Five-Year Community Surveillance Study for Acute Respiratory Infections Using Text Messaging: Findings From the MoSAIC Study

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Background. Acute respiratory infections (ARI) are the most common infectious diseases globally. Community surveillance may provide a more comprehensive picture of disease burden than medically attended illness alone.

Methods. In this longitudinal study conducted from 2012 to 2017 in the Washington Heights/Inwood area of New York City, we enrolled 405 households with 1915 individuals. Households were sent research text messages twice weekly inquiring about ARI symptoms. Research staff confirmed symptoms by follow-up call. If ≥2 criteria for ARI were met (fever/feverish, cough, congestion, pharyngitis, myalgias), staff obtained a mid-turbinate nasal swab in participants’ homes. Swabs were tested using the FilmArray reverse transcription polymerase chain reaction (RT-PCR) respiratory panel.

Results. Among participants, 43.9% were children, and 12.8% had a chronic respiratory condition. During the 5 years, 114,724 text messages were sent; the average response rate was 78.8% ± 6.8%. Swabs were collected for 91.4% (2756/3016) of confirmed ARI; 58.7% had a pathogen detected. Rhino/enteroviruses (51.9%), human coronaviruses (13.9%), and influenza (13.2%) were most commonly detected. The overall incidence was 0.62 ARI/person-year, highest (1.73) in <2 year-olds and lowest (0.46) in 18–49 year-olds. Approximately one-fourth of those with ARI sought healthcare; percents differed by pathogen, demographic factors, and presence of a chronic respiratory condition.

Conclusions. Text messaging is a novel method for community-based surveillance that could be used both seasonally as well as during outbreaks, epidemics and pandemics. The importance of community surveillance to accurately estimate disease burden is underscored by the findings of low rates of care-seeking that varied by demographic factors and pathogens.

Keywords. influenza; SMS; text message; surveillance; acute respiratory infections.

Acute respiratory infections (ARI) are the most common infectious diseases globally [1]. ARI leads to over 25 million primary care and 9 million emergency department (ED) visits annually in the United States [2, 3] and is 1 of the 5 most common medical conditions associated with the highest amount of direct medical spending for children [4]. ARI also result in indirect costs and societal burden due to healthcare resource use [5, 6], reduced productivity, and an estimated 42 million missed work/school days annually [7].

ARI surveillance, including influenza, is primarily performed by assessing medically-attended episodes, including outpatient visits and/or hospitalizations. Community-based surveillance may provide a more comprehensive picture of disease burden; for the influenza A H1N1 pandemic, the Centers for Disease Control and Prevention (CDC) calculated the median multiplier needed to more accurately report estimated cases was 79 [8].

One challenge in conducting community-based ARI surveillance is the timely identification of illness and laboratory sample collection. Previous studies have used phone calls, either in person or automated, to conduct ARI assessments [9, 10]. Text messaging is a potentially novel way to rapidly, consistently, and frequently conduct surveillance longitudinally for ARI in a community sample. More recently, other surveillance studies have used emails and text messages as a prompt to complete symptom questionnaires online and collect swabs [11]. However, the use of stand-alone text messages, which may be more accessible to low-income populations with limited data plans, has been less well described. Limited information is also available on longitudinal use.

The objectives of this 5-year community surveillance study were to describe ARI incidence, etiology, and factors associated with infection and care-seeking, as well as to evaluate use of text messaging for longitudinal surveillance in a low-income population.
METHODS

Study Design and Population

In the Centers for Disease Control and Prevention (CDC)-funded Mobile Surveillance for Acute Respiratory Infections and Influenza-Like Illness in the Community (MoSAIC) study, we recruited and followed households in a low-income community in New York City from December 2012 to September 2017 in which 20% of residents live in poverty [12]. Recruitment methods have been previously reported [13] and were supplemented in subsequent years by participant referral. Eligibility criteria included: living within the surveillance community located in Washington Heights/Inwood in Northern Manhattan; household with ≥3 persons, including ≥1 member <18 years-old; Spanish or English-speaking; and having a household member with a cellphone with text messaging capabilities who agreed to complete twice-weekly symptom assessments for all household members and participate in monthly home visits. Households were required to participate for 1 year, October through September, and could remain in the next year if they continued to meet eligibility. For the 2012–13 season, 161 household were under surveillance, for subsequent seasons, new households were recruited through February 2017 to maintain 250 households.

