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# **Key Messages**

- Local exhaust ventilation concepts derived from industrial settings can be successfully adapted and applied in clinical environments for infection control at source.
- 2. Local exhaust ventilation devices developed during this study effectively removed infectious airborne bioaerosols at source.

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# Controlling infectious bioaerosols at source using novel local exhaust ventilation devices

### Introduction

Patients with respiratory illnesses can generate large volumes of infectious aerosols when they vocalise, sneeze, or cough. Certain clinical procedures such as bronchoscopy, endotracheal intubation, sputum induction, etc can also produce high volumes of infectious aerosols. In most health care settings, the current strategy for controlling exposure to infectious aerosols relies on three major types of control measure: (i) patient care practices, (ii) use of personal protective equipment (PPE), and (iii) ward ventilation. These conventional infection control practices only provide personal protection for health care workers (HCWs). In some health care facilities with isolation wards equipped with special ventilation systems, infectious bioaerosols are largely free to disperse and travel within these units, exposing personnel and articles in the ward to the risk of contamination.

A hazard control system with designs based on 'controlling at the source' and 'local exhaust ventilation' (LEV) attempts to capture contaminants at their sources of emission. The contaminants are thus prevented from dispersing within the room and the room air should therefore be kept continually clean. This greatly increases the margin of safety for HCWs.

After the 2003 severe acute respiratory syndrome (SARS) outbreak, we developed a series of novel LEV devices including Infection Control at Source (ICAS) [Fig 1], Isotent (Fig 2), and Isobooth (Fig 3) to control infectious bioaerosols at the source and improve levels of protection against infectious respiratory disease for HCWs and the public.

# Aims and objectives

This study aimed to develop LEV devices to control infectious bioaerosols at source. The objectives were:

- 1. To adapt designs of novel LEV devices to various clinical environments and procedures;
- 2. To develop a validation protocol for LEV devices intended for infection control;
- 3. To verify the effectiveness of the novel LEV devices according to the validation protocol;
- 4. To conduct field trials in three clinical settings including two Hospital Authority (HA) hospitals and several Department of Health (DH) chest clinics to collect user feedback; and
- 5. To formulate an affordable and sustainable deployment scheme for LEV devices in local hospitals.

# Methods

This study was conducted from December 2004 to February 2006. The basic design principle of our novel LEV devices is creation of an enclosure to isolate the source of potentially infectious bioaerosols from patients with respiratory diseases. Using negative pressure created by a fan, an inward airflow is induced at the capturing device (either a booth, a tent, or a hood) and the bioaerosols are contained inside, thereby preventing the spread of bioaerosols into the



Fig 1. (a) Infection Control at Source (ICAS), and (b) ICAS used during bronchoscopic examination in a hospital setting

immediate environment. The Industrial Ventilation Manual recommends that an airflow between 0.4 and 0.7 m/s in linear velocity across any open surface of the device be maintained to achieve good containment.<sup>1</sup> The captured and potentially contaminated air is continuously drawn by a fan or a pump through a high-efficiency particulate air (HEPA) filter, which traps the infectious particles. The HEPA-filtered air, which is free of microbes, is returned to the immediate environment. The HEPA filtering is a filtration process, not a disinfection process. For occupational safety, disinfection is a standard requirement before replacement of HEPA



Fig 2. (a) Isotent installed on an emergency trolley, and (b) Isotent used for patient transport in hospital

filters and during maintenance operations that may expose a worker to the contaminated surface of a filter. The trapped bioaerosols can be inactivated using standard disinfection procedures such as fumigation with formaldehyde.

To test the performance of our LEV devices and disinfection techniques, we used several standard protocols and experimental protocols developed in this project (Table). We also conducted field trials on our LEV devices in the Haven of Hope Hospital (ICAS), Tseung Kwan O Hospital (Isotent), and DH chest clinics (Isobooth) to obtain feedback from clinical workers and patients, using two types of questionnaire.

#### Results

#### **Performance testing**

All devices passed performance tests including a smoke test, air velocity measurement, and aerosol challenge test. The Isotent barely passed the smoke test and air velocity measurement tests due to difficulties achieving a large enough airflow through a high-resistance HEPA filter for a long enough period of time using the limited battery power available.

#### Table. Tests performed

Tests	Aim
Performance testing	
Smoke test	To visualise the airflow
Air velocity measurement	To measure the air velocity at openings
Aerosol challenge test	To test the effectiveness of high-efficiency particulate air filters
Surrogate challenge test	To demonstrate the biological effectiveness of the device
Disinfection protocol	
Formaldehyde fumigation	To fully disinfect high-efficiency particulate air filters
Replicate Organism Detection And Counting plate test	To verify effectiveness of surface disinfection



Fig 3. (a) Isobooth, and (b) Isobooth used during diagnostic procedure in a chest clinic

The Isobooth was selected for the surrogate challenge test. The overall efficiency of this LEV device was demonstrated using an *Escherichia coli*-phage system in which phage concentrations inside and outside of the Isobooth were compared to indicate the degree of containment.

#### **Disinfection protocol**

The HEPA filters of the ICAS and Isobooth were successfully fumigated using formaldehyde. There was no need to disinfect the HEPA filter cartridges used in the Isotent as they were designed to be disposable.

The Replicate Organism Detection And Counting (RODAC) plate test was performed on PVC boards using several liquid disinfectants (75% ethanol, 1:99 bleach, and 1:49 bleach). This test clearly supported the value of the RODAC plate as a tool for assessing surface microbial contamination.

