Swab stories: Scaling up tuberculosis and Covid-19 screening while protecting worker health

Jerry Cangelosi
Professor, Department of Environmental and Occupational Health Sciences
Adjunct Professor, Departments of Epidemiology and Global Health
April 30, 2020

ENVIRONMENTAL & OCCUPATIONAL HEALTH SCIENCES
UNIVERSITY of WASHINGTON | SCHOOL OF PUBLIC HEALTH

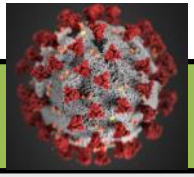
Swab stories:
Scaling up tuberculosis and Covid-19 screening while protecting worker health

1. Non-invasive oral sampling for infectious disease: Rationale
2. Improving TB sample acquisition
3. Improving COVID-19 sample acquisition
4. CoTB: Dual non-invasive sampling for TB and COVID-19

Some recent respiratory disease pandemics

	Cases	Deaths
2002-2003 SARS-CoV-1 coronavirus (source: WHO)	8,422	916
2019-2021 **SARS-CoV-2 (COVID-19)** **(source: WHO, JHU)**	**>123 million to date**	**>2.7 million to date**
Tuberculosis **(source: WHO)**	**10.4 million annually**	**1.6 million annually**

Comparing TB and COVID-19

	Tuberculosis 	COVID-19 
Etiology	*Mycobacterium tuberculosis* bacterium	SARS-CoV-2 coronavirus
Transmission	Airborne droplet nuclei	Airborne droplet nuclei
Presentations of active disease	**Fever, cough, difficulty breathing, fatigue, chills**, wasting, night sweats, loss of appetite.	**Fever, cough, difficulty breathing, fatigue, chills**, aches, sore throat, headache, diarrhea, vomiting, loss of smell or taste,
Immunological prevalence	~33% of human population is latently infected	<2% to >20% are seropositive, depending on location and methodology

Tuberculosis: Occupational risks to healthcare workers (HCW)

- Washington state, USA: Risk of active disease ~1.5X risk over community (OSHA)
- High prevalence countries: Difficult to discern over community background.

Reception area, TB referral clinic in Dhaka, Bangladesh, March 2017

Sputum collection pavilion at a Dhaka TB referral clinic

Occupational Risk Pyramid for COVID-19

VERY HIGH EXPOSURE RISK

Jobs with a high potential for exposure to known or suspected sources of COVID-19 during specific medical, postmortem, or laboratory procedures. Workers include:

- Healthcare and morgue workers performing aerosol-generating procedures on or collecting/handling specimens from potentially infectious patients or bodies of people known to have, or suspected of having, COVID-19 at the time of death.

The four exposure risk levels represent probable distribution of risk.

HIGH EXPOSURE RISK

Jobs with a high potential for exposure to known or suspected sources of COVID-19. Workers in this category include:

- Healthcare delivery, healthcare support, medical transport, and mortuary workers exposed to known or suspected COVID-19 patients or bodies of people known to have, or suspected of having, COVID-19 at the time of death.

COVID-19: Chronic shortages of personal protective equipment (PPE) for healthcare workers in the US

Nurses Die, Doctors Fall Sick and Panic Rises on Virus Front Lines

The pandemic has begun to sweep through New York City's medical ranks, and anxiety is growing among normally dispassionate medical professionals.

Nurses at Jacobi Medical Center in the Bronx gathered early Saturday to protest a shortage of protective equipment, including N95 masks. Gregg Vigliotti for The New York Times

TIME

Begging for Thermometers, Body Bags, and Gowns: U.S. Health Care Workers Are Dangerously Ill-Equipped to Fight COVID-19

Blake Nissen—The Boston Globe/Getty Images

60° Seattle, WA >
Tue, Apr 28, 2020

Newsweek

U.S. | World | Business | Tech & Science | Culture | Newsgeek | Sports | Health | The Debate

HEALTH

HEALTH CARE WORKERS IN 10 STATES FILE COMPLAINTS ABOUT PPE SHORTAGES DURING CORONAVIRUS PANDEMIC

BY BRYAN KIRK ON 4/28/20 AT 4:59 PM EDT

Tuberculosis: Why move beyond sputum collection/analysis?

- Occupational safety for healthcare workers
- Some patients can't always provide sputum (e.g. HIV coinfected)
- Logistically difficult to collect sputum in community settings
- Difficult to process and analyze
- To reduce the burden of disease we need better methods for active case-finding in communities and workplaces.

Sputum samples await processing at Shyamoli TB Clinic, Dhaka, Bangladesh

TB diagnosis by oral swab analysis

What is it?

- 7-10 strokes across tongue dorsum with disposable swab
- qPCR for *Mycobacterium tuberculosis* DNA

Why is it better than sputum?

- Occupational safety
- Some patients can't provide sputum
- Easy to collect and process
- Potential for active case finding

How well does it work?

- Clinical studies in South Africa (N = 209) and Uganda (N = 52)
- Relative to sputum testing:
  - 90-95% sensitive
  - 79-100% specific

TB diagnosis by oral swab analysis

What is it?

- 7-10 strokes across tongue dorsum with disposable swab
- qPCR for *Mycobacterium tuberculosis* DNA

Why is it better than sputum?

- Occupational safety
- Some patients can't provide sputum
- Easy to collect and process
- Potential for active case finding

How well does it work?