Text Messaging and Swab Collection

Study procedures have been previously reported [13]. Briefly, one person (the household reporter) received a text message twice-weekly: “Reply with 1 or 2. Does anyone in the household have runny nose, congestion, sore throat, cough, body aches, or fever, or feels [sic] hot? 1: yes; 2: no.” In May 2015, the term “allergies” was added because households were not reporting qualifying symptoms that they believed were due to allergies as illness. Messages were sent in English or Spanish based on reporter’s preference. Research staff followed up by phone for positive responses to confirm symptoms and elicit secondary symptoms. For those ≥1 year-old, if ≥2 criteria for ARI were met (fever [feverish], runny nose/congestion, sore throat, cough, and/or myalgias) research staff obtained a mid-turbinate nasal swab from the ill participant in their home, generally within 2 days. For those <1 year-old, congestion alone qualified. All households were visited monthly to promote retention, update household composition if someone left the household for >2 weeks, and capture illnesses not reported. If a household member met ARI criteria at an enrollment or monthly visit, a swab was obtained.

Research staff made follow-up phone calls starting 10 days post-illness to capture illness length, medical care sought, and missed school and work. The household reporter received $20/month for responding to ≥75% of text messages. Families who stopped responding were called, and alternative cell phones used to continue messaging if needed. The Columbia University Irving Medical Center and CDC institutional review boards approved this study. Informed consent from adults and verbal consent from appropriately aged children were obtained to collect swabs.

Respiratory Pathogen Detection

Swabs were analyzed using a multiplex reverse transcription polymerase chain reaction (RT-PCR) (FilmArray Respiratory panel BioFire Diagnostics, Inc) for 20 respiratory pathogens including adenovirus, human coronavirus (HKU1, NL63, 229E, OC43); human metapneumovirus (HMPV), rhino/enterovirus; influenza (A, A/H1, A/H3, A/H1-2009, B); parainfluenza (type 1, 2, 3, 4); respiratory syncytial virus (RSV), Bordetella pertussis; Chlamydia pneumoniae, and Mycoplasma pneumoniae [14]. Results were not reported to households.

Statistical Analysis

Text message response rates and proportions of each pathogen detected were calculated. Annual incidence (ARI/person-year) was assessed overall and by age group. Number of ill days (symptom onset to reported normal activity resumption) were assessed overall and by pathogen.

The association with ARI of factors (age, sex, self-reported health [excellent, good, fair, poor], chronic respiratory or nonrespiratory condition, smoking status [≥18 years], smokers in household, birthplace [in/outside US], health insurance, occupation [≥18 years], having a child in household ≤5 years [≥18 years], education, and surveillance season October–September annually) was assessed using a generalized linear mixed model (GLMM) with logit-link function (logistic) [15]. The GLMM included a random intercept for each household and for each individual nested within each household. Backward elimination was utilized for final model selection at P < .05. Season was controlled for by including trigonometric functions for the month of year as fixed effectors. Analyses were using SAS version 9.4 (SAS Institute Inc., Cary, North Carolina, USA) and SPSS, version 26 (IBM Corp. Armonk, New York, USA).

RESULTS

Study Population

Overall, 405 households were enrolled; 54.6% enrolled in year 1 or 2 remained under surveillance until year 5. All households eligible to continue chose to do so; household loss was due to moving outside of surveillance community or household change including a child aging out and/or <3 household members. Education level of the household reporter, but not sex, language, or insurance status, was associated with not remaining (≤high school 64.2% vs high school/college 47.9%, P = .006). Of the 1915 unique participants, 43.9% were children, and 12.8% had a chronic respiratory condition including asthma or chronic obstructive pulmonary disease (COPD) (Table 1). The mean number of persons per household was 4.8 ± 1.8 (range...
Household density (ratio of people to bedrooms) was 2.4 ± 1.2 (range 0.6–11). Overall, 40.2% of households were multigenerational.