# *Field trials and user survey* Infection Control at Source

The HCWs surveyed considered ICAS an effective means of providing additional occupational health protection, and they were also willing to accept the changes in procedure needed for its use. As patients were sedated during the procedures, none felt discomfort and all were willing to use the device again. Nonetheless, because of the additional work imposed by use of ICAS, coupled with reduction in infection risk, HCWs are using it less often as the threat from SARS has subsided.

#### Isotent

The Isotent was generally accepted by HCWs. Nonetheless, they continued to rely on PPE even with the protection of the Isotent, perhaps partly as a result of the SARS experience. Patients were invited to give feedback and some reported discomfort, mainly because of the plastic smell or slight warming inside the tent, but all patients were willing to use the Isotent again.

#### Isobooth

Both HCWs and patients were positive about the Isobooth. The large number of respondents in this study provided the statistical power to support unequivocal acceptance of Isobooth, including the work imposed by the necessary modification of procedures and the additional disinfection work needed between patients.



Fig 4. Isohood

#### Deployment plan

A proposed deployment plan for the three LEV devices was assembled. The total cost was broken down into initial cost, annual maintenance cost, and recurrent cost. The initial costs of the ICAS, Isotent, and Isobooth are \$16 000, \$22 000, and \$31 000, respectively. The service life of each unit is expected to be 10 years. The annual maintenance cost is \$6400 for each unit, covering two field service sessions. A HEPA filter replacement, including disinfection by fumigation, costs \$7000. The total maintenance cost for each unit is approximately \$10 000 per year. The recurrent costs for ICAS and the Isobooth are minimal, while recurrent costs for the Isotent depend on levels of usage; each disposable tent costs \$400. The overall need for the ICAS may be 12 units for the whole territory, translating to an initial cost of \$192 000, plus an annual maintenance budget of \$120 000. Assuming each HA acute hospital acquires three Isotent units, the total initial cost will be \$924 000 and the annual maintenance cost will be \$520 000, with a recurrent cost of \$400 for each patient. According to the DH procurement plan of one Isobooth for each of the 17 regional chest clinics, the initial cost is estimated at \$527 000 with \$170 000 annual maintenance costs. We are uncertain about the need for this across the HA as the field trials for this unit were not conducted in hospitals.

# Discussion

#### Performance testing

Using performance tests, all LEV devices were found to be effective for removing infectious bioaerosols. The Isotent needs further refinements in its fan and battery design to enhance its overall performance. The surrogate challenge test for the Isobooth needs further refinement to enhance its robustness.

#### **Disinfection protocol**

The RODAC plate test was found to be a successful means of evaluating the effectiveness of liquid disinfectants. Ultraviolet-C germicidal irradiation (UVGI) was considered an alternative to liquid disinfectants for surface disinfection of our LEV devices. The RODAC technique could potentially be used to test the effectiveness of UVGI.

#### Field trials and user survey

All the LEV devices were well-received by both HCWs and patients, with the Isobooth receiving the strongest support and acceptance in a large survey of clinical staff. On the other hand, although the numbers of users surveyed in hospital field trials were less than what was conventionally considered a 'large enough' sample of 30, we still consider the collected responses useful for the further development of our devices.

At least two of the LEV devices (ICAS for bronchoscopy and Isobooth for various respiratory procedures) are at a stage of development, or close to it, where they can be routinely used in different clinical settings. Nonetheless, we experienced a number of difficulties in the prototype development. Generally, the smaller the unit, the more difficult it was to make and use. Stationary units, including the ICAS and Isobooth, allow a more bulky configuration and consequently fewer restrictions on size, weight, and power requirements. By contrast, the portable Isotent for emergency trolleys faced several technological hurdles, mainly due to the existing limitations of battery technology, in addition to the lack of suitable compact mechanical components, such as fans, air pumps, and HEPA filters. Development of the Isohood (Fig 4), a design initially targeted for patient transportation, involved more technical difficulties, for example, ergonomic factors and appropriate material selection. When these technical problems are solved, use of LEV devices for transporting infectious patients may become standard practice.

### Deployment plan

Based on the development of the LEV devices, cost estimates for deployment of these devices were provided to local health care facilities in need of such equipment. The costs include manufacturing, installation, and maintenance and provide good references for future development and provision of the LEV devices.

#### Recommendations

- 1. The RODAC plate technique should be applied to test the effectiveness of surface disinfection of LEV devices using UVGI, which is a good substitute for liquid disinfectants.
- 2. Further refinement of the surrogate challenge test is necessary for achieving a 1/10 000 reduction between

the inside and outside of the device. A possible way to do this is to adjust the sampling time for both internal and external samples, so that a larger volume of air is collected outside the booth, rendering the detection of one plaque less significant in the final percentage reduction calculation.

- 3. Further work should be done to overcome the technical difficulties encountered with the Isotent, in particular the limitations in battery technology, availability of compact fans/pumps that suit the purpose, and the supply of HEPA filters of a suitable size and configuration.
- 4. Isohood is the most compact prototype available, intended to fit on the head of a patient. To solve ergonomic and material selection difficulties, manufacturers of PPE or medical equipment could be approached for assistance and advice.

# Conclusions

The project achieved both the stated objectives and a significant breakthrough in terms of bridging an important gap between infection control and occupational hygiene. We demonstrated that LEV devices could be developed and customised, with close collaboration with HCWs and occupational hygiene practitioners, for specific clinical procedures. We believe these devices can be adopted for routine use and become part of a better occupational

health protection system for frontline HCWs dealing with emerging airborne infectious diseases. These LEV devices should be deployed to every hospital and clinic where there is a risk of airborne disease transmission. Further, the use of these LEV devices should become part of routine practice to provide better protection for clinical staff.

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