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Photographic grading to evaluate facial cleanliness and trachoma outcomes among children in Amhara region, Ethiopia

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_____

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# Photographic grading to evaluate facial cleanliness and trachoma outcomes among children in Amhara region, Ethiopia

By

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Bachelor of Arts
Pomona College
2015

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## Abstract

Photographic grading to evaluate facial cleanliness and trachoma outcomes among children in Amhara region, Ethiopia

By Ramoncito Caleon

**Background:** Facial cleanliness is an integral part of the SAFE strategy for trachoma. However, facial cleanliness is typically assessed by simple visual inspection in the field at the time of a trachoma survey, which is subject to bias. We performed and graded face photographs among children in a hyperendemic region of Ethiopia to assess for the presence of facial cleanliness measures and their relationship with trachoma outcomes.
**Methods:** Face photographs, conjunctival photographs, and conjunctival swabs were obtained on a random sample of 0–9-year-old children from each of 40 communities in Amhara region, Ethiopia. Face photos were assessed for the presence of 7 measures of an unclean face (i.e., wet nasal secretions, dry nasal secretions, wet ocular secretions, dry ocular secretions, food, dust/dirt, and flies). Conjunctival photos were graded for signs of clinically active trachoma. Conjunctival swabs were processed for the presence of *Chlamydia trachomatis* DNA.
**Results:** Inter-rater agreement between graders ranged from poor for food (Kappa -0.18 [95% CI -0.19 to -0.17]) to substantial (Kappa 0.80 [95% CI 0.79 to 0.82]) for flies. On multivariable analysis of 8,717 children, dry ocular secretion was the facial feature with the strongest association to trachoma outcomes, with age- and gender-adjusted prevalence ratios of 1.29 (95% CI 1.22–1.37) for trachomatous inflammation–follicular, 1.57 (95% CI 1.47–1.68) for trachomatous inflammation–intense, 1.32 (95% CI 1.26–1.39) for active trachoma, and 1.56 (95% CI 0.56–4.30) for ocular chlamydia. Measures of an unclean face exhibited a dose-dependent relationship with trachoma outcomes.
**Conclusions:** Our more objective method of assessing measures of an unclean face through photography found a strong association between dry ocular discharge and trachoma outcomes, and thus has the potential to aid in trachoma survey programs.

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**TITLE:** Photographic grading to evaluate facial cleanliness and trachoma outcomes among children in Amhara region, Ethiopia

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**Keywords:** CHLAMYDIA TRACHOMATIS; CONJUNCTIVA; HYGIENE; SANITATION; TRACHOMA

# Introduction

Trachoma is the most common infectious cause of blindness, affecting approximately 2 million people worldwide [1, 2]. The WHO has endorsed the 4-pronged SAFE strategy for the elimination of trachoma: Surgery for trichiasis, Antibiotics, Facial cleanliness, and Environmental improvements in water, sanitation, and hygiene (WASH) [3]. Facial cleanliness is thought to be important because the infectious agent, *Chlamydia trachomatis*, is present in ocular and nasal secretions, and because flies may serve as a mechanical vector to spread chlamydia from an unclean face to another child [4, 5]. Previous observational studies have frequently found an association between various features of an unclean face and the clinical signs of trachoma [6]. However, facial cleanliness is typically assessed by simple visual inspection in the field at the time of a trachoma survey. Such assessments are subject to bias since the face and conjunctiva are evaluated at the same time by the same person, and thus it is possible that an examiner's assessment of the conjunctiva could be influenced by the face findings, and vice versa.

In a recent study, we performed face photography and conjunctival photography in communities with hyperendemic trachoma, which were then graded for facial cleanliness and trachoma by masked graders, allowing for evaluation of several facial features with less bias. Using this more objective and rigorous method, the goal of the present analysis was to determine which measures of an unclean face were most associated with clinically active trachoma and ocular chlamydial infection.

# Methods

## Study Design and Participants

The present study is an observational analysis using data collected for the WASH Upgrades for Health in Amhara trial (WUHA; clinicaltrials.gov NCT02754583) [7, 8]. WUHA was a cluster-randomized trial of 40 rural communities in a trachoma-hyperendemic region of Ethiopia that assessed the effectiveness of an integrated WASH intervention for control of trachoma. During annual study visits (at baseline and at 12, 24, and 36 months afterwards), a door-to-door population census was performed, and then a random sample of approximately 60 children aged 0–9 years per community were monitored for facial cleanliness and trachoma.

## Procedures

Photographs of the face and the everted right superior tarsal conjunctiva were taken in triplicate with a Samsung Galaxy NX camera equipped with a 60 mm $f/2.8$ macro lens (Seoul, South Korea) using the following camera settings: ISO 400, native flash engaged, automatic white balance, aperture priority ($f/11$ for face and $f/32$ for conjunctiva). A Dacron swab (Puritan Medical Products, Guildford, ME, USA) was then passed three times over the everted conjunctiva. Photos were graded at a grading center at the University of Gondar (Gondar, Ethiopia) by 6 trained ophthalmology residents masked to treatment allocation, study visit, and participant identifier. Conjunctival swabs were stored at -20ºC and processed at the Amhara Public Health institute (Bahir Dar, Ethiopia) with the Abbott RealTime assay (Abbott Molecular, Des Plaines, IL, USA) on the m2000 platform to detect *C. trachomatis* DNA.

