American Journal of Infection Control 47 (2019) 1090–1095

Contents lists available at ScienceDirect

American Journal of Infection Control

journal homepage: www.ajicjournal.org

Major Article

Cystic fibrosis program characteristics associated with adoption of 2013 infection prevention and control recommendations

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Key Words:
Infection control

Background: The Cystic Fibrosis (CF) Foundation disseminated an updated guideline for infection prevention and control (IP&C) practices for CF care programs in 2013. Assessing adoption rates of IP&C recommendations is crucial to evaluate their impact.

Methods: CF care programs provided their written IP&C policies for CF. Policies were analyzed to determine adoption of selected recommendations new in 2013, as well as recommendations made in both 2003 and 2013. Weighted adoption scores were analyzed for association with program characteristics.

Results: The median number of new recommendations adopted by each program was 7 (mean 6.3, range 0-9). The most commonly adopted new recommendations were universal mask use by patients in both inpatient and outpatient settings (85% and 87%, respectively) and contact precautions for CF patients in inpatient and outpatient settings (90% for both). The least frequently adopted new recommendations were the "6-foot rule" in inpatient settings (n = 66, 53%) and auditing disinfection of surfaces in clinic (n = 64, 49%). Larger program size was associated with a higher weighted adoption score (odds ratio [OR] 1.9, P =.02).

Conclusions: Whereas most programs adopted more than one-half of the selected IP&C recommendations assessed, adoption was variable. Efforts to improve adoption of IP&C recommendations should focus on smaller programs with fewer resources.

Acquisition and patient-to-patient transmission of respiratory pathogens, including *Burkholderia cepacia* complex, *Pseudomonas aeruginosa*, and *Staphylococcus aureus* have been documented in people with cystic fibrosis (CF) in health care settings.[1-4] In 2013, the CF Foundation (CFF) disseminated an updated infection prevention and control (IP&C) guideline to CF programs in the United States to replace the 2003 IP&C guideline. The updated guideline presented new evidence concerning pathogen transmission associated with adverse outcomes and new evidence-based infection control measures.[5] Some key changes in the 2013 guideline included: (1) contact precautions for all CF patients, regardless of pathogen status (in 2003, contact precautions were only recommended for those with multidrug-resistant organisms), (2) mask use by all CF patients in common areas in health care settings (in 2003, this was an "unresolved" issue), (3) maintaining a minimum of 6 feet between CF patients (in 2003, a minimum of 3 feet was recommended), and (4) strategies to reduce transmission during pulmonary function testing (PFT) (in 2003, this issue was not addressed). Additionally, several recommendations made in 2003 remained unchanged in 2013 (eg, emphasizing hand hygiene and avoiding socialization among individuals with CF).

To fully understand the impact of IP&C recommendations on patient outcomes, knowing the extent of adoption of specific recommendations by CF programs is crucial. In this study, our primary goal was to assess whether new recommendations from 2013 were incorporated into the written policies of CF programs. Additionally, we aimed to determine whether recommendations made prior to 2013 (that were also included in the 2003 guideline) were contained in IP&C

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Previous presentation: Presented, in part, at the North American Cystic Fibrosis Conference, Indianapolis, IN, November 2017.

Funding support: Supported by the US Cystic Fibrosis Foundation (grant Nos. SAIM15A0 and STOUDE16B0).

Conflicts of interests: None to report.

Author contributions: M.S.M. and L.S. contributed equally to this work.

https://doi.org/10.1016/j.ajic.2019.03.015

policies. Furthermore, we determined program characteristics associated with adoption. Finally, we sought to gain insights into potential strategies that could improve adoption of IP&C at CF programs.

METHODS

CF care center and program terminology

The CFF accredits and supports CF care centers in the United States. Care centers may consist of several individual care programs. As of 2014, there were 277 individual care programs, including 119 pediatric care programs, 105 adult care programs, and 53 affiliate care programs.[6] Affiliate programs are smaller CF programs that provide care in partnership with a larger CF care center or program. These programs may see pediatric patients, adult patients, or both. We evaluated care programs individually, and, therefore, use the term "program" instead of "center" throughout this article.

