals infected during international travel were identified by the border control measures. **Note:** Immense human resources are needed to undertake border screening. Trained health staff are finite resources and their deployment to border control and health monitoring efforts reduces the number available for other aspects of pandemic management. **Conclusions:** Testing cannot discriminate between infection with seasonal and pandemic strains. Symptomatic passengers were detected by the various entry screening measures. Additional measures are necessary to identify missed cases.

Fujita 2011 **Analysis of Period I subset of Study A dataset** **Cross-sectional study** **DOI: 10.3357/asem.3023.2011**	**Population / setting:** Imported influenza cases arriving directly from the United States, Canada, and Mexico detected by quarantine inspections by the Japanese government. Patients with overseas history were defined as those diagnosed with influenza within 7 days from entry at the airports. **Patient demographics:** ***Mean age:*** NR ***Sex:*** NR **Virus type:** pandemic (H1N1) 2009 **Temperature detection method:** Health questionnaire form or thermography. **Lab-confirmation test:** PCR	**Cases identified and subsequently confirmed:** Passengers screened: 120,069 Passengers indicated for testing: 391 Cases confirmed: 6 **Secondary transmission:** In the course of the quarantine, no secondary transmission was found among passengers seated near cases. **Conclusion:** Intensive airport quarantine control is not recommended because of its poor cost effectiveness and low detection rates.
Quilty 2020 **Modelling study** **doi: 10.2807/1560-7917.ES.2020.25.5.2000080**	**Population/setting:** Exit and entry screening for detecting travellers entering Europe with SARS-CoV-2 infection**.** **Model:*** Estimated the proportion of infected travellers who would be detected by exit and entry screening, develop severe symptoms during travel, or go undetected, under varying assumptions of: (i) the duration of travel (12 hours days at baseline); (ii) the sensitivity of exit and entry screening (86% days at baseline); (iii) the proportion of asymptomatic infections (17% days at baseline);	**Cases identified and subsequently confirmed:** At baseline, of 100 infected travellers: • 44/100 (95% CI: 33–56) would be detected by exit screening. • no case (95% CI: 0–3) would develop severe symptoms during travel. • 9 (95% CI: 2–16) additional cases would be detected by entry screening. • 46 (95% CI: 36–58) would not be detected. ***Drivers of the effectiveness of exit and entry screening for travellers:*** **Approach to screening:** The effectiveness of entry screening is largely dependent on the effectiveness of the exit screening in place. Under baseline assumptions, entry screening could detect 53 (95% CI: 35–72) instead of nine infected

	(iv) the incubation period (mean 5.2 days at baseline) (v) the time from symptom onset to hospitalisation (mean 9.1 days) **Patient demographics**: simulated 100 infected travellers **Virus type:** SARS-CoV-2 **Temperature detection method:** Detection of mild to severe symptoms via equipment such as thermal scanners. *While the most up-to-date data on the incubation period or the time until recovery from SARS-CoV-2 infection was used in this model, these figures may change over time as more data become available	travellers if no exit screening was in place. However, the probability of developing symptoms during the flight increases with flight time and hence exit screening is more effective for longer flights. **Incubation period:** If the baseline scenario is modified to have 0% asymptomatic SARS-CoV-2 infections and 100% sensitivity of entry screening, the incubation period would need to be around 10-fold shorter than the period from symptom onset to severe disease (e.g. hospitalisation) in order to detect more than 90% of infected travellers that would not otherwise report illness at either exit or entry screening. **Conclusion:** Airport screening is only effective if the rate of asymptomatic infections that are transmissible is negligible, screening sensitivity is almost perfect, and the incubation period is short. Estimates from this model indicate that likely more travellers infected with SARS-CoV-2 have not been detected by screening. Due to the duration of the incubation period, exit or entry screening at airports for initial symptoms, via thermal scanners or similar, is unlikely to prevent passage of infected travellers into new countries or regions.

Key: CI – confidence interval; ED – emergency department; MERS-COV – Middle East respiratory syndrome-related coronavirus; NR – not reported; PCR – polymerase chain reaction; PPV – positive predictive value; R - Reproductive number; RTI – respiratory tract infection; RT-PCR – reverse transcription polymerase chain reaction; SARS-CoV – severe acute respiratory syndrome; TTSH – Tan Tock Seng Hospital.