## Photographic Grading

Each set of conjunctival photos was assigned to 3 trained photo-graders, who assessed for the presence of trachomatous inflammation—follicular (TF) and trachomatous inflammation—intense (TI) according to the World Health Organization's simplified grading system [9]. Each face photo was evaluated by 3 photo-graders for the presence of each of the following 7 features:

wet nasal secretions, dry nasal secretions, wet ocular secretions, dry ocular secretions, food, dust/dirt, and flies. Multiple photos were taken of each eye and face to increase the chances of a high-quality photo; a single grade was provided for each set of photos. For each trachoma and facial cleanliness grade, the majority consensus among the 3 photo-graders was used for analyses.

## Data Analysis

The 4 outcome variables for this study include TF, TI, TF and/or TI, and ocular chlamydia. The exposure variables included each of the 7 measures of an unclean face. Inter-rater agreement among the 3 graders of each face photo was calculated using Fleiss' Kappa and interpreted as defined by Landis and Kock [10] and using Cohen's Kappa between each grader. The association between each trachoma outcome and each measure of an unclean face was assessed as an age- and gender-adjusted prevalence ratio using repeated measures robust Poisson regression [11]. This method accounted for repeated measurements of the same children while using a clustered Huber/White/sandwich variance estimator to account for intragroup correlation of study clusters. Several permutations of facial cleanliness were explored: first, the presence of any of the 7 measures of an unclean face, and second, a summary facial cleanliness score calculated as the sum of the 7 measures present in a face, with a range from 0 to 7. Statistical analyses were conducted using R v4.2.0 (R Project for Statistical Computing, Vienna, Austria) and Stata version 17 (StataCorp, College Station, TX, USA).

## Ethics Statement

Study protocols were approved by human subjects review boards at the University of California, San Francisco, Emory University, the Ethiopian Food and Drug Authority, and the

Ethiopian Ministry of Science and Technology. Due to high illiteracy levels in the study area, verbal consent was obtained from guardians of participants.

# Results

Between November 9, 2015 and March 5, 2019, face photographs and conjunctival photographs were collected from 8,717 randomly sampled 0–9-year-old children (Fig 1). TF and TI were present in 38% (95% CI 37–39%) and 26% (95% CI 37–39%) of participants, respectively (Table 1). 48% (95% CI 47–49%) of participants were positive for TF and/or TI and 20% (95% CI 19–21%) were positive for ocular chlamydia. Agreement between the photo-graders ranged from poor to substantial for each of the 7 measures of an unclean face, with a Fleiss' kappa value of -0.18 (95% CI -0.19 to -0.17) for food and 0.80 (95% CI 0.79 to 0.82) for flies (Table 2). Agreement between graders 1 and 2 were generally higher than agreement between graders 1 and 3, and between grader 2 and 3 (S1 Table 1)

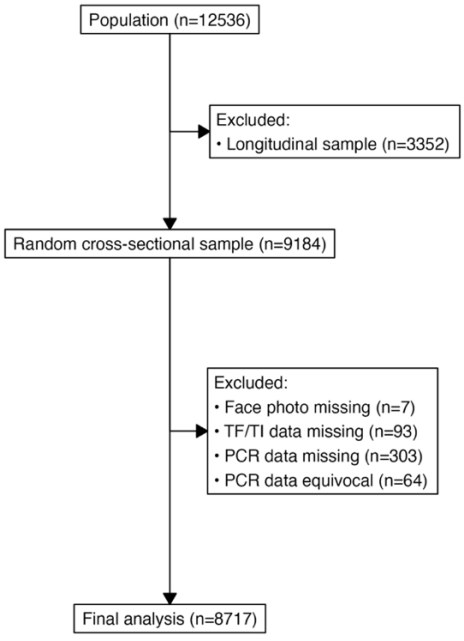


**Figure 1. Flow chart of sampled and analyzed participants.**

**Table 1. Characteristics of study participants (n = 8,717).**

| Variable | n (% of Total) | 95% CI |
|---|---|---|
| **Age (months)**[a] | 60 (36, 84) | - |
| **Gender** | | |
| Female | 4,443 (51) | 50–52 |
| Male | 4,274 (49) | 48–50 |
| **Wet Nasal Secretion** | | |
| Present | 2,250 (26) | 25–27 |
| Absent | 6,467 (74) | 73–75 |
| **Dry Nasal Secretion** | | |
| Present | 3,928 (45) | 44–46 |
| Absent | 4,789 (55) | 54–56 |
| **Wet Ocular Secretion** | | |
| Present | 369 (4) | 4–5 |
| Absent | 8,348 (96) | 95–96 |
| **Dry Ocular Secretion** | | |
| Present | 3,212 (37) | 36–38 |
| Absent | 5,505 (63) | 62–64 |
| **Food** | | |
| Present | 513 (6) | 5–6 |
| Absent | 8,204 (94) | 94–95 |
| **Dust/Dirt** | | |
| Present | 6,632 (76) | 75–77 |
| Absent | 2,085 (24) | 23–25 |
| **≥1 Flies** | | |
| Present | 2,912 (33) | 32–34 |
| Absent | 5,805 (67) | 66–68 |
| **Facial Cleanliness Score** | | |
| 0 | 762 (9) | 8–9 |
| 1 | 1,942 (22) | 21–23 |
| 2 | 2,268 (26) | 25–27 |
| 3 | 2,092 (24) | 23–25 |
| 4 | 1,256 (14) | 14–15 |
| 5 | 346 (4) | 3.6–4.4 |
| 6 | 49 (1) | 0–1 |
| 7 | 2 (0) | 0–1 |
| **TF** | | |
| Positive | 3,299 (38) | 37–39 |
| Negative | 5,418 (62) | 61–63 |
| **TI** | | |
| Positive | 2,249 (26) | 25–27 |
| Negative | 6,468 (74) | 73–75 |
| **TF and/or TI** | | |
| Positive | 4,174 (48) | 47–49 |