Study design and sites

From December 2015 to June 2016, the research team e-mailed the directors of the 277 CF care programs in the United States requesting them to provide the research team with their written IP&C policies for CF. This request was sent to CF program directors along with a request to complete a survey on IP&C practices, the results of which we have previously described.[7] Respondents were provided with a $25 gift card for their survey participation, but were not provided compensation for providing IP&C policies. Relevant policies included institutional IP&C policies for inpatient and outpatient settings, as well as other written material addressing IP&C, including proposed IP&C policies, presentation materials, and written communications, as available. Three reminder e-mails were sent. The institutional review boards of Columbia University Medical Center and The University of North Carolina approved this study with a waiver of documentation of written consent.

Analysis of IP&C policies

Written material from each program was de-identified and independently analyzed by 2 members of the research team (including W.S., P.M., and J.Z.) using a structured data collection tool. The content of provided material was reviewed for mention of selected recommendations, including new recommendations in 2013 (n = 9) and from both 2003 and 2013 (n = 8), as shown in Table 1 and Table 2. A more detailed description of the 9 new recommendations from 2013 is provided in Supplementary Table S1.

These selected recommendations were evidence-based and thus, likely to be included in written policies, as previously described.[4,5,8] Discrepancies encountered during data abstraction were resolved by discussions with a senior researcher (L.S.). Since written policies did not usually contain the recommendation to perform exam room cleaning audits, adoption of this recommendation was derived from the responses of the CF program directors to a previous survey, in addition to data from written policies.[7] Survey data for cleaning audits were only used for the programs that provided written IP&C material.

Statistical analysis

A Welch's 2-sample t test was used to compare the mean percentages of programs adopting recommendations from 2013, with the mean percentages of programs adopting the recommendations from both 2003 and 2013. Logistic regression was used to analyze the association between program characteristics, including program size, type (pediatric, adult, or affiliate), and geographic region (Northeast, South, West, and Midwest) and IP&C policies. Program size was determined by the number of patients who had at least 2 visits to the program in 2014. Program characteristics were obtained from the CFF Patient Registry.[6] Affiliate for program type and for program region were chosen as reference groups in the regression models. A X^2 test was performed to compare the characteristics of responding versus nonresponding programs. Adjustment for over-representation of program types was applied to each responding program, as they may not represent the true distribution of adoption of IP&C practices in all CF programs.

To assess adoption of the selected new IP&C recommendations, first, we evaluated adoption of the 9 new recommendations from 2013, 3 of which were applicable to both inpatient and outpatient settings, and 3 of which were only applicable to the CF clinic (n = 9 total recommendations). Second, as adopting certain recommendations may affect the likelihood of adopting other recommendations, item response theory was applied to adjust for this.[9] A Rasch model with a varying slope was fitted, and the Monte Carlo maximization likelihood estimation with the Metropolis-Hastings algorithm was used to calculate the weight of the ability of each of the 9 recommendations to differentiate the programs for adoption of recommendations, while considering the influence of adopting different recommendations.[10,11] To do so, we calculated a weighted score (range 0-1) (ie, a summation of adoption [binary 0 or 1]) across the 9 new recommendations from 2013.[10]

We also assessed the association of program characteristics with adoption of new recommendations. This analysis was performed both with and without including the 14 programs that responded but did not have written IP&C policies. In the analysis including these programs without written IP&C policies, the programs were counted as having adopted no recommendations. The weighted adoption scores

Table 1
Selected new infection prevention and control recommendations from the 2013 guideline assessed for adoption by CF care programs.

New recommendations from 2013			
		Guideline	
No.		2003	2013
1	Mask use by all CF patients −inpatient settings*	Unresolved	New
2	Mask use by all CF patients −outpatient settings*	Unresolved	New
3	Contact precautions for all CF patients−inpatient settings*	NA	New
4	Contact precautions for all CF patients−outpatient settings*	NA	New
5	At least 6 feet between CF patients−inpatient settings*	3 feet‡	New
6	At least 6 feet between CF patients−outpatient settings*	3 feet‡	New
7	Perform PFT in CF clinic*,†	NA	New
8	Exam room cleaning between patients in CF clinic*	NA	New
9	Audits of cleaning and disinfection of surfaces and equipment in CF clinic*	NA	New

CF, cystic fibrosis; *NA*, not addressed; *PFT*, pulmonary function test.
*The recommendations were included in weighted adoption score analysis.
†Four options, including PFT in exam room or in PFT lab with negative pressure, high-efficiency particulate air filtration, or 30 minutes between CF patients.
‡The recommendation was 3 feet in the 2003 guideline.

