SARS-CoV-2: Dynamics of Airborne Transmission and Air Disinfection

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Is SARS-CoV-2 airborne?

• Circumstantial evidence:
  – if large respiratory droplets contain virus – small ones must also.
    • Virus detected by air sampling using PCR and culture methods
  – Other similar coronaviruses, including SARS and MERS have had airborne components
  – Examples of spread likely to be airborne: Washington state choir, Hong Kong apartment building, Wuhan restaurant, etc
  – Impact of interventions – face coverings, etc – favor airborne predominance in one recent paper.
  – *Impact of indoor environment on transmission*
  – *Modeling routes of infection*
Change in covid-19 cases/million as a function of cooling degree days
(May 28-June 11, 2020)

The hottest states are suffering the worst outbreaks

Increasing cases

Increased AC use
More time indoors

Data from covidtracking.com
Chart by @binarybits
The key finding was that droplet and inhalation transmission routes predominate over the contact route, contributing 35%, 57%, and 8.2% of the probability of infection, on average, without use of personal protective equipment.
Where is most Covid transmission occurring?

- In the room?
  - Rebreathed air fraction
  - High volume ventilation, Room air cleaners
  - Upper room UV air disinfection

- Throughout the ventilation circuit?
  - Dilution in return air
  - Air filter or UV in return duct
Global Warming: Ductless AC requires closed windows

AC produces little if any air exchanges with outdoor air

Ventilation reduced by 80% or more

AC sales in India, 2010 – 2015
Red bars are ductless models
Risk of airborne infection increases promptly when windows are closed?

CO₂ measurements over time CO₂ is a good surrogate for Rebreathed Air Fraction and risk of infection.

In one hour after window was closed in an occupied room, the risk of airborne infection doubled!

EDITORIAL
Cool but dangerous: How climate change is increasing the risk of airborne infections
Air Disinfection

1. Natural Ventilation
2. Mechanical ventilation
3. Room air cleaners
4. Upper room germicidal ultraviolet (GUV) air disinfection
Alternatives to Natural Ventilation:

• Natural ventilation:
  – Climate dependent, variable, closed windows (AC, air pollution)

• Mechanical ventilation:
  – Absent or poorly maintained
  – Flow limits: 6-12 ACH recommended – hard to achieve
  – Costly to cool or heat outside air

• Room air cleaners (portable or fixed; filter or UV):
  – Flow limits – rarely more than 1 or 2 ACH, depending on room size
  – Recapture of just processed air

• Germicidal UV air disinfection
  – In ducts – air disinfected after it leaves the room – not optimal!
  – Upper room – highly efficient and effective, requires know-how, manageable safety issues, other barriers
  – New modality may allow surface disinfection in occupied rooms
Germicidal UV is not new technology

Luckiesh’s 1946 monograph

75 years later – the application of upper room UV is an important tool for dealing with the Covid pandemic
Upper Room UVC effectively prevented measles transmission in schools

Wells and Wells Am J Hyg 1942;35:97-121.

FIGURE 45. MEASLES EPIDEMIC IN PHILADELPHIA, 1941. Weekly attack rate among susceptibles (home secondaries excluded)
Upper Room GUV Disinfects a Large Volume of Air at Once

Low velocity ceiling fans assure good air mixing
Cost effectiveness: ventilation vs 3 different room air cleaners vs GUV

Grigory V. Volchenkov, MD, Oblast TB Dispensary, Vladimir, Russia in collaboration with Paul Jensen, PE, IH, PhD (CDC)

Test chamber studies: aerosolized 2 test bacteria, mechanical air sampling

Cost of 1 equivalent ACH in the patient room

Operating cost per year per Eq ACH
Comparison:
Room air cleaner vs upper room GUV
(Pretoria meeting, July, 2016)

Room Air cleaner (RSA) = 60 cfm CADR
= 28.3 l/s
= 2.1 ACH (assuming no re-capture and good air mixing)

Upper room UVGI – avg 30 uW/cm²
For TB, Z = 41
With good air mixing,
= approx 20 ACH!
Room air changes per hour (ACH) and equivalent ACH by UV or other means

- 1 ACH (48 m$^3$/h) removes 63% of room air contaminants (well mixed)
  - The next AC removes 63% of what is left = 86% total
  - If UV inactivates 86% of room air contaminants = 2 equivalent ACH

With continuous contamination higher ACH required to reduce probability of infection ($p$).

CDC recommends 6 – 12 ACH for airborne infection control
Where upper room GUV should be considered for COVID-19?

• In areas where airborne transmission is likely
  – Healthcare: emergency rooms, ICUs, OPD waiting rooms, corridors, jails, shelters, nursing homes, *in addition to PPE*

• From asymptomatic persons who may have Covid: public buildings, stores, restaurants, banks, schools
  – *In addition to* physical distancing, mouth/nose covers, hand washing, etc.

• Caveat: not beneficial if airborne spread is not the principal pathway in that situation, e.g., nursing homes?
Where is most Covid transmission occurring?

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- Throughout the ventilation circuit?