- Clinical studies in South Africa (N = 209) and Uganda (N = 121)
- Relative to sputum testing:
  - 90-95% sensitive
  - 79-100% specific

Tongue swab ≠ Saliva

Dept. of Environmental and Occupational Health Sciences
University of Washington

- Rachel Wood, MS
- Kris Weigel
- Alaina Olson
- Meagan Deviaene
- Grant Whitman
- Renee Codsi
- Ethan Valinetz, MD
- Claire Yang
- Divya Naidoo
- Felicia Nguyen
- Rita Olsen
- Nicole Errett

Angelique Luabeya and Mark Hatherill,
South African Tuberculosis Vaccine Initiative (SATVI)

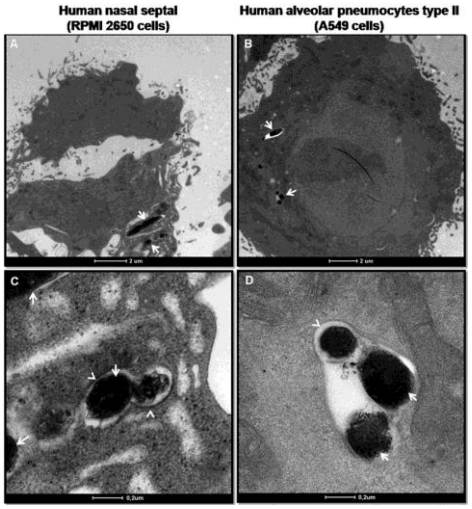
Global Good/Intellectual Ventures: Corrie Ortega, Kyle Minch, Kevin Nichol, Akos Somoskovi, Gleda Hermansky, Paras Jain, Anne-Laure Le Ny, Zarah Radjavi, Tim Motley
University of California, San Francisco: Adithya Cattamanchi
Makere University, Kampala: Alfred Andama
Stellenbosch University: Grant Theron, Loren Rockman
University of Washington Department of Global Health: Sylvia LaCourse, Adrienne Shapiro, Paul Drain
University of Washington Department of BioEngineering: Paul Yager, Steven Bennett, Sujatha Kumar, Erin Heininger

Oral Swab Analysis (OSA): Detection of *Mycobacterium tuberculosis* on oral swabs

Hypothetical mechanism: MTB bacilli and/or DNA accumulate on oral mucosa, based on:

- Reports of zoonotic MTB DNA detection using oral and nasal swabs from monkeys and cows.
- Bacterial adherence to cells and other surfaces

Lisa Jones-Engel



Silva CA et al, 2013

Search for alternatives to sputum

Sample matrix	Sensitivity of GeneXpert testing relative to confirmed TB Dx
Sputum	26/26 (100%)
Saliva	10/26 (39%)
Blood	2/24 (8%)
Urine	1/26 (4%)
Exhaled breath condensate	0/26 (0%)

Data from Shenai S et al (2013). Exploring alternative biomaterials for diagnosis of pulmonary tuberculosis in HIV-negative patients by use of the GeneXpert MTB/RIF assay. Journal of Clinical Microbiology 51(12): 4161-6.

Oral Swab Analysis (OSA): Evaluations in adult pulmonary TB

Oral site	Swab	Sens relative to sputum Xpert® MTB/RIF	Sens relative to all TB cases	Spec relative to ill non-TB & healthy controls	Site
Buccal (cheek)	Whatman OmniSwab 3 swabs/subject	18/20 (90%)	ND	20/20 (100%)	South Africa, USA (Wood et al 2015)
Tongue dorsum	Puritan Purflock 2 swabs/subject	128/138 (93%)	49/59 (83%)	65/71(92%)	South Africa (Luabeya et al 2019)

AMERICAN SOCIETY FOR MICROBIOLOGY | Journal of Clinical Microbiology®

MYCOBACTERIOLOGY AND AEROBIC ACTINOMYCETES

Noninvasive Detection of Tuberculosis by Oral Swab Analysis

Angelique K. Luabeya,[a] Rachel C. Wood,[b] Justin Shenje,[a] Elizabeth Filander,[a] Cynthia Ontong,[a] Simbarashe Mabwe,[a] Hadn Africa,[a] Felicia K. Nguyen,[b] Alaina Olson,[b] Kris M. Weigel,[b] Lisa Jones-Engel,[c] Mark Hatherill,[a] Gerard A. Cangelosi[b]

[a]South African Tuberculosis Vaccine Initiative (SATVI), Institute of Infectious Disease & Molecular Medicine and Division of Immunology, Department of Pathology, University of Cape Town, Cape Town, South Africa
[b]Department of Environmental and Occupational Health Sciences, School of Public Health, University of Washington, Seattle, Washington, USA
[c]Department of Anthropology, University of Washington, Seattle, Washington, USA

OmniSwab PurFlock

Why is there more MTB DNA on tongue swabs than on cheek swabs?

	Cheek OmniSwabs (mean Cq ± SD)	Tongue OmniSwabs (mean Cq ± SD)	*P* (paired T-test)
M. tuberculosis IS6110 (N=49)	36.7 ± 5.5	31.0 ± 5.4	<0.0001

Why is there more MTB DNA on tongue swabs than on cheek swabs?

	Cheek OmniSwabs (mean Cq ± SD)	Tongue OmniSwabs (mean Cq ± SD)	*P* (paired T-test)
M. tuberculosis IS6110 (N=49)	36.7 ± 5.5	31.0 ± 5.4	<0.0001
Human mtDNA (N=42)	21.9 ± 2.6	22.0 ± 2.7	0.52

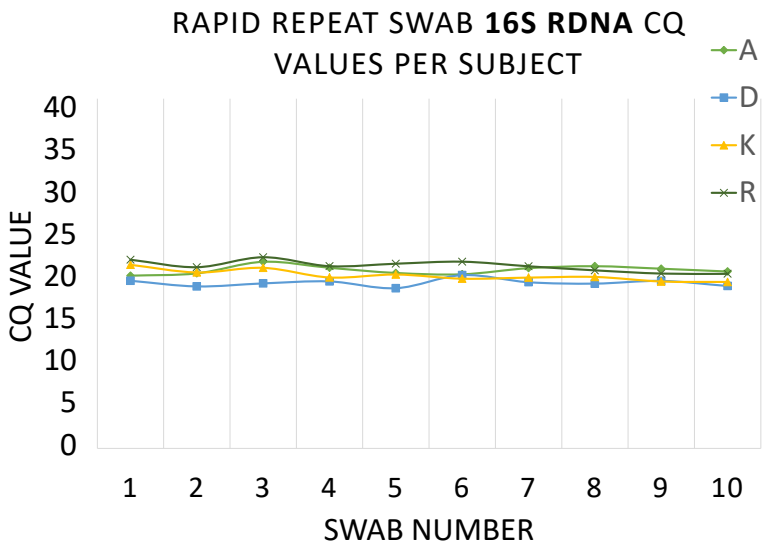
- No difference in human mtDNA between cheek and tongue samples

Why is there more MTB DNA on tongue swabs than on cheek swabs?