| | | |
|---|---|---|
| Negative | 4,543 (52) | 51–53 |
| **Ocular Chlamydia** | | |
| Positive | 1,734 (20) | 19–21 |
| Negative | 6,983 (80) | 79–81 |

[a]Median (IQR)

Abbreviations: TF, trachomatous inflammation–follicular; TI, trachomatous inflammation–intense.

**Table 2. Inter-rater agreement among 3 photo-graders for each measure of an unclean face and trachoma grade.**

| Variable | Kappa | 95% CI | Strength of Agreement |
|---|---|---|---|
| **WNS** | 0.38 | 0.37, 0.39 | Fair |
| **DNS** | 0.46 | 0.45, 0.47 | Moderate |
| **WOS** | -0.02 | -0.03, -0.01 | Poor |
| **DOS** | 0.25 | 0.24, 0.26 | Fair |
| **Food** | -0.18 | -0.19, -0.17 | Poor |
| **Dust/Dirt** | 0.10 | 0.09, 0.11 | Slight |
| **Flies** | 0.80 | 0.79, 0.82 | Substantial |
| **TF** | 0.56 | 0.55, 0.57 | Moderate |
| **TI** | 0.68 | 0.67, 0.69 | Substantial |

[a]Strength of agreement based on interpretation of Landis and Kock (1977) [10].

Abbreviations: WNS, wet nasal secretion; DNS, dry nasal secretion; WOS, wet ocular secretion; DOS, dry ocular secretion TF, trachomatous inflammation–follicular; TI, trachomatous inflammation–intense.

After summarizing the measure of an unclean face according to the majority consensus, dust/dirt was the most prevalent (76.1%, [95% CI 75.2–77.0%]), while wet ocular secretion was the least prevalent (4%, [95% CI 4–5%]) (Table 1). All 7 measures were absent in 9% (95% CI 8–9%) of participants. While most children had various combinations of ocular secretions, nasal

secretions, food/dust/dirt, and flies, 23% (95% CI 23–24%) presented with only 1 of these 4 categories (Fig 2).

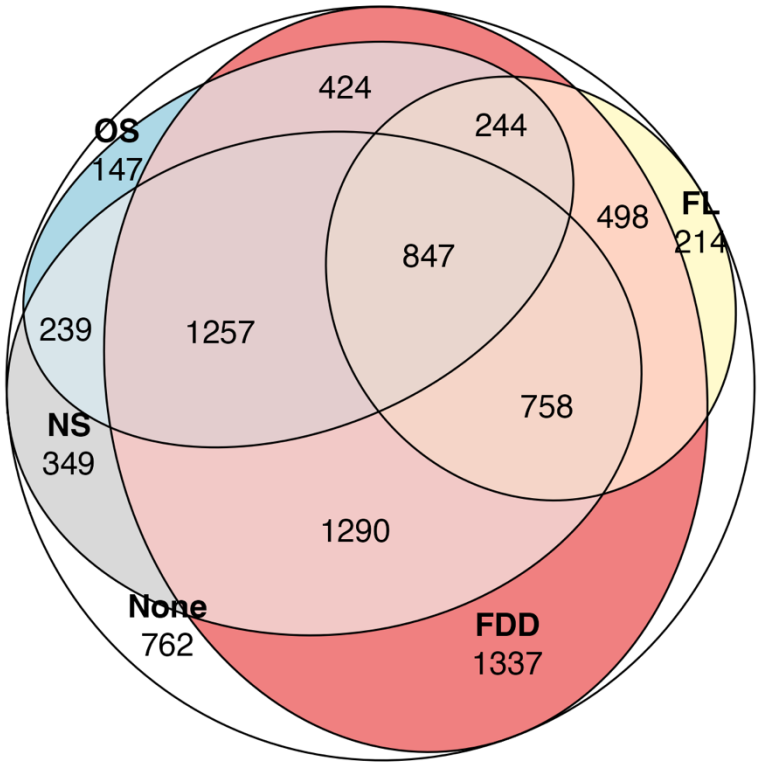


**Figure 2. Number of participants presenting with various combinations of measures of an unclean face.** For visual simplicity, several measures were collapsed, except for flies (FL): wet and dry nasal secretions (NS), wet and dry ocular secretions (OS), food and dust/dirt (FDD).