ARI Incidence

In total, 114,724 text messages were sent. Across the 5 years, the mean response rate per twice-weekly prompts was 78.8% ± 6.8% (range: 52% to 100%). Mean response rate differed significantly by year, but remained above 75%: year 1: 75.2% ± 8.8%; year 2: 75.4% ± 6.2%; year 3: 80.5% ± 4.6%; year 4: 78.5% ± 5.2%; year 5: 83.9% ± 4.9%; \( P < .05 \) (Supplementary Figure 1).

Swabs were collected for 91.4% of confirmed ARI (2756/3016); median 2 days from ARI onset (interquartile range [IQR] 1–4). Overall, 1.4% refused swabbing, and 7.3% of ARI were missed not reported at the time of illness but reported retrospectively in a monthly visit. Half (54.1%) of ARI were in children. In 58.7% of ARI (1617/2756), a pathogen was detected (71.4% in children <5 years). Rhino/enteroviruses, human coronaviruses, and influenza were most commonly detected (Figure 1); 5.6% of swabs had more than 1 pathogen detected. Seasonal variations occurred by pathogen (Supplementary Figure 2). Influenza was detected as early as October and as late as June. Symptoms also varied by pathogen (Supplementary Figure 3). Nearly half (45.8%) of ARI episodes included multiple people within a household; 48.4% for episodes that included a child <5 years.

The overall ARI incidence was 0.62 per person-year, with the highest incidence in <5 year-olds (Table 2; Supplementary Table 1). Pathogen-specific incidence varied by age. While most pathogens had the highest incidence in <5 year-olds, influenza A had the greatest incidence in 2–17 and 50–64 year-olds and influenza B in 2–17 year-olds. Children <5 years had the greatest disease burden with almost 13 days of illness/year. Adults had, on average, 4–5 days of illness/year. The mean number of ill days for an ARI also varied by pathogen (Supplementary Table 2). ARI with \textit{C. pneumoniae} had the longest illnesses (average 13 days). Those with influenza had, on average, 9 days of illness.

Among children, age <5 years-old, a chronic respiratory condition, being born in the United States, and surveillance year were associated with ARI. Among adults, being female, being a homemaker, a college education, a chronic nonrespiratory condition, and surveillance year were associated with ARI (Table 3).

Care-Seeking for ARI

Only 26.0% of participants with an ARI reported seeking medical care. Visits were to primary care providers (84.8%), emergency departments (12.6%), urgent care (2.2%), and retail clinics (0.7%). Ten participants (1.4%), including 3 children and 7 adults, reported hospitalization; 4 had a pathogen detected (3 rhino/enterovirus and 1 influenza). Among those hospitalized, the following were reported: 1 influenza, 3 pneumonia, 3 asthma,

Table 1. Characteristics of Study Population

| Characteristic                                      | N = 1915 |
|----------------------------------------------------|----------|
| Median length of enrollment (interquartile range)  | 908 [395, 1453] |
| Number of people enrolled per season               |          |
| 10/2012 to 9/2013                                  | 973      |
| 10/2013 to 9/2014                                  | 1506     |
| 10/2014 to 9/2015                                  | 1387     |
| 10/2015 to 9/2016                                  | 1233     |
| 10/2016 to 9/2017                                  | 1146     |
| Age                                                |          |
| <2 y                                               | 110 (5.7) |
| 2-4 y                                              | 121 (6.3) |
| 5-17 y                                             | 610 (31.9) |
| 18-49 y                                            | 760 (39.7) |
| 50-64 y                                            | 230 (12.0) |
| ≥65 y                                              | 84 (4.4)  |
| Sex                                                |          |
| Female                                             | 1149 (60.0) |
| Male                                               | 766 (40.0)  |
| Race                                               |          |
| Black                                              | 4 (0.2)  |
| White                                              | 458 (23.8) |
| Asian                                              | 1 (0.1)  |
| American Indian                                    | 16 (0.8) |
| Other                                              | 1444 (75.1) |
| Ethnicity                                          |          |
| Latino                                             | 1905 (99.5) |
| Nativity (adults and children)                     |          |
| Born in US                                         | 878 (46.0) |
| In US ≥10 y                                        | 622 (32.6) |
| In US <10 y                                        | 407 (21.3) |
| Preferred language (adults)                        |          |
| Spanish                                            | 775 (72.2) |
| Education level (adults)                           |          |
| Less than high school                              | 436 (41.1) |
| Completed high school                              | 262 (24.7) |
| Beyond high school                                 | 364 (34.3) |
| Education/Child care (children)                    |          |
| Elementary/high school                             | 606 (75.8) |
| Day care/prenursery                                | 29 (3.6)  |
| Head Start                                         | 21 (2.6)  |
| Care in outside private home                       | 55 (6.9)  |
| No routine care outside of home                    | 89 (11.1) |
| Insurance                                          |          |
| Public                                             | 1466 (77.0) |
| Commercial                                         | 203 (10.7) |
| Uninsured                                          | 235 (12.3) |
| Self-reported health status                         |          |
| Excellent                                          | 413 (21.6) |
| Good                                               | 954 (49.9) |
| Fair                                               | 478 (25.0) |
| Poor                                               | 67 (3.5)  |
| Chronic respiratory condition (including asthma or chronic obstructive pulmonary disease) | 244 (12.8) |
| Chronic non-respiratory condition                  | 512 (26.7) |
| Occupation                                         |          |
| Unemployed/ retired/ on disability                 | 203 (19.3) |
| Homemaker                                          | 183 (17.4) |
| Healthcare- related field                          | 109 (10.3) |
| Other employment                                   | 398 (37.8) |
| Babysitter/ daycare/school employee                | 66 (6.3)  |
| College/ other type of student                     | 95 (9.0)  |