Table 2
Selected infection prevention and control recommendations from both the 2003 and 2013 guideline assessed for adoption by CF care programs.

Recommendations from 2003 and 2013			
		Guideline	
No.		2003	2013
1	Emphasize hand hygiene by CF patients−inpatient settings	Both	
2	Emphasize hand hygiene by CF patients−outpatient settings	Both	
3	Emphasize hand hygiene by families−inpatient settings	Both	
4	Emphasize hand hygiene by families−outpatient settings	Both	
5	Avoid socialization among CF patients−inpatient settings	Both	
6	Avoid socialization among CF patients−outpatient settings	Both	
7	Minimize time in CF clinic waiting room	Both	
8	Case-by-case participation in activities outside hospital room	Both	

CF, cystic fibrosis.

were analyzed against program size (continuous), type (pediatric, adult, or affiliate), and geographic region (Northeast, South, West, and Midwest) using a simple linear regression for the continuous variable of program size and analysis of variance models for the 2 categorical variables of type and region. Next, a multiple linear regression of weighted scores determined the association of increased adoption of recommendations with program characteristics. Program characteristics were analyzed with continuous weighted scores and with a binary cut-point between modes to assess for variance between the 3 characteristics. Pseudomonas and methicillin-resistant *Staphylococcus aureus* prevalence rates at individual programs were analyzed as potential confounding variables but did not significantly affect the results. Therefore, they were excluded from the final analysis. Each new recommendation was also analyzed individually by logistic regression with these program characteristics.

A paired sample Student t test was applied to compare adoption of new recommendations from 2013 with recommendations from both 2003 and 2013, on average. Specifically, we determined whether the mean difference in numbers of adopting 2 sets of recommendations, the new recommendations from 2013 (without cleaning audit) (Table 1) and the recommendations from both 2003 and 2013 (Table 2), is 0 for all 130 programs. All analyses were performed in R 3.4.4.[12] The significance level was chosen to be 0.05.

RESULTS

Response rate and characteristics of responding programs

A total of 144 (52%) of 277 US CF care programs responded 130 programs (47%) provided written IP&C policies and/or other materials (including 124 inpatient and 125 outpatient policies as shown in Fig 1), and 14 (5%) reported they did not have written IP&C policies or materials and/or reported that they "followed CFF guidelines." Responding programs with IP&C policies and/or materials included 40 (38%) of the 105 US adult programs, 73 (61%) of the 119 US pediatric programs, and 17 (32%) of the 53 US affiliate programs. Analysis of the responding versus nonresponding programs revealed that a higher proportion of pediatric programs provided IP&C policies and/or materials than adult and affiliate programs (P <.001) and larger programs were more likely to provide IP&C policies/materials with an odds ratio (OR, 2.5) for each size increase of 100 patients (P <.001). Thus, the analyses for adoption were adjusted for program type and size. Among the regions, 33 (54%) of 61, 41 (44%) of 93, 20 (40%) of 50, and 36 (49%) of 73 programs in the Northeast, South, West, and Midwest, respectively, responded. The response rates in the 4 regions were similar (P =.57).

Adoption of selected recommendations

Adoption of the 9 new 2013 recommendations by each program ranged from 0-9 (median 7 [interquartile range, 5-8] and mean 6.3 [SD 2.1]). Two programs (2%) adopted none of the recommendations, and 13 programs (10%) adopted all 9 of the recommendations (Fig 2). The proportion of CF programs adopting specific new recommendations from 2013 and recommendations made in both 2003 and 2013 is shown in Figure 3. The most frequently adopted new recommendations were the use of contact precautions for all CF patients: in inpatient settings (94%, n = 117/124 programs with inpatient policies) and outpatient settings (94%, n = 117/125 programs with outpatient policies) and masks by all CF patients. Fewer programs had adopted the recommendations for the 6-foot rule (53% and 54% for inpatient and outpatient settings, respectively), room cleaning audits (49%), and for performing PFTs (57%). Overall, the mean number of adopted new recommendations from 2013 (mean 6.3, SD 2.1) is higher than the mean number of recommendations from both 2003 and 2013 (mean 5.0, SD 2.4) across the 130 programs (based on a paired Student t test, P <.0001).