The proportions of participants with TF and/or TI, and ocular chlamydia were higher if a measure of facial uncleanliness was present (Fig 3). TF and/or TI were most prevalent in those with wet ocular secretions (65% [95% CI 60–70%]) followed by food (61% [95% CI 57–65%]) and dry ocular secretions (61% [95% CI 59–62%]). Ocular chlamydia was most prevalent in those with dry ocular secretions (26% [95% CI 25–28%]) followed by wet ocular secretions (24% [95% CI 20–29%]) and flies (24% [95% CI 23–26%]).

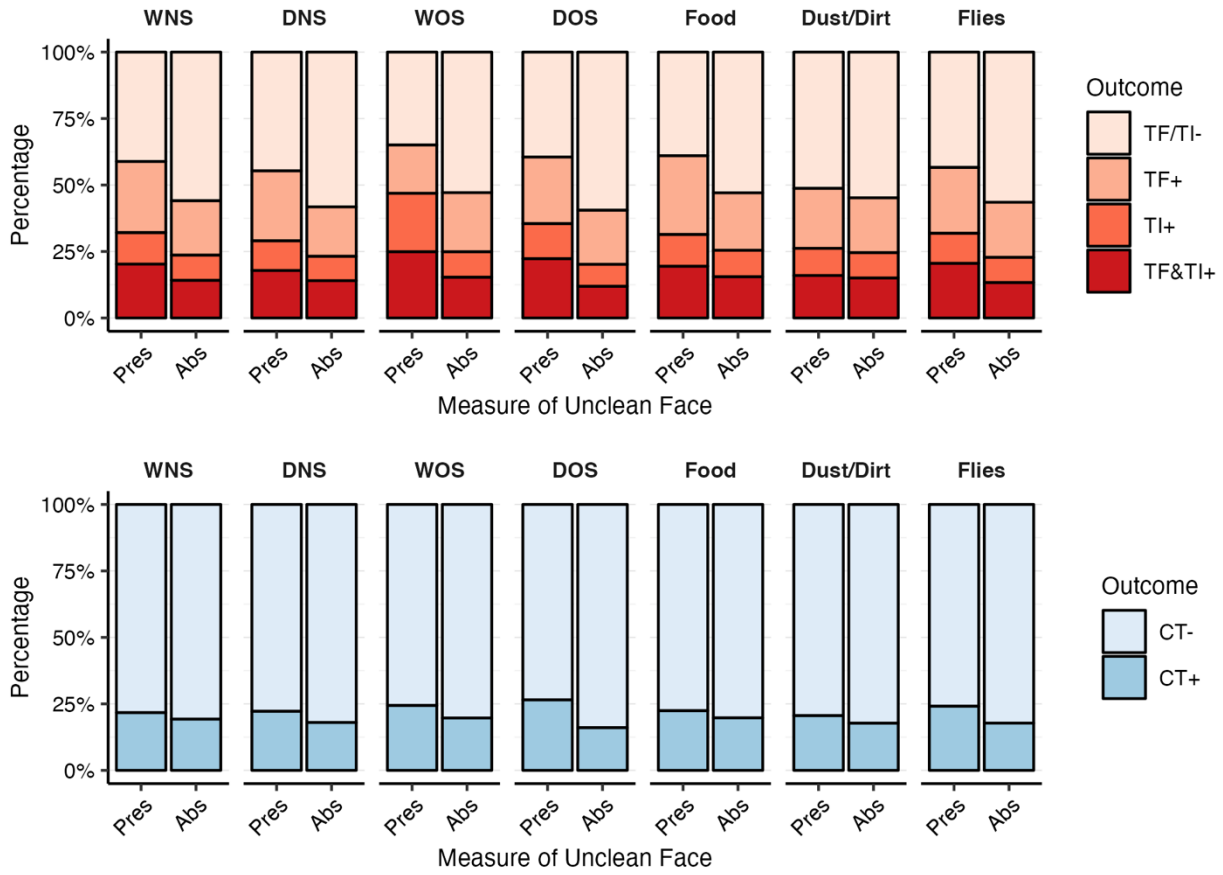


**Figure 3. Prevalence of trachoma outcomes based on the presence (Pres) or absence (Abs) of specific measures of an unclean face.** Abbreviations: TF, trachomatous inflammation–follicular; TI, trachomatous inflammation–intense; CT, ocular *C. trachomatis*; WNS, wet nasal secretion; DNS, dry nasal secretion; WOS, wet ocular secretion; DOS, dry ocular secretion.

Compared to other measures of facial uncleanliness, dry ocular secretions were associated with the highest adjusted prevalence ratios (aPRs) for all trachoma outcomes (Fig 4). The presence of dry ocular secretions was associated with an increased prevalence of TF (aPR 1.29, 95% CI 1.22–1.37), TI (aPR 1.57, 95% CI 1.47–1.68), TF and/or TI (PR 1.32, 95% CI 1.26–1.39), and ocular chlamydia (aPR 1.56, 95% CI 0.56–4.30). Other measures that showed some association to clinical trachoma outcomes were wet nasal secretion (TF aPR 1.15 [95% CI

1.10–1.21]; TI aPR 1.11 [95% CI 1.02–1.19]; and TF and/or TI aPR 1.12 [95% CI 1.07–1.16]) and flies (TF aPR 1.24 [95% CI 1.13–1.36]; TI aPR 1.32 [95% CI 1.15–1.52]; and TF and/or TI aPR 1.22 [95% CI 1.12–1.34]).