	Cheek OmniSwabs (mean Cq ± SD)	Tongue OmniSwabs (mean Cq ± SD)	*P* (paired T-test)
M. tuberculosis IS6110 (N=49)	36.7 ± 5.5	31.0 ± 5.4	<0.0001
Human mtDNA (N=42)	21.9 ± 2.6	22.0 ± 2.7	0.52
Universal bacterial rDNA (N=126)	21.43 ± 5.7	18.22 ± 5.6	<0.0001

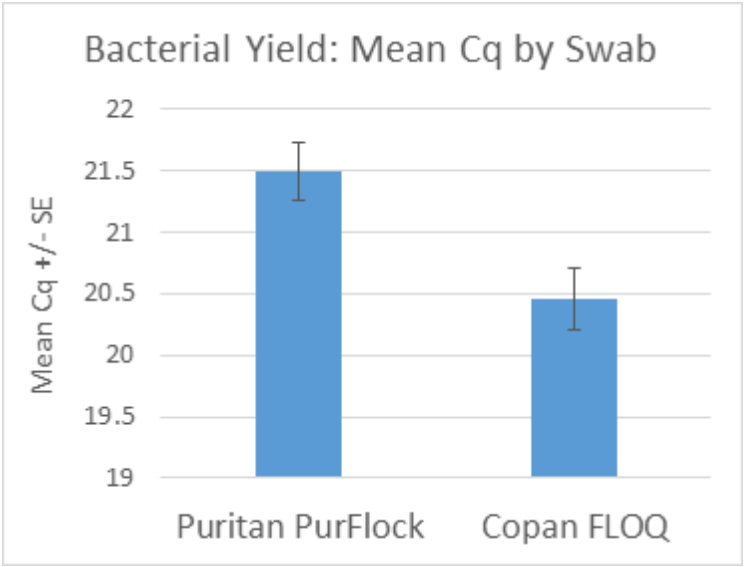
- No difference in human mtDNA between cheek and tongue samples
- Tongues have much more bacterial biomass than inner cheeks
- The oral cavity has sub-environments that differ markedly in microbial biomass
  - Tongue > cheek > gums > saliva

PurFlock swabs collect only a small fraction of bacterial biomass (total 16S rDNA) present on the tongue dorsum



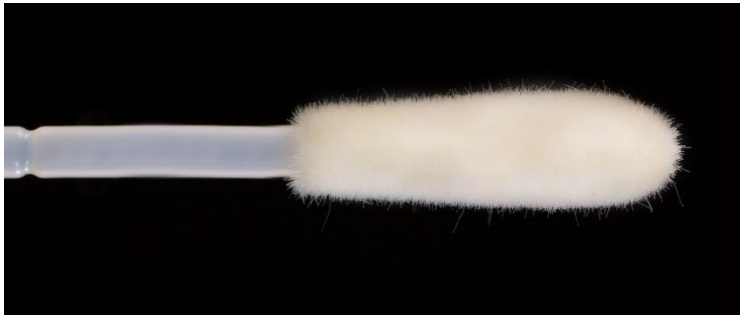
Ten consecutive samplings of four volunteers

Some swab products pick up more material (e.g. Copan FLOQswabs)