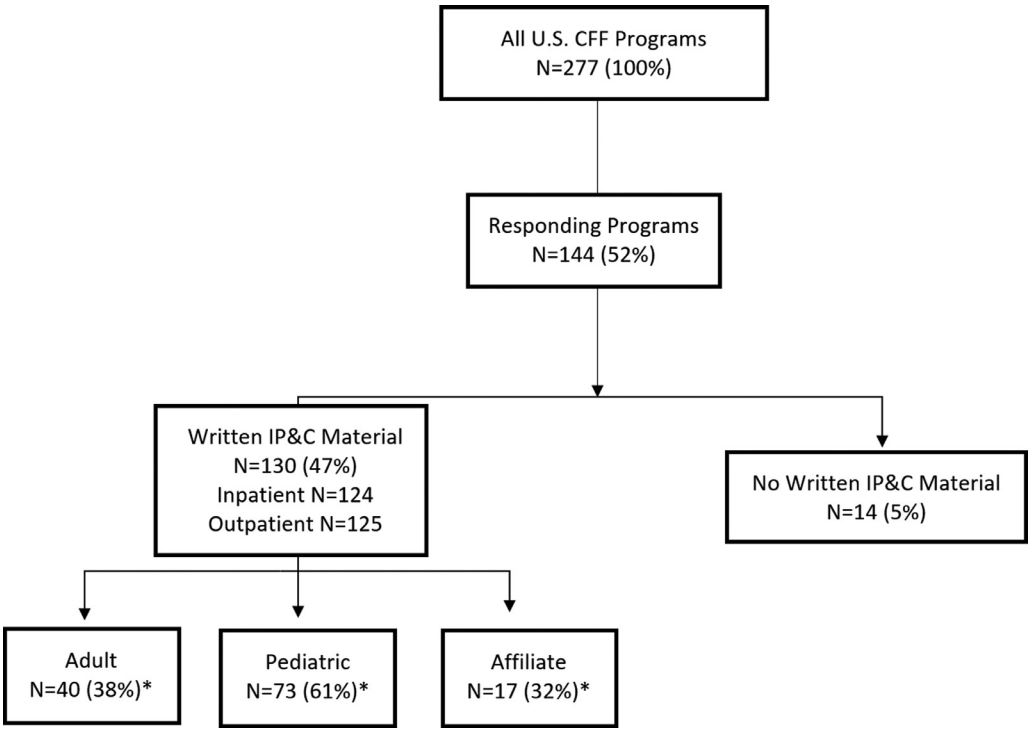

Fig 1. Diagram showing the response of US cystic fibrosis programs to our request for written infection prevention and control policy information. Percentage of programs that provided written IP&C material out of the total number of US cystic fibrosis programs of each program type (*). *CFF*, Cystic Fibrosis Foundation; *IP&C*, infection prevention and control.

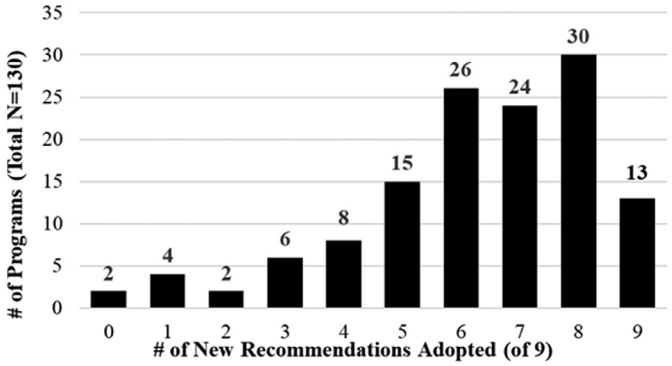

Fig 2. Distribution of adoption of specific new recommendations from the 2013 guideline. The x-axis indicates the total number of key recommendations adopted by an individual program (of 9 total). The y-axis indicates the total number of programs that adopted a certain number of recommendations. Policies from 130 total programs were analyzed, including 124 programs with inpatient policies and 125 programs with outpatient policies. Therefore, not all programs had the potential to adopt all 9 policies since some programs only provided outpatient or inpatient policies.

Adoption of recommendations "not recommended" or "unresolved"

Although wearing masks by all staff caring for CF patients was not recommended in 2003 or 2013, 16 (12%) inpatient and 11 (8%) outpatient policies recommended this practice. Although the use of airborne isolation for nontuberculous mycobacteria (NTM) was unresolved in 2013, 24 (18%) inpatient and 22 (17%) outpatient policies recommended this practice.