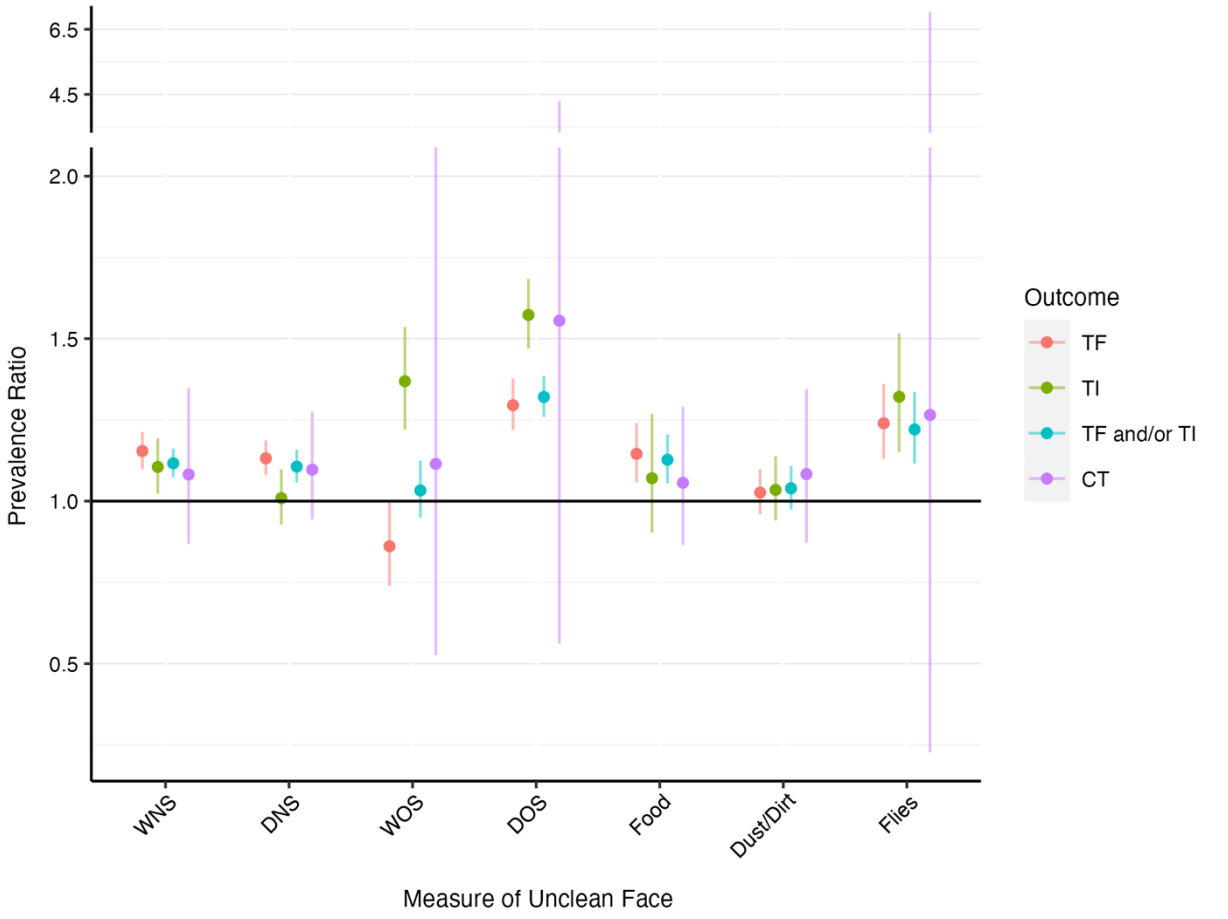


**Figure 4. Age- and gender-adjusted prevalence ratios of trachoma outcomes by measures of an unclean face.** Abbreviations: TF, trachomatous inflammation–follicular; TI, trachomatous inflammation–intense; CT, ocular *C. trachomatis*; WNS, wet nasal secretion; DNS, dry nasal secretion; WOS, wet ocular secretion; DOS, dry ocular secretion.

Combining individual facial features into a summary facial cleanliness score resulted in generally higher aPRs for all trachoma outcomes with each increase in the cleanliness score (Fig

5). Compared to having a cleanliness score of 0 (i.e., having no facial feature present), the prevalence of TF and/or TI was 1.17 (95% CI 1.05–1.30) times higher with a cleanliness score of 1 and 2.19 (95% CI 1.81–2.65) times higher with a cleanliness score of 6 or 7.