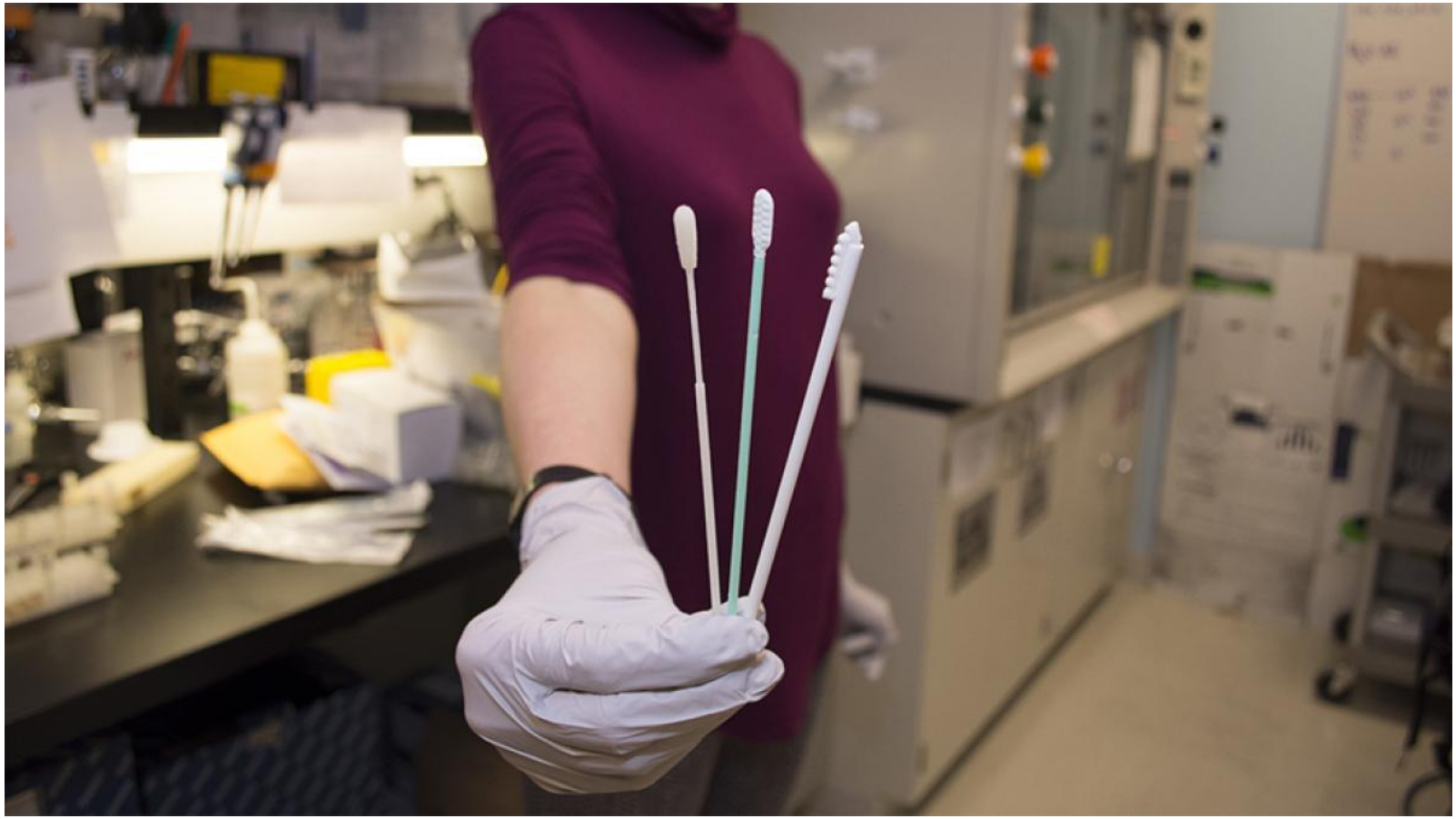


Oral Swab Analysis (OSA): Evaluations in adult pulmonary TB

Oral site	Swab	Sens relative to sputum Xpert® MTB/RIF	Sens relative to all TB cases	Spec relative to ill non-TB & healthy controls	Site
Buccal (cheek)	Whatman OmniSwab 3 swabs/subject	18/20 (90%)	ND	20/20 (100%)	South Africa, USA (Wood et al 2015)
Tongue dorsum	Puritan Purflock 2 swabs/subject	128/138 (93%)	49/59 (83%)	65/71(92%)	South Africa (Luabeya et al 2019)
Tongue dorsum	Copan FLOQswab 1 swab/subject	61/68 (90%)	ND	41/53 (77%)	Uganda (submitted manuscript)



Copan Italia



Ongoing evaluations:

- Additional off-the-shelf products
- Custom designs (with UW BioEngineering and Oasis Diagnostics, Inc.)

SCIENTIFIC REPORTS

OPEN

Microbiological diagnosis of pulmonary tuberculosis in children by oral swab polymerase chain reaction

Received: 21 January 2019
Accepted: 15 July 2019
Published online: 25 July 2019

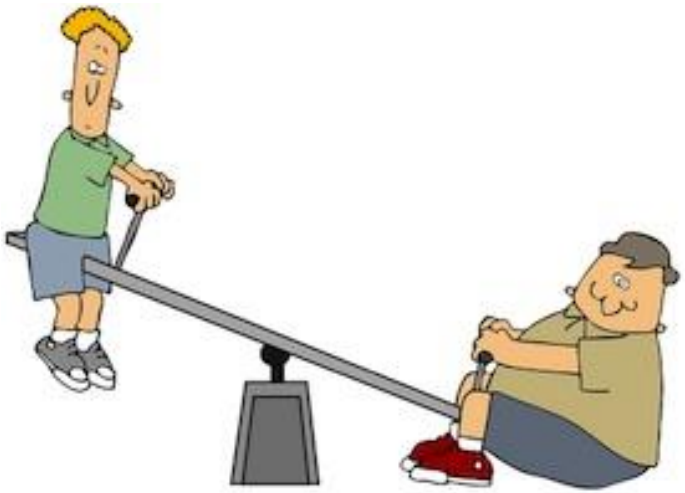
Mark P. Nicol[1,2], Rachel C. Wood[3], Lesley Workman[4], Margaretha Prins[4], Cynthia Whitman[4], Yonas Ghebrekristos[1], Slindile Mbhele[1], Alaina Olson[3], Lisa E. Jones-Engel[5], Heather J. Zar[4] & Gerard A. Cangelosi[3]

OSA for diagnosis of pediatric TB

- Low sensitivity (43%) in sputum-positive children
- However, equal or better than induced sputum when presumptive (sputum-negative) TB cases are included in the baseline (tongue swabs 31%, sputum 21%, p = 0.045)

Improving PCR readouts

- Swab samples are less complex than sputum but may have fewer MTB bacilli
- Therefore, <u>emphasize yield over purification</u>
- Excessive purification (as in standard Cepheid GeneXpert protocol) may be counterproductive. Xpert protocols may be improved for OSA
    - Grant Whitman, Kris Weigel, Rachel Wood
- Purpose-designing sample processing systems that fully exploit the advantages of swabs for POC use
    - With Paul Yager, Steven Bennett, Sujatha Kumar, Erin Heininger, UW BioE



Preprint from Kang et al:

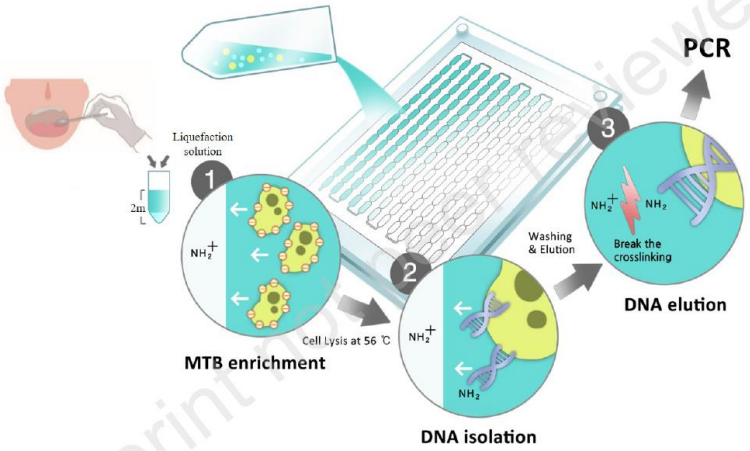
- Single oral swab for TB
- Preliminary non-specific concentration ("enrichment") of bacteria, using homobifunctional imidoesters (HIs)
- Reported to enable excellent sensitivity.