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1 cold/viral infection, 1 thyroid issue, and 1 did not report diagnosis. Care-seeking varied by pathogen and was highest for *M. pneumoniae* (63.6%), adenovirus (60.7%), HMPV (45.9%), *Chlamydia pneumoniae* (40.9%), RSV (42.6%), or any influenza (40.0%) and lowest for human coronaviruses (17.3%). Age, sex, insurance, chronic respiratory condition, birthplace, and type of regular provider were associated with care-seeking (Table 4). Care-seeking was higher in those reporting fever (40.9% vs 19.1%, *P* < .001).

Overall, 25.9% of ARI were associated with someone in the household missing work or school. The highest proportion of missed work and/or school was associated with adenovirus (46.4%), influenza (45.3%), RSV (42.6%), or *Mycoplasma pneumoniae* (40.0%). Care-seeking was associated with missed
school/work (48.8% who sought care missed work vs 17.7% who did not seek care, \( P < .0001 \)).

**DISCUSSION**

This 5-year study identified a number of important findings that contribute to our understanding of ARI epidemiology. First, it underscores the additional importance of community-based surveillance to more completely understand disease burden by capturing non-medically attended ARI during year round surveillance. Second, it adds to the literature that demonstrates the feasibility of text messaging as a surveillance method, including use of this method over a sustained period of time. Our findings have potential implications not only for seasonal surveillance, but also for outbreaks, epidemics and pandemics. Third, it provides measures of ARI incidence, factors associated with infection in both adults and children, and causative pathogens.

Only a quarter of ARI episodes were associated with healthcare-seeking; this proportion increased to 40% of ARI associated with influenza. Not all demographic groups sought care equally. Therefore, potential biases likely exist when disease burden calculations are made based solely on medically attended illness, which may differ for different demographic groups. However, medically attended illness surveillance has been the primary data source for a variety of important public health activities, including disease burden estimates, the impact of public health interventions like vaccination, understanding spread of novel pathogens (e.g., severe acute respiratory syndrome coronavirus 2 [SARS-CoV-2] or pandemic influenza), and forecasting influenza activity [16]. Furthermore, only half of ARI associated with missed school or work were associated with care-seeking. These findings underscore that even non-medically attended illness can lead to substantial disease burden and societal impact that may not be fully captured in current modeling of respiratory diseases. Thus, community-based surveillance provides an important complement to current medically attended disease surveillance strategies.