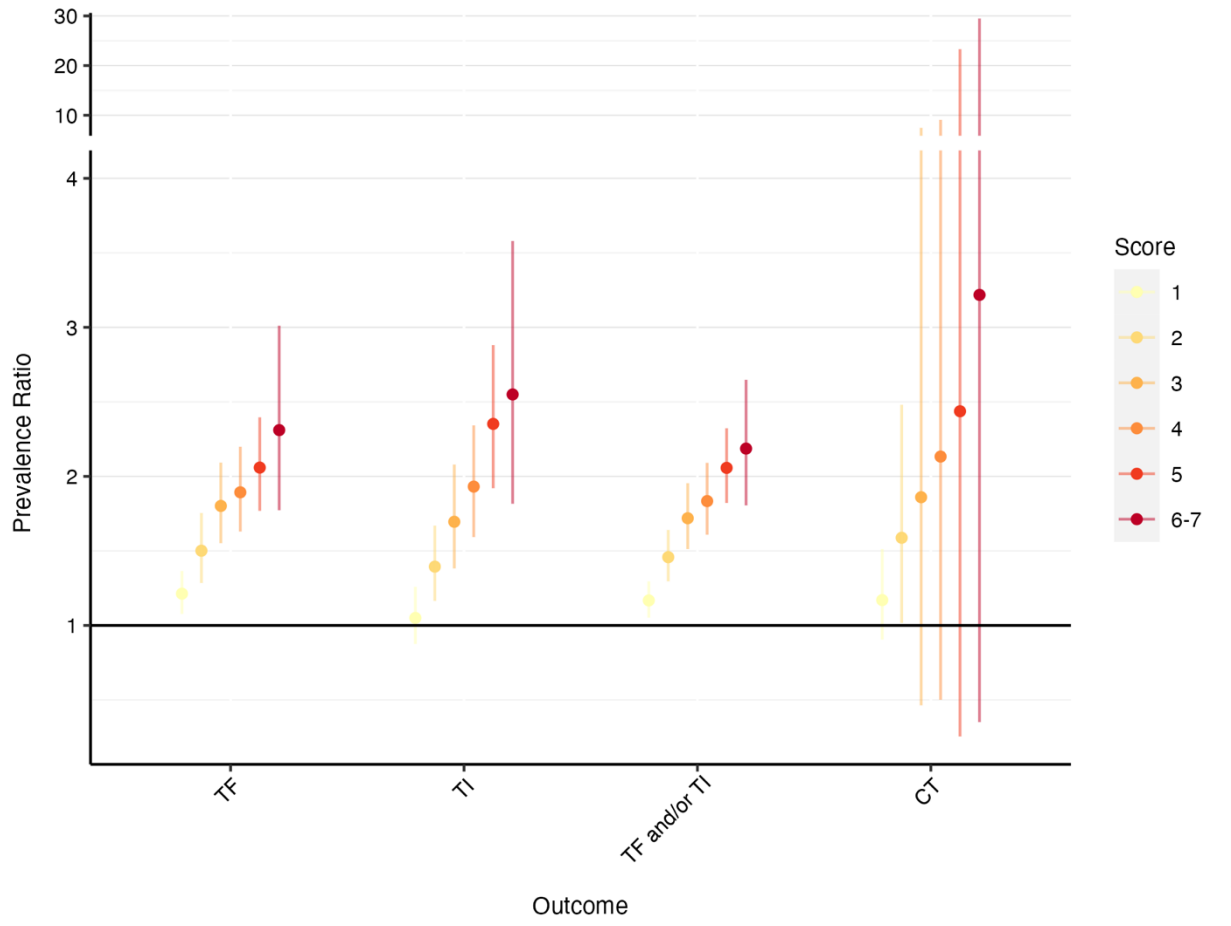


**Figure 5. Age- and gender-adjusted prevalence ratios of trachoma outcomes by facial cleanliness score.** The reference value was a score of 0 (i.e., absence of all facial uncleanliness features). Abbreviations: TF, trachomatous inflammation–follicular; TI, trachomatous inflammation–intense; CT, ocular *C. trachomatis*.

# Discussion

The present study used face and conjunctival photographs to evaluate facial uncleanliness and clinical signs of trachoma in a masked fashion, providing a less biased assessment of the

associations between various features of facial uncleanliness and trachoma. To our knowledge, only one prior study has relied on face photos graded by trained image graders to evaluate facial cleanliness [12]. Compared to our inter-rater agreement, the values reported in this prior work were higher but followed the same pattern, with the weakest agreement in evaluating food and dust, and near perfect agreement for flies. High prevalence in one category is known to lower kappa values, which may have biased our results; our measures with the lowest kappa values were either the most present (e.g., dust/dirt) or absent (e.g., wet ocular secretion, food) in our study population. In contrast to face photos, conjunctival photos have long been used in research studies to detect trachoma. Compared to kappa values for TF and TI from prior studies, our kappa statistics were lower than the median but within range [13].

The 3 graders of each face photograph had varying inter-rater agreement for each of 7 measures of an unclean face. This wide range of inter-rater agreement highlights the importance of consensus among multiple graders. Prior work in the same hyperendemic region of Amhara compared trachoma grading methods and found that inter-rater agreement was lower for photographic versus in-field assessment, but both were comparably high when assessed as a consensus grade [14].