Gene-based diagnosis of tuberculosis from oral swabs with a new generation pathogen enrichment technique in real-world practice

Young Ae Kang[1,2*], Bonhan Koo[3*], Ock-Hwa Kim[4], Joung Ha Park[5], Ho Cheol Kim[4], Hyo Joo Lee[3], Myoung Gyu Kim[3], Youngwon Jang[4], Yong Seo Koo[6], Yong Shin[3,7†], Sei Won Lee [4†] and Sung-Han Kim[5]

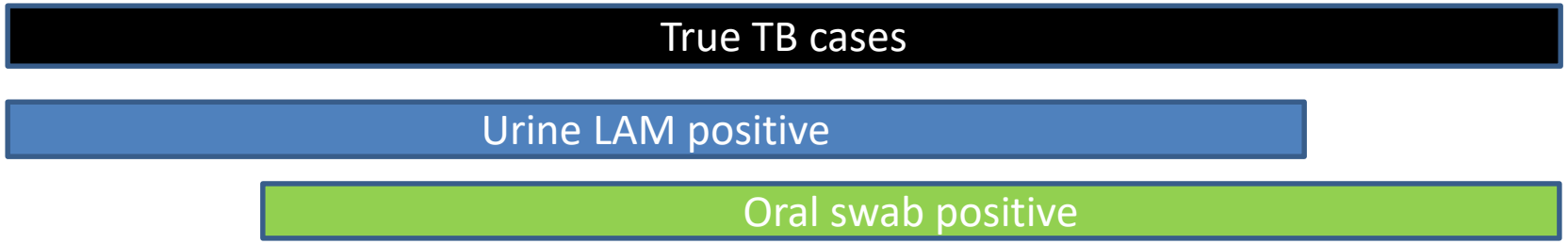
Findings A total of 272 patients (TB, n=128 [47·1%]; not TB, n=144 [52·9%]; mean age, 59·8 years) were enrolled. Overall, the sensitivity of the oral swab-based SLIM assay (65·6%) was higher than that of the sputum-based Xpert assay (43·4%; p=0·001). Specifically, the SLIM oral swab assay showed a notably higher sensitivity in culture-negative TB cases compared with the Xpert assay (64·7% *vs* 9·4%; p=0·001). The specificities of the SLIM and the Xpert were 86·1% and 100%, respectively.

Interpretation The oral swab-based SLIM assay showed a superior sensitivity for TB diagnosis over the sputum-based Xpert assay, especially for culture-negative cases. The novel non-sputum-based diagnostic method may confer a better performance in paucibacillary TB compared with the currently available sputum-based methods.



Toward non-sputum diagnosis of TB in HIV-coinfected patients

- Sputum is often paucibacillary and/or difficult to collect from AIDS patients
- Tests mycobacterial lipoarabinomannan (LAM) in urine are viable alterantives but rarely >80% sensitive relative to composite diagnosis
- Can a noninvasive LAM + OSA algorithm approach 100%?
- BMGF grant: Tongue swab collection in KwaZulu Natal, South Africa complete. Sample analysis began this week.



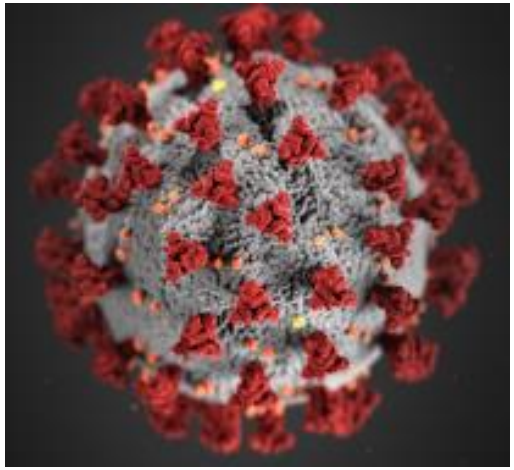
TB diagnosis by OSA: Summary

- For diagnosing active pulmonary TB in adults, tongue swabs are ≥90% sensitive and specific relative to sputum testing.
- Tongue swabbing works much better than cheek or gum swabbing.
  - May involve entrainment of TB bacilli in tongue biofilm
- Copan FLOQswabs are optimal.
- Potential for expanding TB case finding in children.
- Potential for improving diagnosis of TB in HIV-coinfected people.
- Enhancement of methodology is ongoing.

COVID-19:

Non-invasive self-collection of nasal and oral swabs

- **Non-invasive methods approach or match the sensitivity gold-standard invasive (nasopharyngeal swab) methods**
- **Faster and easier → improved throughput**
- **Potential for decreasing occupational exposure of HCW's**

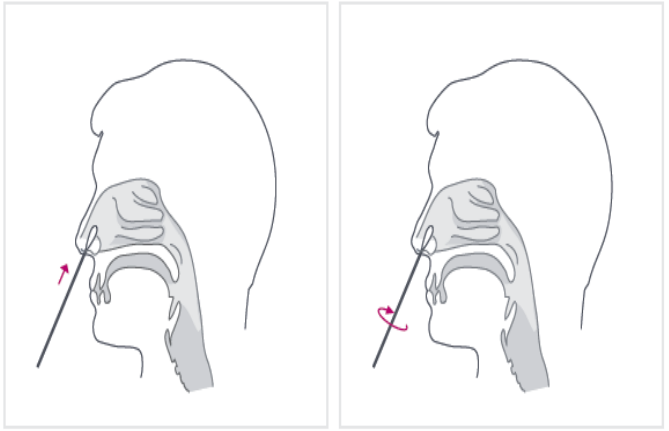


Nasopharyngeal swabbing

- Uncomfortable, not well tolerated by patients
- Induces sneezing and coughing → Hazardous for healthcare workers.
- PPE required!
- Saliva is an attractive alternative
- …. and nasal swabs… and oral swabs

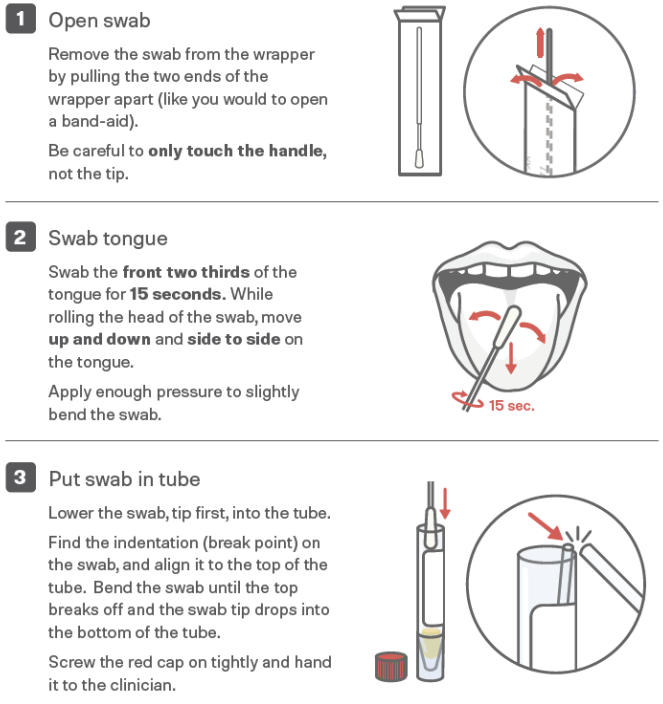
Evaluation of nasal swab and oral swab self-collection