Association of program characteristics with adoption

Weighted adoption scores were calculated from 129 programs, as program characteristics were not available for 1 program. Weighted adoption scores (0-1) for all 9 new recommendations showed a bimodal distribution, with 1 mode slightly under 0.6 ($n \approx 30$) and the other mode at approximately 1 ($n \approx 60$). The majority of programs had very high adoption rates (maximum possible weighted score = 1). There was no association between weighted adoption scores and program characteristics, including type ($P = .3$), size ($P = .14$), or geographic region ($P = .8$). Analysis of the association of the weighted adoption score and the 3 characteristics by linear regression also did not show any significant associations (data not shown). However, when treating weighted adoption scores as a binary variable (ie, 0 if [0-0.9] [n = 63] vs 1 if [> 0.9-1] [n = 66]), a logistic regression model showed that programs of the same type and from the same region had 2.1 times the odds of being in the high adoption group for each increase in size of 100 patients ($P = .01$). This association was also significant when data were analyzed without correcting for program type and region (OR, 1.9, $P = .02$).

Analyses of each of the 9 new recommendations individually revealed that the 6-foot rule was more likely to be adopted by larger programs (OR, 2.0 for each size increase of 100 patients, $P = .02$). Adjustment for response rate by region did not affect the results (data not shown).

Additional analysis was performed including the programs that responded that they did not have written IP&C policies, counting these programs as having adopted no recommendations. Analysis of program adoption score as a binomial variable with these programs did not change the results described above.

DISCUSSION

CF patients represent a patient population at high risk of health care–associated infections, and IP&C practices to reduce the risk of spread of pathogens between these patients are important. We assessed the adoption of 9 specific new IP&C recommendations by US