Appendix 2: Characteristics of systematic reviews included in this summary

Author Study design DOI	Included studies	Primary outcome results	Other results/conclusions/ recommendations
Health Improvement Scotland **Rapid review**	**Aim:** To examine the evidence on the effectiveness and clinical validity of thermal scanning specific to the infectious disease context **Included studies:** Previous reviews: • ECRI evidence review • CADTH • Mouchtouri et al. Primary studies: • Diagnostic cohort studies • Diagnostic case-control studies • Diagnostic case series Guidance documents: • WHO technical guidance • FDA guidance • ISO guidance Simulation studies **Relevant studies**	*ECRI evidence review* • Unfavourable evidence to suggest that screening by thermal scanning alone or alongside a questionnaire was effective for detecting infected persons. • Low or inconsistent sensitivity of the devices examined. *CADTH review 2014* • Fever screening at international airports was generally not effective at detecting (H1N1) 2009 or SARS-CoV due to the long incubation periods and delayed appearance of febrile symptoms for these infectious diseases. • It is unclear whether thermal scanning based screening in other community and healthcare settings would vary in effectiveness from levels observed at airports and border crossings. • Accuracy of temperature screening can be subject to significant variation based on agent characteristics and epidemic stage. • Generalisability of the evidence is uncertain due to many confounders associated with temperature measurement.	**Approach to screening:** Screening alone or alongside a questionnaire was not effective at detecting infected persons. Evidence on whether screening would be effective in healthcare or other community settings besides points of entry is lacking. **Limitations:** The uncertainty around the effectiveness of thermal imaging systems arises from variability in analytic validity, extreme difficulty in detecting asymptomatic carriers and absence of clinical specificity to epidemic/pandemic strains. **Conclusion:** The evidence on whether screening by thermal imaging systems is effective in controlling infectious disease transmission is weak or inconclusive.

	n = 2 reviews n = 2 simulation studies **Pathogen:** Any infectious disease **Population:** Mass gatherings **Intervention:** Thermal scanning **Outcomes:** Clinical effectiveness, diagnostic test accuracy **Setting:** clinical and community settings		
ECRI Clinical evidence assessment **USA** **Rapid review**	**Aim:** To investigate the accuracy of infrared (IR) temperature screening to identify potentially infected staff or visitors during infectious disease outbreaks. **Included studies:** Systematic reviews n =2 • Mouchtouri et al • CADTH 2014 Simulation studies n =3 Diagnostic cohort studies n =6 Case-control studies n =3 Case series n =2 Guidance documents n =8 **Relevant studies** N =1 systematic review	**Overall findings:** After assessing the available published clinical evidence, the balance of benefits and harms of infrared temperature screening was found to be unfavourable. Temperature screening programs are ineffective for mass screening because of the low number of infected individuals who have fever at the time of screening and inconsistent technique by operators. **Evidence from simulation studies:** Under best case scenarios, screening would miss more than half of infected individuals. **Limitations of screening:** IR thermography, even when used with a questionnaire was not reliable for screening due to environmental temperatures, false answers to questions, and the use of fever-reducing drugs.	**Conclusion:** Temperature screening programmes using IR thermography devices alone or with a questionnaire for mass screening are ineffective for detecting infected persons. Using such an approach to reduce infection risk from visitors and staff entering healthcare facilities could provide a false sense of safety.

	N=2 simulation studies Other studies included in this rapid review were not relevant to this evidence summary for a variety of reasons, namely: no outcome measure, absence of laboratory confirmed virus, use in non-pandemic respiratory virus setting or in pandemics caused by viruses other than respiratory viruses. **Pathogen:** any infectious disease **Population:** Mass gatherings (excluded paediatric patients) **Intervention:** infrared (IR) temperature screening devices with or without questionnaires **Outcomes:** clinical effectiveness, diagnostic test accuracy **Setting:** public entry points such as health systems and airports.	**Evidence limitations and strengths:** • The evidence base is fairly large and up to date. • The effectiveness of airport screening with IR devices has been examined in a recent SR with 27 studies, and the effectiveness of IR device screening has been examined in an SR with 20 studies and 11 additional studies identified in our searches. • Variations across studies are due primarily to variations in the devices used both for noncontact IR measurements and standard reference temperature measurements.	
Mouchtouri 2019 **Systematic literature review** **DOI:10.3390/ijerph16234638**	**Objective:** To gain insight into entry and exit screening referring to travellers at points of entry worldwide. **Included studies:** N = 27 N = 14 potentially relevant	**Cases identified:** *SARS-CoV:* Entry screening measures did not detect any confirmed SARS-CoV cases in Australia, Canada and Singapore. *Pandemic (H1N1) 2009 :* The detection rate among all passengers screened ranged from 2.2 to 0.01 per 10,000	**Approach to screening:** Targeted screening measures (e.g., to travellers coming from affected countries or certain direct flights) rather than screening all travellers may improve the PPV. Entry screening alone seems to be ineffective in preventing/delaying introduction of diseases; however, it could be justified for severe diseases, as part of a