Of the 7 measures, the presence of dry ocular secretions consistently had the strongest associations with clinical and laboratory indicators of trachoma, with aPRs from 1.30 to 1.57. However, these estimates were lower than previously reported (Table 3). A 2014 meta-analysis of studies on ocular discharge reported odds ratios (ORs) of 2.38 (95% CI 1.64–4.35) for TF and/or TI, and 2.50 (95% CI 2.04–3.23) for ocular chlamydia [6]. More recently Last et al, published ORs of 2.71 (95% CI 1.39–5.29) for TF and/or TI and 2.33 (95% CI 1.25–4.35) for ocular chlamydia [15]. Harding-Esch et al, used trachoma outcomes to model the presence of

ocular secretion and found adjusted ORs of 7.2 (95% CI 4.7–10.8) for TF and 2.6 (95% CI 1.0–6.4) for ocular chlamydia [16]. The presence of wet nasal secretions and face flies had less pronounced but statistically significant associations with clinical trachoma outcomes, with respective aPRs of 1.12 and 1.22 for TF and/or TI. These estimates were also lower than previously reported, which ranged between 1.31–2.87 for nasal discharge and 1.37–5.82 for flies (Tables 3 and 4).

**Table 3. Association between measures of an unclean face and trachoma outcomes in selected studies.**

| Outcome | Study First Author (Year) | Sample Size | OR (95% CI)[a] | | | | |
|---|---|---|---|---|---|---|---|
| | | | Ocular discharge | Nasal discharge | Flies | Dust/Dirt | Food |
| TF | Harding-Esch (2020) [16][b] | 1,613 | 7.2 (4.7–10.8) | 2.3 (1.6–3.2) | 1.8 (1.2–2.7) | 2.2 (1.5–3.1) | |
| TF and/or TI | West (1991) [17] | 472 | 1.13 (0.77–1.64) | 1.31 (0.87–1.97) | 1.37 (0.93–2.00) | 1.18 (0.79–0.76) | 0.91 (0.63–1.34) |
| | Cumberland (2005) [18] | 1,960 | 3.0 (1.94–4.55) | 1.80 (1.29–2.52) | 3.40 (2.37–4.88) | | |
| | Edwards (2008) [19] | 1,722 | 4.09 (1.26–13.25) | 2.87 (1.32–6.26) | 3.29 (1.27–8.91) | | |
| | Ayele (2011) [20] | 571 | 3.23 (1.90–5.49) | 1.46 (1.00–2.12) | 1.59 (0.97–2.61) | | |
| | King (2011) [12] | 424 | 4.2 (2.4–7.4) | 1.7 (1.1–2.8) | 2.7 (1.7–4.2) | 0.3 (0.1–0.6) | 0.3 (0.2–0.5) |
| | Last (2014) [15] | 618 | 2.71 (1.39–5.29) | 2.26 (1.35–3.77) | | | |
| | Stocks (2014) [6][c] | 13-14 studies | 2.38 (1.64– | 1.61 (1.39– | | | |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| | | | 4.35) | 1.92) | | | |
| CT | Burton (2005) [21] | 1,319 | 1.69 (0.76–3.76) | 1.70 (1.00–2.87) | 2.50 (1.38–4.54) | | |
| | Edwards (2008) [19] | 1,722 | 1.98 (0.89–4.39) | 1.41 (0.70–2.87) | 1.21 (0.62–2.36) | | |
| | Ayele (2011) [20] | 575 | 4.69 (1.37–16.04) | 0.90 (0.36–2.28) | 1.18 (0.37–3.80) | | |
| | Amza (2012) [22] | 4,484 | 1.21 (0.97–1.51) | 1.12 (0.89–1.42) | 1.30 (1.02–1.63) | | |
| | Last (2014) [15] | 618 | 2.33 (1.25–4.35) | 2.17 (1.48–3.20) | 2.00 (0.57–7.10) | | |
| | Stocks (2014) [6][c] | 4 studies | 2.50 (2.04–3.23) | 1.78 (1.32–2.70) | | | |
| | Harding-Esch (2020) [16][b] | 1,613 | 2.6 (1.0–6.4) | 1.5 (0.7–3.3) | 2.0 (0.8–5.2) | 1.4 (0.6–3.4) | |

[a]Different studies used various models (e.g., univariable vs multivariable) were used to calculate an odds ratio.
[b]This study used trachoma outcomes as explanatory variables measures of an unclean face as response variables.
[c]Studies featured in this meta-analysis which only reported on ocular and/or nasal secretions were excluded from this table.

Abbreviations: CI, confidence interval; TF, trachomatous inflammation–follicular; TI, trachomatous inflammation–intense.

**Table 4. Association between presence flies on the face and trachomatous inflammation–follicular (TF) and/or trachomatous inflammation–intense (TI) in selected studies.**

| Study First Author (Year) | Sample Size | OR (95% CI)[a] |
|---|---|---|
| Schemann (2002) | 15,187 | 1.92 (1.62-2.29) |

| | | |
|---|---|---|
| Schemann (2003) | 16,514 | 5.82 (4.74-7.16) |
| Faye (2005) | 1,648 | 2.26 (1.43—3.58) |
| Baggaley (2006) | 12,415 | 3.98 (2.98–5.31) |
| Schemann (2007) | 14,656 | 1.69 (1.42—2.01) |
| Golovaty (2009) | 507 | 4.03 (1.40–11.59) |
| Hagi (2010) | 14,627 | 2.36 (1.95–2.85) |
| Mpyet (2010) | 639 | 4.14 (2.72–6.29) |
| Mpyet (2012) | 1,572 | 1.98, (1.30–3.02) |

[a]Different studies used various models (e.g., univariable vs multivariable) were used to calculate an odds ratio.

