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Review

Antimicrobial stewardship staffing: How much is enough?

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Abstract

Antimicrobial stewardship improves patient care and reduces antimicrobial resistance, inappropriate use, and adverse outcomes. Despite high-profile mandates for antimicrobial stewardship programs across the healthcare continuum, descriptive data, and recommendations for dedicated resources, including appropriate physician, pharmacist, data analytics, and administrative staffing support, are not robust. This review summarizes the current literature on antimicrobial stewardship staffing and calls for the development of minimum staffing recommendations.

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Antimicrobial resistance (AMR) is a critical patient safety and public health crisis emphasized by the Centers for Disease Control and Prevention (CDC) and the World Health Organization (WHO).[1,2] Calls for a coordinated approach to antibiotic stewardship emerged in the literature more than 40 years ago.[3] The Infectious Diseases Society of America (IDSA) and the Society for Healthcare Epidemiology of America (SHEA) first recommended antibiotic stewardship in acute-care hospitals (ACH) in 1997 then updated guidelines for implementation in 2007.[4,5] In 2012, SHEA, IDSA, and the Pediatric Infectious Diseases Society (PIDS) urged for antibiotic stewardship programs (ASPs) to be required through regulatory mechanisms.[6]

In 2014, the Presidential Executive Order—Combating Antibiotic-Resistant Bacteria (CARB)—called for a comprehensive antibiotic stewardship plan, and the CDC's "7 Core Elements" for a successful hospital ASP.[7,8] The following year, the National Action Plan directed all ACHs to establish ASPs by 2020 and to expand antibiotic stewardship across the healthcare continuum.[9] The National Quality Forum and the Joint Commission's standards incorporated the CDC core elements, 3 of which refer directly to resource allocation: dedicated human, financial, and information technology resources.[8,10,11] However, the degree of resources required for a successful ASP at a given institution is not standardized and is influenced by numerous variables including bed size, case-mix index, healthcare delivery model, level of training, and number of support pharmacists. These factors were specifically acknowledged in a recent multisociety white paper.[12]

Mounting evidence demonstrates that ASPs can optimize individual patient outcomes, improve the quality of care, and provide critical patient safety processes while reducing antimicrobial-associated adverse events (eg, acute kidney injury and *C. difficile* infection rates), length of stay, and AMR development.[8,13,14] Antibiotic stewardship strategies can be implemented in any healthcare setting, and they are often cost-saving for institutions. Multidisciplinary engagement and myriad interventions from allergy management to rapid diagnostic review have demonstrated profound success.

Researchers have studied optimal provider staffing, including physicians, nurses, and pharmacy and quality personnel, in diverse healthcare settings, often demonstrating improved patient outcomes with appropriate staffing standards, particularly in intensive care units (ICUs).[15–22] This review describes the existing literature on antibiotic stewardship staffing, builds on the historical parallel of infection prevention staffing standardization, and concludes with a call to action for formal antibiotic stewardship staffing standards.

The infection prevention parallel

Infection prevention programs serve as an important model for leveraging ASP infrastructure and implementation resources.[23] Reviewing the timeline reveals similar struggles with establishing formal staffing guidelines and appropriate funding mechanisms (Fig. 1). One of the first infection prevention studies addressing staffing was an 18-month evaluation of time required to "carry out a surveillance program of at least intermediate effectiveness (p 314)" in 6 community hospitals from 1965 to 1966.[24] The outcomes informed the initial CDC infection prevention staffing recommendation of 1 infection preventionist full-time equivalent (FTE) per 250 occupied beds.[25] The CDC's landmark Study on the Efficacy of Nosocomial Infection Control (SENIC) project demonstrated that several foundational infection prevention activities and a ratio of 1 infection preventionist for every 250 beds yielded a 32% reduction in nosocomial infection (Table 1).[26] Further analysis to explore a more "lenient" staffing ratio confirmed these findings: infection reductions "declined sharply" as the number of occupied beds per infection preventionist rose above 250.