One potential challenge in conducting community surveillance is how to rapidly identify when illnesses occur and collect data from disparate households in a scalable-efficient manner. With advances in technology and creative approaches to follow-up and community engagement, there may be ways for community-level surveillance to be more routinely conducted. This study demonstrated that large-scale text message-based surveillance was feasible with continued high response rates throughout 5 years. The rapid replies also allowed collection of samples within 1–2 days of symptom onset. Although text messaging was successfully used for performing vaccine adverse event surveillance by us and others [17], there had been limited experience with using text messaging for ARI surveillance. In Madagascar, text messaging was used to collect aggregate practice-level incidence [18], and in Mexico, it was utilized as a 1-time cross-sectional survey of symptoms during the 2009 H1N1 influenza pandemic [19]. Since the onset of this study, others have studied using text messages as a prompt to complete a web-based symptom questionnaires and to prompt self-collected samples; however, this strategy relies on families having a data plan on their phone or access to WiFi to use the linked system [11, 20]. Other surveillance systems have also been explored to complement outpatient and hospital-based surveillance, including Twitter, Wikipedia, the now defunct Google Flu Trends, and crowd-source reporting like Flu Near You [21]. However, these type of surveillance do not include collection of samples which precludes determining how much of the observed illness burden is attributable to a specific pathogen, like influenza.

The overall ARI incidence calculated in this study is less than that calculated in previous studies performed decades ago, although as with previous studies, incidence varied by year [22]. However, previous studies also included enteric infections and used broader definitions of respiratory illness including single symptoms and symptoms, such as earache, not included in the current CDC definition [9, 23, 24]. Other possibilities for differences in incidence calculations include increased influenza vaccination, household composition changes such as size of households, and study design differences [25, 26]. Of note, a recent community surveillance study that assessed
Table 3. Factors Associated With Incidence of Acute Respiratory Infections (ARI) in Children and Adults

| Children | Adjusted Odds Ratio | 95% Confidence Intervals |
|----------|---------------------|-------------------------|
| Age      |                     |                         |
| <2 y     | 2.57                | 2.14–3.09               |
| 2–4 y    | 1.99                | 1.71–2.31               |
| 5–17 y   | ...                 | ...                     |
| Chronic respiratory condition (present) | 1.27 | 1.06–1.54 |
| Birth place |                  |                         |
| Non-US   | ...                 | ...                     |
| US       | 1.29                | 1.03–1.62               |
| Study year |                   |                         |
| 2012–13  | 1.92                | 1.57–2.35               |
| 2013–14  | 1.34                | 1.13–1.58               |
| 2014–15  | 1.38                | 1.18–1.62               |
| 2015–16  | 1.08                | 0.92–1.27               |
| 2016–17  | ...                 | ...                     |
| Adult    |                     |                         |
| Sex      |                     |                         |
| Male     | ...                 | ...                     |
| Female   | 2.39                | 1.95–2.94               |
| Chronic non-respiratory condition (present)* | 1.37 | 1.17–1.62 |
| Occupation |                   |                         |
| Unemployed/retired/on disability | 1.31 | 0.92–1.87 |
| Homemaker | 1.64                | 1.18–2.31               |
| Healthcare-related field | 1.14 | 0.79–1.85 |
| Other employment | 1.15 | 0.83–1.59 |
| Babysitter/daycare/school employee | 0.99 | 0.65–1.52 |
| Student  | ...                 | ...                     |
| Education |                   |                         |
| Less than high school | ... | ... |
| Completed high school | 0.97 | 0.78–1.20 |
| Beyond high school | 1.36 | 1.12–1.66 |
| Study year |                   |                         |
| 2012–13  | 1.81                | 1.46–2.25               |
| 2013–14  | 1.13                | 0.95–1.35               |
| 2014–15  | 1.11                | 0.94–1.33               |
| 2015–16  | 1.10                | 0.93–1.31               |
| 2016–17  | ...                 | ...                     |

Model includes trigonometric functions for the month of the year as fixed effectors. Adult model adjusted for presence of child under 5 in the household. Abbreviation: ARI, acute respiratory infection.

*The most common comorbidities in those with an ARI were asthma and type 2 diabetes mellitus.

partial respiratory seasons also had lower ARI incidence than previously reported, even when accounting for its shortened surveillance period [27]. Some studies, like a recent one that demonstrated ARI incidence of ~5% per week, only took place during the winter [28]. Another study from Utah also found higher incidence but collected weekly samples regardless of symptoms and included a broader symptom constellation than the CDC ARI definition used in this study [29].