	Number of relevant studies included: N = 6 **Viruses:** SARS-CoV, Influenza Pandemic (H1N1) 2009 and Ebola Virus Disease (EVD). **Population**: Travellers (crew and passengers) crossing borders. **Intervention:** entry or exit screening. **Outcomes**: cost-effectiveness; public health impact. **Settings:** Airports, ports and ground crossings.	travellers in China and Japan, respectively. A survey conducted by WHO showed an aggregate rate of 4 confirmed cases per 1,000,000 screened travellers for pandemic (H1N1) 2009 in 10 countries. **Diagnostic test accuracy:** The diseases targeted by entry screenings such as SARS-CoV and the pandemic (H1N1) 2009 have a very low prevalence among travellers, therefore the PPV of entry screening is expected to be close to zero. **Beneficial effects:** *Influenza:* • Obtaining contact information of travellers to be used if needed for contact tracing or public health observation purposes. *SARS-CoV:* • May have helped to dissuade ill persons from travelling by air. • Preserving public confidence, relieving political and social pressure and limiting negative economic consequences from travel and trade restrictions. • Limit negative economic consequences from travel and trade restrictions. Enabled business continuity to trade and transport sectors. **Adverse effects:** *SARS-CoV:* • High cost of screening measures.	set of measures complementing each other, after setting priorities and where there are available resources. **Limitations of screening** • Screening measures may be ineffective due to false declarations by travellers, or taking antipyretic drugs. • Screening measures (health alert questionnaires and thermal scanning machines) are non-specific for SARS-CoV. • Inability to detect pre-symptomatic or asymptomatic travellers • Reliance on self-identification. • False positive and false negative results. **Conclusion:** The evidence suggested that the primary objective of entry screening implemented in response to public health emergencies (to detect imported cases at borders) was not achieved, but screening measures have important concomitant effects when implemented in combination with health education and informative strategies for travellers.

		• Investing in screening measures reduces the resources available for other effective measures.	
NSW Health Covid-19 Critical Intelligence Unit **Australia** **Rapid Review** **https://www.aci.health.nsw.gov.au/__data/assets/pdf_file/0003/580026/20200408-Evidence-Check-Thermal-Screen-Review.pdf**	**Research question:** Is mass thermal imaging an effective way of identifying people with COVID-19? **Included studies:** Reviews: • CADTH Primary studies n = 8 **Relevant studies:** n = 1 review n = 2 cross sectional study n = 1 simulation study **Population /setting:** mass gatherings **Virus type:** COVID-19; MERS-CoV; coronavirus; dengue fever; (H1N1) 2009 **Intervention:** thermal scanning	**Overall findings:** No synthesis of findings. Results of individual studies presented. **Evidence from modelling studies:** A recent study of airport screening for COVID-19 estimated that using thermal screening, 46% of infected travellers would not be detected. **Limitations of screening:** Asymptomatic or atypical clinical presentation • Not everyone who has an infection or is infectious will have a fever. Inability to detect asymptomatic individuals • Early estimates of asymptomatic infections are between 18-42% of patients. • According the WHO, the virus can initially be detected in upper respiratory samples 1-2 days prior to symptom onset, suggesting potential pre-symptomatic transmission. • Anti-pyretic medications. • Fevers can be lowered by using antipyretic medications.	**Conclusions** • Infrared thermal detection systems have been shown to be accurate in identifying people with no fever but much less so in identifying people with fever. • Thermal screening will lack sensitivity to reliably detect COVID-19 in community settings.

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