- Hypothesis: SARS-CoV-2 samples can be self-collected by patients, which would reduce worker exposure.
- Collaboration of UnitedHealth Group, Quest Diagnostics, Bill & Melinda Gates Foundation, DEOHS/UW
- March 2020
- 500 ambulatory, symptomatic patients in 5 Puget Sound area clinics.
- Clinician-collected nasopharyngeal swabs (NP).
- Self-collected nasal, tongue, mid-turbinate, swabs.
- All samples tested by RT-PCR (Quest, San Luis Obispo, CA).
- Sensitivity and specificity of self-collected swabs quantified relative to NP results.



1 To collect a nasal swab sample, carefully insert the swab into the nostril exhibiting the most visible drainage, or the nostril that is most congested if drainage is not visible.

2 Using gentle rotation, push the swab until resistance is met at the level of the turbinates (less than one inch into the nostril). Rotate the swab several times against the nasal wall then slowly remove from the nostril.

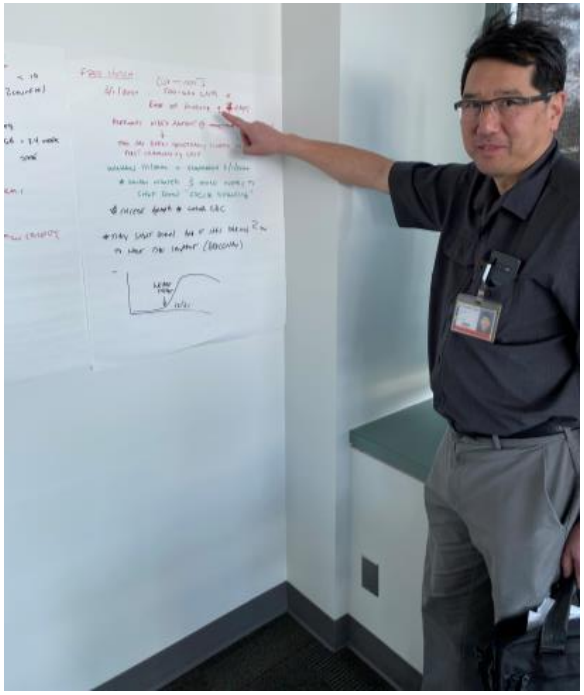


Results:

- Nasal swabs almost as well as NP swabbing → Updated FDA guidance
- Easy, well tolerated, fast (~3 min total)
- Less hazardous to healthcare workers, minimal PPE requirement – breaks logjam
- Nasal swab: 94.0% sensitive (95% CI: 84.6%, 100%)
- Tongue swab: 89.8% sensitive (95% CI: 80.2%, 100%)
- Mid-turbinate: 96.2% sensitive (95% CI: 87.7%, 100%)
- March 23: FDA updated guidance to recommend method

Table 3: A 2x2 table of the test results for all patients who had an NP and a Nasal sample tested.

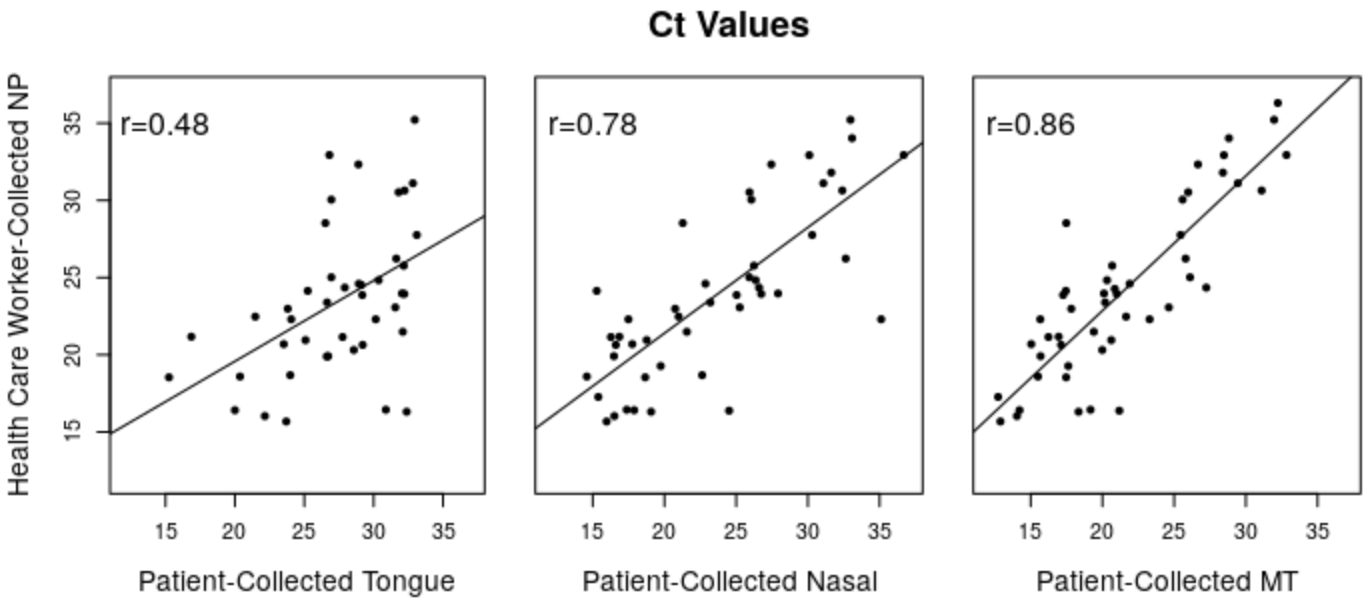
Sensitivity (95% CI): 94.0% (84.6%, 100.0%)		Nasal		
		Negative	Positive	Total
NP	Negative	447	1	448
	Positive	3	47	50
	Total	450	48	498



Tu YP, Jennings R, Hart B, Cangelosi GA, Wood RC, Wehber K, Verma P, Vojta D, Berke EM. Swabs Collected by Patients or Health Care Workers for SARS-CoV-2 Testing. N Engl J Med. 2020 Jul 30;383(5):494-496. PMC7289274.