This current study confirmed some ARI-associated factors identified in previous studies and highlighted new ones. In this and previous studies, young age in children was associated with higher ARI incidence [9, 23, 27, 30], as were being an adult female and/or a homemaker likely due to caretaking roles [9, 27]. We also observed that ARI incidence was associated with higher education [30]. Although a study published in 1971 speculated higher education may have been associated with reporting of minor symptoms, in our study, surveillance was conducted by prompting symptom reporting regardless of whether participants felt ill. We also identified some different risk factors for ARI. Although in previous studies, sex played a role in childhood infection [30], it did not in this study. Nor did household density [31]; however, it may be patterns of contact within households rather than density that matter most [32]. We also found that increased ARI incidence was associated with respiratory (children) or non-respiratory (adults) chronic medical condition. Although those factors are known to increase respiratory illnesses severity, they had not themselves been identified as risk factors for ARI [27]. These comorbid conditions may be associated with an increased risk of infection or of symptomatic infection. It is also possible that those with a chronic condition were more attuned to symptoms. In addition, being US born was associated with higher ARI incidence in children. One previous cross-sectional study suggested that being US born was linked to poorer respiratory health [33].

This study also adds to the knowledge about which respiratory pathogens are causing ARI year-round over multiple seasons. Previous studies focused on specific viruses [34–36], medically attended groups such as hospitalized or ambulatory patients [34, 35], certain ages [37, 38], certain characteristics like attending daycare [39], or only conducted partial-year surveillance [11, 27, 28]. More modern diagnostic techniques are also available, and can detect more respiratory pathogens. In our study, similar to the 1970s, rhino/enteroviruses and influenza were commonly detected [11]. However, in the 1970’s, parainfluenza was one of the most common respiratory pathogens detected [30], although in our study human coronaviruses were common. Although human coronaviruses can cause mild ARI, even nonpandemic coronaviruses can cause severe disease [40, 41]. A recent study demonstrated that influenza, human coronavirus, and RSV were most commonly associated with medically attended ARI [42], and a community surveillance study in Seattle that focused on the respiratory season similarly found rhinovirus, human coronaviruses, and RSV to be most common [11]. We also found differential pathogen representation by month, highlighting the importance of year-round surveillance. Finally, pathogen detection differed by age. Although younger children had higher pathogen-specific ARI incidences for most pathogens than older children and adults, age did not impact patterns for influenza.

This study has limitations. First, households were from a single low-income, primarily Latino community in New York City and thus are not nationally representative. However, understanding ARI epidemiology may be particularly important...
in low-income communities, as individuals may be at different risk of infection and transmission due to crowded living conditions as highlighted in some but not other studies [31], and having multigenerational households [43]. Low-income communities have also been disproportionately affected during the SARS-CoV-2 pandemic and therefore important to study. They may also have decreased healthcare access leading to under-representation in previous surveillance studies relying on medically-attended illness [44]. Requiring there to be a child in the household could overestimate disease burden in the population as children are thought to play a major role in introduction of infection in households [45]; this requirement also affected the number ≥65 year-old participants as few participants were in this age strata. In addition, this high-intensity study required substantial staff resources and families needed to have text messaging; for such surveillance to be sustainable low-touch methods may need to be explored such as phone follow-up only and collection of self-swabs [11, 46]. Other limitations include under-reporting although prompts were sent twice-weekly, false negative results although the percentage of swabs with a pathogen detected was consistent with other studies [27], being part of the study could increase or decrease care-seeking, and enrollment of only Spanish and English speakers [47].

**CONCLUSION**

Text messaging is a novel method for community-based surveillance that could be used both seasonally as well as during
outbreaks, epidemics and pandemics as a complementary mode of potential case identification. The importance of adding community surveillance to medical visit based surveillance to accurately estimate disease burden is underscored by the findings of low rates of care-seeking that varied by demographic factors and pathogens and the burden of missed work/school.

**Supplementary Data**
Supplementary materials are available at Clinical Infectious Diseases online. Consisting of data provided by the authors to benefit the reader, the posted materials are not copyrighted and are the sole responsibility of the authors, so questions or comments should be addressed to the corresponding author.

**Notes**

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