Abbreviations: CI, confidence interval

Our relatively lower estimates of association may be due to our use of prevalence ratios as a more appropriate measure for this cross-sectional study, in contrast to most other studies on the topic that have relied on ORs. When the outcome is common, such as in the present study, the OR can overestimate the prevalence ratio [11, 23]. To our knowledge, only one other study, relied on prevalence ratios, with an unadjusted prevalence ratio of 2.71 (95%, CI 1.19–6.14) among children with eye discharge [24].

Differentiating between wet and dry secretions allowed us to individually analyze 7 facial components and create a new scoring system to further characterize facial cleanliness. In our study, measures of an unclean face exhibited a dose-dependent relationship with trachoma outcomes, with a higher prevalence of trachoma in faces exhibiting more types of facial components. Few studies have explored this dose-dependent relationship; Cumberland et al observed an increase in the adjusted odds ratio for TF and/or TI from 3.0 (95% CI 1.94–4.55) to 8.30 (95% CI 4.94–13.90) when ocular discharge but no flies were present versus when both were present [18].

In addition, few studies on this topic have differentiated between wet and dry secretions [12, 25]. The present study found that wet and dry ocular and nasal secretions had variable associations with trachoma outcomes, suggesting that more information may be provided by differentiating between wet and dry secretions. The question of which features of facial uncleanliness should be used to define an unclean face is challenging and may depend on the specific context. For example, although dry ocular secretions had the strongest association with trachoma outcomes in this study, ocular secretions are a common sequela of ocular chlamydia infection, and thus may simply be an indicator of trachoma as opposed to a risk factor for transmission of trachoma [26].

The present study employed a novel method of using both face and conjunctival photography for a more objective assessment of facial cleanliness and trachoma outcomes. During the trial, high-quality face photographs were taken, which have been shown to have good agreement with in-field grades and offer the benefit of a masked outcome [27, 28]. Our study was also the first to evaluate the relationship between 7 facial features with various trachoma outcomes in a huge study population over multiple years. This study is also one of few that have

used prevalence ratios to measure association, differentiated between wet and dry secretions, and characterized a dose-dependent relationship between trachoma outcomes and measures of an unclean face.

A number of limitations must be acknowledged. First, despite the more objective approach of photo-grading, the graders could still subject to bias in assessing the presence or absence of facial features. Gender, age, and culture of graders may have played a role in what constitutes facial secretions or "dirt." Second, we did not compare our photographic grades to in-field assessments, although a systematic review on conjunctival photographs have shown acceptable agreement between grades on images and in the field [13]. Third, although we evaluated the relationship between measures of an unclean face and trachoma outcomes, we are not able to comment on the relationship with face-washing behavior, an upstream factor in the causal pathway and important variable to monitor program outputs. However, prior work found that assessments conducted in the household setting, compared to a clinical setting, more accurately reflect the true prevalence of unclean faces [29]. This is another potential benefit of remote grading of photographs taken in-field. Last, varying prevalence of facial features across different communities, which may be due to cultural and geographic differences, may limit the applicability of our findings outside of the study region.

In summary, the present study used face and conjunctival photographs and found that among 7 measures of an unclean face there was a dose-dependent relationship with trachoma outcomes, and dry ocular secretion having the strongest association. While further work is necessary to characterize the causality between various features of an unclean face and trachoma, there is potential in incorporating our novel method to trachoma survey programs, particularly in those already employing conjunctival photograph grading.

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# Supporting Information

**S1 Table 1. Inter-rater agreement (Cohen's Kappa) among each of the photo-graders for each measure of an unclean face and trachoma grade.**

| Variable | Rater 1 vs Rater 2 | Rater 1 vs Rater 3 | Rater 2 vs Rater 3 | Mean Among Raters |
|---|---|---|---|---|
| **WNS** | 0.69 | 0.31 | 0.34 | 0.45 |
| **DNS** | 0.53 | 0.44 | 0.40 | 0.46 |
| **WOS** | 0.38 | 0.06 | 0.07 | 0.17 |
| **DOS** | 0.28 | 0.27 | 0.24 | 0.26 |
| **Food** | 0.22 | 0.03 | 0.04 | 0.10 |
| **Dust** | 0.04 | 0.16 | 0.16 | 0.12 |
| **Flies** | 0.78 | 0.79 | 0.84 | 0.80 |
| **TF** | 0.55 | 0.56 | 0.57 | 0.56 |
| **TI** | 0.69 | 0.69 | 0.65 | 0.68 |

Abbreviations: WNS, wet nasal secretion; DNS, dry nasal secretion; WOS, wet ocular secretion; DOS, dry ocular secretion TF, trachomatous inflammation–follicular; TI, trachomatous inflammation–intense.