Results:

- Nasal swabs almost as well as NP swabbing! (94% sensitivity)
- Easy, well tolerated, fast (~3 min total)
- Less hazardous to healthcare workers, minimal PPE requirement – breaks logjam
- Nasal swab: 94.0% sensitive (95% CI: 84.6%, 100%)
- Tongue swab: 89.8% sensitive (95% CI: 80.2%, 100%)
- Mid-turbinate: 96.2% sensitive (95% CI: 87.7%, 100%)
- March 23: FDA updated guidance to recommend method



Why did tongue swabs exhibit variable results for SARS-CoV-2?

- Saliva well known to be good sample for COVID-19
  - Azzi L et al 2002, Senok A et al 2020, Williams E et al 2020, Bababy E et al 2020, To KK et al 2020, Procop G et al 2020, Czumbel LM et al 2020, Hansen KE et al 2020….
- But tongue swabs exhibited variable results in our March 2020 study.
- They were stored in viral transport medium for up to 4 days
  - Opportunities for microbial overgrowth
- Chaotrophic or dry storage may do better than buffer.

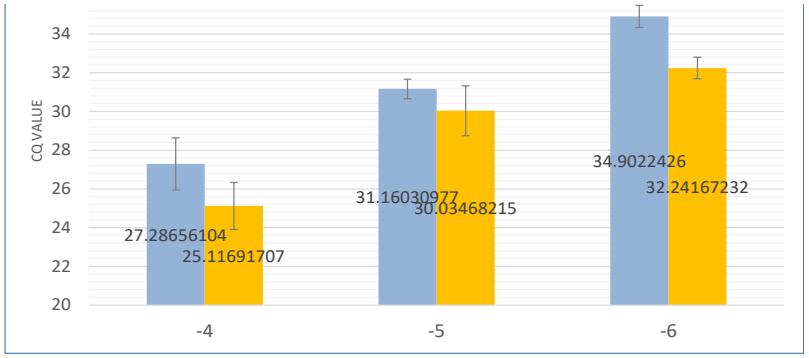
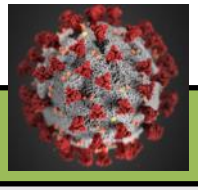


Figure 3. Stability of cultured coronavirus OC43 on tongue swab samples stored for 48 hours frozen in buffer (blue) or dry at room temperature (orange). X axis values are dilution series.

Dry-stored samples have lower Cq values = stronger signals

Co-TB: Co-TB Duplex TB/COVID-19 testing

- Challenges:
  - TB and COVID-19 can present with similar symptoms
  - There is competition for clinical and laboratory resources
- Vision:
  - Tongue swabs as unified samples for TB and COVID-19 (sputum and nasal swabs won't work for this)
  - Every TB sample is a COVID-19 sample, and vice versa
- Funder: Bill & Melinda Gates Foundation

	Tuberculosis 	COVID-19 
Etiology	Mycobacterium tuberculosis bacterium	SARS-CoV-2 coronavirus
Transmission	Airborne droplet nuclei	Airborne droplet nuclei
Presentations of active disease	**Fever, cough, difficulty breathing, fatigue, chills**, wasting, night sweats, loss of appetite.	**Fever, cough, difficulty breathing, fatigue, chills**, aches, sore throat, headache, diarrhea, vomiting, loss of smell or taste,

Co-TB: Co-TB Duplex TB/COVID-19 testing

- Challenges:
  - TB and COVID-19 can present with similar symptoms
  - There is competition for clinical and laboratory resources
- Vision:
  - Tongue swabs as unified samples for TB and COVID-19 (sputum and nasal swabs won't work for this)
  - Every TB sample is a COVID-19 sample, and vice versa
- Funder: Bill & Melinda Gates Foundation

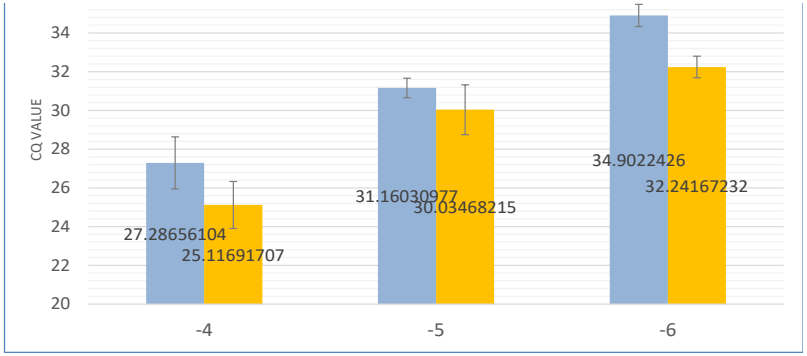


Figure 3. Stability of cultured coronavirus OC43 on tongue swab samples stored for 48 hours frozen in buffer (blue) or dry at room temperature (orange). X axis values are dilution series.