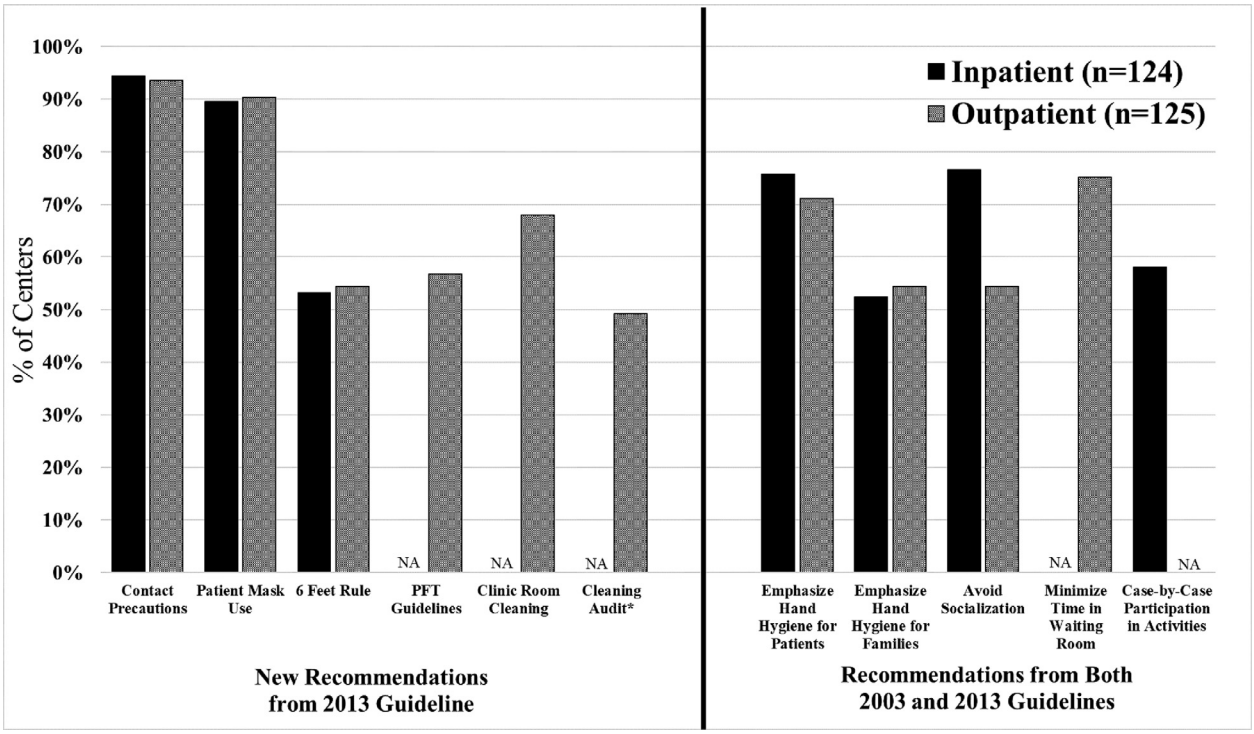

Fig 3. Adoption of specific recommendations from the 2013 (left panel) and 2003/2013 (right panel) guidelines. The x-axis indicates the specific recommendations, and the y-axis indicates the percentage of programs that adopted the recommendations. Policies applicable to inpatient and outpatient settings were analyzed separately. Data for adoption of this recommendation (*) were derived from responses to a previous survey of cystic fibrosis program directors, in addition to data from written policies.

CF programs as a crucial step needed to evaluate the effectiveness of specific recommendations to prevent acquisition and transmission of CF pathogens. Overall adoption was high, as the median number of adopted recommendations was 7, although adoption was variable and larger programs had a higher likelihood of both overall adoption and adoption of the 6-foot rule. We also found that pediatric and larger programs were more likely to provide IP&C policies. These findings are consistent with previous studies of IP&C practices, in which we found that smaller programs were less likely to participate in research on IP&C practices and less likely to have written IP&C policies.[8,13] The finding of lower adoption in smaller programs may reflect fewer resources or less institutional support for implementing IP&C practices. The decreased likelihood of smaller programs adopting the 6-foot rule may also stem from the perception that fewer interactions occur between people with CF at smaller CF programs. Although smaller programs may have fewer resources to create formal IP&C policies, written IP&C policies are a requisite to ensuring consistent IP&C practices. Our findings suggest that efforts to support smaller programs to create IP&C policies and implement IP&C recommendations would be useful.

The new recommendation for the use of contact precautions by health care workers when caring for all CF patients was rapidly adopted by the majority of programs. We speculate that this rapid adoption reflected CF programs and local IP&C team's agreement with this recommendation, presumably because they found the evidence to be convincing. Furthermore, this recommendation is familiar as contact precautions are frequently used for hospitalized patients with or suspected of harboring epidemiologically significant pathogens. Mask use by all CF patients was also adopted by the majority of responding programs. It is notable that although mask use was an unresolved issue in the 2003 guideline, it was previously included in 69% and 35% of in- and outpatient policies, respectively, suggesting that CF programs felt that this strategy would reduce transmission prior to published evidence supporting the practice.[8] It is also feasible that recommendations to implement contact precautions and mask use may be easier to implement than those requiring intense education or restructuring patient flow. Fewer programs seemed to adopt the 2013 6-foot rule recommendation and recommendations for performing PFTs. These findings may reflect difficulties operationalizing these recommendations, challenges to work flow, and/or the expense of purchasing more equipment or making renovations. These speculations are supported by prior studies that demonstrated decreased adoption of IP&C recommendations that required significant changes to workflow and/or extensive educational efforts.[14,15] These findings may also reflect lack of agreement with the evidence underlying these recommendations or hesitation adopting policies for which compliance is difficult to measure, which has been suggested in other IP&C studies.[16]

We found that new recommendations made in 2013 were more likely to be adopted than recommendations made in both 2003 and 2013. Although our data are insufficient to explain why this is true, there are several possible explanations. First, new recommendations that represent changes to current IP&C practices may receive greater attention from the medical and patient community, increasing the likelihood of CF programs incorporating these into IP&C policies. Also, CF programs may feel that the evidence for these new recommendations to prevent spread of pathogens between patients is stronger than for recommendations made in the prior guidelines. Additionally, new recommendations included in the 2013 guideline may have already been in place at programs, making it easier to incorporate these into formal IP&C policies. Finally, the endpoints of some of the recommendations made in both 2003 and 2013 may be difficult to measure (eg, avoiding socialization) and, therefore, less likely to be included in IP&C policies.