- Rebreathed air fraction
- Dilution in return air

High volume ventilation, Room air cleaners
**Upper room UV air disinfection**

Air filter or UV in return duct
Advances in Upper Room GUV Application

- Proof of efficacy
- Proof of safety
- Practical, evidence-based, dosing guidelines
- Fixture performance specifications defined.
  - Need to measure total fixture output:
    - gonioradiometry - for CAD (Visual-UV)
    - total integrating sphere
    - Rudnick traverse method for louvered fixtures
  - Importance of mean ray length in GUV design.
- Novel fixture designs – the Brandston fixture
- LED UV fixtures, or alternative ways of deployment
- Beyond fixture – ”eggcrate” ceiling UV concept
- Beyond 254 nm – Far UV-C air and surface disinfection
Upper room GUV light for the prevention of airborne tuberculosis transmission

R Escombe, R Ramirez, RH Gilman, M Navincopa, E Ticona, P Sheen, C Noakes, B Mitchell, D Moore, JS Friedland¹, C Evans


UVGI reduced TB: 72% (80%)
Ionisers reduced TB: 58%

Not entirely characterized
– did not use the results to propose guidelines
The Airborne Infections Research (AIR) Facility
Witbank, Mpumalanga Province, SA
Ventilation ducts in patient rooms

Paddle Fans Assure Good Air Mixing
AIR, Experimental Plan

Guinea Pig Air Sampling
Sol Permutt – experimental design, ATS, 1993

Odd days
UVGI or other intervention

Even days
3 patient rooms
Plus common areas

Pt. TB RFLP

Intervention on/off on alternative days
### Results:

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* p<0.0005

**Combined** hazard ratio 4.9 (CI.95: 2.8, 8.6) or **about 80% effective** - corrected for multiple hits.

**Note:** 6 ACH (mechanical) but UVGI added the equivalent of 24 EqACH
**Institutional Tuberculosis Transmission**

**Controlled Trial of Upper Room Ultraviolet Air Disinfection: A Basis for New Dosing Guidelines**

Matsie Mphaphlele\(^1\), Ashwin S. Dharmadhikari\(^2\), Paul A. Jensen\(^3\), Stephen N. Rudnick\(^4\), Tobias H. van Reenen\(^5\), Marcello A. Pagano\(^6\), Wilhelm Leuschner\(^7\), Tim A. Sears\(^8\), Sonya P. Milonova\(^4\), Martie van der Walt\(^9\), Anton C. Stoltz\(^10\), Karin Weyer\(^11\), and Edward A. Nardell\(^8,12\)

**Upper Room Germicidal Ultraviolet Systems for Air Disinfection Are Ready for Wide Implementation**

Shelly Miller editorial

### AIR, Experimental Plan

- **Guinea Pig Air Sampling**
- **Guinea Pig TB RFLP**

- **A**
  - Odd days
  - UVGI or other intervention
  - Plus common areas
  - Pt. TB RFLP

- **B**
  - Even days

### Images

- **80% effective**
- **Added 24 equivalent ACH**

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*Images depict upper room germicidal ultraviolet systems for air disinfection.*
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Upper Room 254 nm GUV is Safe for Room Occupants

ACGIH TLV: 6.0 mJ/cm² for 8-hour period

\[ 0.4 \text{ – } 0.6 \, \mu\text{W/cm}^2 \text{ for 8-hour} \]

- exposure is **not** continuous!

- Tuberculosis UV Shelter Study (TIUSS) showed no eye or skin complaints compared to placebo lamps

IES: UV-C PHOTOCARCINOGENESIS RISKS FROM GERMICIDAL LAMPS SUMMARY (CIE 187:2010)

- Known side effects of overexposure to UV-C radiation include transient corneal and conjunctival irritation (photo-keratoconjunctivitis) and skin irritation (erythema), which disappear within a 24 – 48-hour period, not currently known to produce lasting biological damage.
- The ACGIH and ICNIRP threshold limit for 8-hour continuous exposure to UV-C radiation at 254 nm is 6 mJ·cm-2 (60 J·m-2), and proper installation of well engineered UV-C systems meet this criteria. However, there have been incidents of poor installations resulting in accidental overexposure.
- General statements that all UVR is carcinogenic have raised safety concerns of open air UV-C systems Although, from basic biophysical principles, UV-C radiation is carcinogenic for the same reason that it is an effective germicidal agent, the attenuation provided by the stratum corneum and epithelial tissues of the skin greatly reduces the risk relative to UV-B radiation. UV germicidal irradiation can be safely and effectively used for upper air disinfection without a significant risk for long term delayed effects such as skin cancer.
Summary:

• Sars-CoV-2 appears to spread primarily indoors by large and small airborne droplets, and less so by contaminated surfaces.
• Spread appears to be primarily in the room of the infectious source with little evidence of spread through HVAC systems – although theoretically possible
  – Air disinfection should focus on rooms not recirculation.
• Upper room UV-C (254 nm) is a well-established, safe, and highly effective method of air disinfection that can be implemented today to help reduce the spread of Covid-19
  – High-intensity UV surface disinfection is also well established for unoccupied hospital rooms
  – LED UV and 222 nm UV are becoming available and will make GUV even more useful