Dry-stored samples have lower Cq values = stronger signals

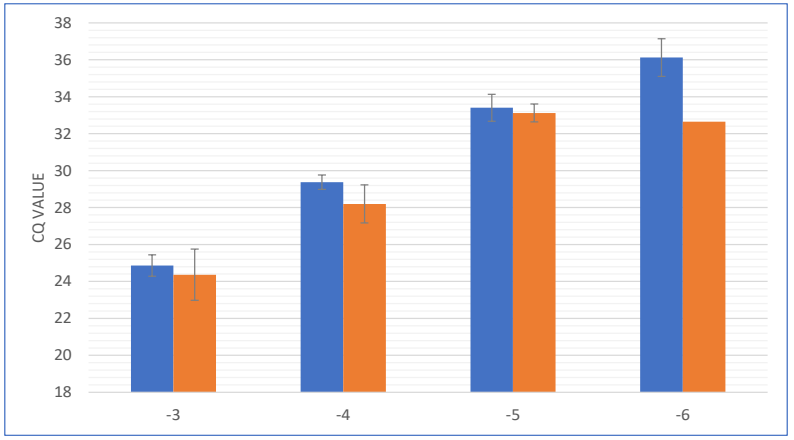


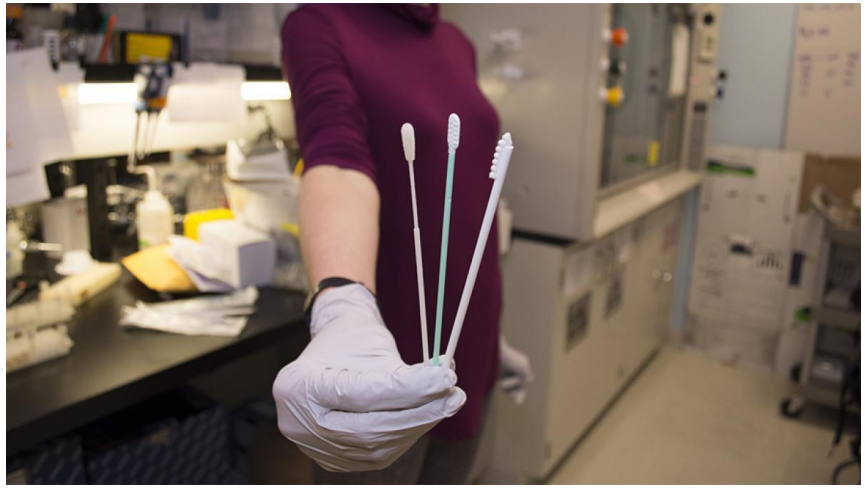
Figure 4. Stability of cultured M. tuberculosis H37Ra on tongue swab samples stored for 48 hours frozen in buffer (blue) or dry at room temperature (red). X axis values are dilution series.

Dry-stored samples have lower Cq values = stronger signals

Dry-stored samples will work for both pathogens

Co-TB: Co-TB Duplex TB/COVID-19 testing

- Challenges:
  - TB and COVID-19 can present with similar symptoms
  - There is competition for clinical and laboratory resources
- Vision:
  - Tongue swabs as unified samples for TB and COVID-19 (sputum and nasal swabs won't work for this)
  - Every TB sample is a COVID-19 sample, and vice versa
- Funder: Bill & Melinda Gates Foundation
- Clinical evaluation under way at the South African Tuberculosis Vaccine Initiative, Western Cape, SA (COVID-19 + TB)



Closing thoughts

- Oral swabs (especially tongue swabs) can become useful samples for diagnosis of <u>infectious diseases that are not normally associated with the oral cavity</u>
  - TB: Accumulation of bacilli from sputum?
  - SARS-CoV-2: Binding to ACE2 receptors in oral epithelial cells?
    - Zhong M et al 2020, Xu H et al 2020…
- Perhaps other diseases as well… (Valinetz and Cangelosi, in revision)

	Sample Type	Sample Collection Notes
Tuberculosis		
Luabeya et al	Tongue swab, buccal swab, gum swab	OmniSwab, PurFlock
Nicol et al[a]	Buccal swab	OmniSwab, PurFlock
Flores et al[a]	Buccal swab	OmniSwab
Mesman et al	Buccal swab	OmniSwab
Lima et al[b]	Tongue swab	
SARS-CoV-2		
Han et al[a]	Saliva	
Kam et al[a]	Buccal swab	Mini UTM Kit with flocked swabs
Azzi et al	Saliva	Drooling technique
Williams et al	Saliva	Spitting out technique
Hanson et al	Saliva	Pooling in mouth then spitting
To et al	Oropharyngeal saliva	Coughing out early morning saliva
Procop et al[c]	Enhanced saliva	Sniffing strongly, coughing out
Mittal et al[c]	Oral rinse	
Babady et al	Oral rinse and saliva	Spitting out technique for saliva
Czumbel et al	Saliva	
Kojima et al[c]	Tongue, buccal, gum, palate swab	Copan flocked swab
Tu et al[c]	Tongue swab	Copan flocked swab
Yokota et al[c]	Saliva	
Senok et al[c]	Saliva	Drooling technique
Pisanic, Randad	Oral mucosal transudate[d]	Oracol device
HIV		
Dziva Chikwari et al[a]	Oral mucosal transudate[d]	OraQuick ADVANCE
Pant Pai et al	Oral mucosal transudate[d]	OraQuick ADVANCE
Beelaert et al	Oral mucosal transudate[d]	DPP HIV 1/2 Assay
Parvovirus B19		
Bodewes et al[a]	Oral mucosal transudate[d]	Oracol device
Pneumocystis jirovecii		
Larsen et al[d]	Oral rinse	
Goterris et al	Oral rinse	
Malaria		
Fung et al	Saliva	Rinse mouth then expectorate
Tao et al[a]	Saliva	Drooling technique
Ebola		
Formenty et al	Oral mucosal transudate[d]	Orasure device
Erickson et al	Oral swab	
Hepatitis C		
Tang et al	Oral mucosal transudate[d]	OraQuick ADVANCE
Liu et al[c]	Oral mucosal transudate[d]	Well Oral Anti-HCV Test,OraQuick

Thank you!

- UW Department of Environmental and Occupational Health Sciences
- Grants from the Bill & Melinda Gates Foundation
- Grants from the NIAID/NIH
- C-THAN
- SURE-EH program
- IVL/Global Good LLC
- Sample donors in South Africa, Uganda, and Washington
- SATVI and the University of Cape Town
- Yuan-Po Tu, Ethan Berke, and colleagues, UnitedHealth Group
- Paul Yager and colleagues, UW Bioengineering
- Paul Drain and colleagues, UW Global Health
- Karen Heichman, Bill & Melinda Gates Foundation
- David Boyle and Jason Cantera, PATH
- Cepheid, Inc.
- Oasis Diagnostics, Inc.
- Santina Castriciano, Copan Italia
- Quest Diagnostics

Questions?