We also found that the "unresolved recommendation"' (ie, use of airborne precautions for NTM) was an IP&C policy at several programs. This likely reflects an increased level of concern about this possible route of transmission due to recent studies describing shared *M abscessus* strains among CF patients cared for at the same CF program.[17] Recent data have demonstrated that some *M abscessus* strains isolated from CF patients cared for at the same CF program are genetically clustered, and that these strains are found at different CF programs around the world.[18] Data from whole-genome sequencing paired with social network and epidemiologic analysis suggested that the source of acquisition was the inpatient hospital environmental (ie, contaminated surface and/or person-to-person transmission via either droplet or airborne routes).[17] Outbreaks of NTM in CF patients have been controlled by improving IP&C measures, both with [19] and without [20] implementing airborne precautions for infected patients, but the most effective IP&C measures to prevent NTM transmission remain unclear.

Fewer CF programs appeared to have adopted recommendations made in both 2003 and 2013, including emphasizing hand hygiene by patients and their families, avoiding socialization between CF patients, minimizing time in the waiting room, and case-by-case consideration for participating in activities outside of the hospital room. Adoption of these recommendations does not appear to be related to a lag in updating policies, as many programs' policies reflected the new 2013 recommendations. We speculate that recommendations for hand hygiene exist in other sections of institutions' IP&C policies that we did not receive. Local IP&C teams may have considered the recommendations to avoid socialization, minimize waiting room time, and allow patients on contact precautions to participate in activities outside of their hospital room to be beyond the scope of their written institutional IP&C policies and/or difficult to monitor for compliance.

Understanding the factors that contribute to adoption of guidelines is necessary to remove potential barriers and improve implementation.[13,21,22] We previously found that most programs involved their local IP&C teams to implement the new guideline; thus, partnering with IP&C could be a potential strategy at some programs.[8] Late adopters could benefit from additional education addressing the evidence base for the recommendations and describing the patient safety and quality implications of implementing IP&C for CF. It is likely that these interventions need to be individualized and provided to both CF care teams and institutional leadership to have a positive effect.

Our study had several limitations. First, there is the possibility of responder bias, as data were available for only 52% of US CF programs, and 10% reported they did not have written IP&C guidelines. Although we do not know the reasons why programs did not provide IP&C policies, one might suspect that non-responding programs may not have had written policies. Therefore, our results may overestimate the overall rate of adoption. There was also overrepresentation of pediatric programs responding. However, the statistical associations between adoption and program characteristics did not change (or remained very close to the 0.05 significance level) when oversampling adjustment for program type was applied to each program. Second, some programs provided informal written IP&C material, which may not fully reflect adoption or endorsement by the local IP&C teams. Additionally, some elements of the recommendations likely were not included in CF-specific IP&C policies provided by some programs (eg, those related to hand-hygiene, resulting in underestimation of adoption of these practices). Another limitation of our study was the inability to investigate other potential program characteristics that may be associated with adoption. In particular, academic versus non-academic affiliation may be correlated with adoption of IP&C recommendations. However, the CFF does not categorize programs into academic versus non-academic affiliation, and given varying degrees of affiliation with academic centers, we were unable to perform this analysis. Finally, we were only able to evaluate written policies, which may not reflect actual IP&C practices.

In summary, we found a high degree of adoption of IP&C recommendations. These findings are consistent with our previous survey,

which found that 70% of responding programs had adopted ≥75% of the recommendations related to education, involving local IP&C teams, and audit and feedback of IP&C practices to CF program staff.[7] However, both studies did find considerable variability between specific recommendations and programs and identified opportunities to improve IP&C, most of which involve developing effective educational strategies and increasing resources. Next steps should evaluate the impact of specific IP&C practices and overall adoption of IP&C recommendations on the acquisition of CF pathogens.

ACKNOWLEDGMENTS

The authors would like to thank the cystic fibrosis (CF) program staff who provided their infection prevention and control policies. We would also like to thank the CF Foundation (CFF) for the use of CFF Patient Registry data to conduct this study. Additionally, we would like to thank the patients, care providers, and clinic coordinators at CF programs throughout the United States for their contributions to the CFF Patient Registry.

SUPPLEMENTARY DATA

Supplementary data related to the article can be found at https://doi.org/10.1016/j.ajic.2019.03.015.

References

1. LiPuma JJ. *Burkholderia cepacia* epidemiology and pathogenesis: implications for infection control. Curr Opin Pulm Med 1998;4:337-41.
2. Ojeniyi B, Frederiksen B, Hoiby N. Cross-infection among patients with cystic fibrosis during a winter camp. Pediatr Pulmonol 2000;29:177-81.
3. Cheng K, Smyth RL, Govan JR, Doherty C, Winstanley C, Denning N, et al. Spread of beta-lactam-resistant *Pseudomonas aeruginosa* in a cystic fibrosis clinic. Lancet 1996;348:639-42.
4. Saiman L, Siegel J, Foundation CF. Infection control recommendations for patients with cystic fibrosis: microbiology, important pathogens, and infection control practices to prevent patient-to-patient transmission. Infect Control Hosp Epidemiol 2003;24(Suppl 5):6-52.
5. Saiman L, Siegel JD, LiPuma JJ, Brown RF, Bryson EA, Chambers MJ, et al. Infection prevention and control guideline for cystic fibrosis: 2013 update. Infect Control Hosp Epidemiol 2014;35(Suppl 1):1-67.
6. Knapp EA, Fink AK, Goss CH, Sewall A, Ostrenga J, Dowd C, et al. The Cystic Fibrosis Foundation patient registry. Design and methods of a national observational disease registry. Ann Am Thorac Soc 2016;13:1173-9.
7. Saiman L, Zhou JJ, Jiang X, Kosorok MR, Muhlebach MS. Surveying cystic fibrosis care centers to assess adoption of infection prevention and control recommendations. Infect Control Hosp Epidemiol 2018: 1-5.
8. Zhou J, Garber E, Saiman L. Survey of infection control policies for patients with cystic fibrosis in the United States. Am J Infect Control 2008;36:220-2.
9. Item response theory: parameter estimation techniques. In: Baker FB, Kim S-H, eds. Item response theory: parameter estimation techniques, 2nd ed Boca Raton (FL): CRC Press; 2004.
10. Chib S, Greenberg E. Understanding the Metropolis-Hastings Algorithm. Am Stat 1995;49(4):9.
11. Hastings WK. Monte Carlo sampling methods using Markov chains and their applications. Biometrika 1970;57:97-109.
12. R Core Team. R: a language and environment for statistical computing. Vienna (Austria): R Foundation for Statistical Computing; 2018.
13. Miroballi Y, Garber E, Jia H, Zhou JJ, Alba L, Quittell LM, et al. Infection control knowledge, attitudes, and practices among cystic fibrosis patients and their families. Pediatr Pulmonol 2012;47:144-52.
14. Mody L, Langa KM, Saint S, Bradley SF. Preventing infections in nursing homes: a survey of infection control practices in southeast Michigan. Am J Infect Control 2005;33:489-92.
15. Yanke E, Moriarty H, Carayon P, Safdar N. A qualitative, interprofessional analysis of barriers to and facilitators of implementation of the Department of Veterans Affairs' *Clostridium difficile* prevention bundle using a human factors engineering approach. Am J Infect Control 2018;46:276-84.
16. Pogorzelska M, Stone PW, Larson EL. Wide variation in adoption of screening and infection control interventions for multidrug-resistant organisms: a national study. Am J Infect Control 2012;40:696-700.
17. Bryant JM, Grogono DM, Greaves D, Foweraker J, Roddick I, Inns T, et al. Whole-genome sequencing to identify transmission of *Mycobacterium abscessus* between patients with cystic fibrosis: a retrospective cohort study. Lancet 2013;381:1551-60.
18. Bryant JM, Grogono DM, Rodriguez-Rincon D, Everall I, Brown KP, Moreno P, et al. Emergence and spread of a human-transmissible multidrug-resistant nontuberculous mycobacterium. Science 2016;354:751-7.
19. Kapnadak SG, Hisert KB, Pottinger PS, Limaye AP, Aitken ML. Infection control strategies that successfully controlled an outbreak of *Mycobacterium abscessus* at a cystic fibrosis center. Am J Infect Control 2016;44:154-9.
20. Johnston DI, Chisty Z, Gross JE, Park SY. Investigation of *Mycobacterium abscessus* outbreak among cystic fibrosis patients, Hawaii 2012. J Hosp Infect 2016;94:198-200.
21. Garber E, Desai M, Zhou J, Alba L, Angst D, Cabana M, et al. Barriers to adherence to cystic fibrosis infection control guidelines. Pediatr Pulmonol 2008;43:900-7.
22. Bowmer G, Latchford G, Duff A, Denton M, Dye L, Lawton C, et al. Adherence to infection prevention and control guidelines: a vignette-based study of decision-making and risk-taking in young adults with cystic fibrosis. J Cyst Fibros 2017;16:146-50.