Participation in the CDC's National Nosocomial Infections Surveillance (NNIS) system is limited to hospitals with a minimum of 1 infection preventionist FTE for the first 100 occupied beds

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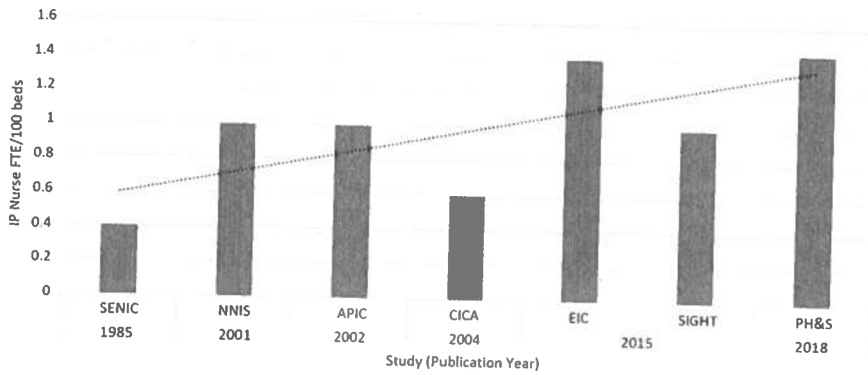

Fig. 1. Recommended Infection Prevention Staffing Resources. IP, Infection Prevention; FTE, full-time equivalent; SENIC, Study on the Efficacy of Nosocomial Control; NNIS, National Nosocomial Infections Surveillance; APIC, Association for Professionals in Infection Control and Epidemiology; CICA, Canadian Infection Control Alliance; EIC, European Infection Control; SIGHT, Systematic Review and Evidence-Based Guidance on Organization of Hospital Infection Control Programmes; PH&S, Providence Health and Services.

Table 1. Selected Studies of Infection Prevention Resources

First Author	Year Published	Study	IP Nurse FTE/100 beds	Recommendation/ Observation
		United States, Inpatient		
Haley[26]	1985	SENIC	0.4	Recommendation – Based on infection surveillance data
Richards[27]	2001	NNIS	1	Recommendation – Requirement for participation
O'Boyle[28]	2002	APIC	1	Recommendation
Stone[29]	2014	P-NICER	1.2	Observation
Bartles[35]	2018	Providence Health & Services	1.45	Recommendation – Needs assessment "aggregated across the organization"
		Non-United States, Inpatient		
Morrison[30]	2004	Canadian Infection Control Alliance	0.6	Recommendation
Zingg[31]	2015	SIGHT	1	Recommendation – Systematic review
Rodriguez-Bano[33]	2015	European infection control	1	Recommendation – Expert review
Hansen[32]	2015	PROHIBIT	0.4	Observation
Dickstein[34]	2016	ESCMID survey	0.8	Observation

Note. IP, infection prevention; FTE, full-time equivalent; SENIC, Study on the Efficacy of Nosocomial Control; NNIS, National Nosocomial Infections Surveillance; APIC, Association for Professionals in Infection Control and Epidemiology; P-NICER, Prevention of Nosocomial Infections and Cost Effectiveness Refined; SIGHT, Systematic Review and Evidence-Based Guidance on Organization of Hospital Infection Control Programmes; PROHIBIT, Prevention of Hospital Infections by Intervention and Training; ESCMID, European Society of Clinical Microbiology and Infectious Diseases.

(and 1 FTE for each additional 250 beds).[27] The increasing volume and complexity of infection prevention activities prompted the Association for Professionals in Infection Control and Epidemiology (APIC) to re-evaluate infection preventionist staffing ratios. Using the Delphi method, a panel of 45 infection preventionists reported 40 of the 46 "essential" tasks identified were not regularly completed, citing many barriers foreshadowing antibiotic stewardship concerns, namely "competing responsibilities" and "access to resources (p 998)." [28] The APIC then recommended 1 infection preventionist FTE per 100 occupied beds, nearly double that of the existing SENIC guidelines and similar to NNIS staffing directives.

The 2011 Prevention of Nosocomial Infections and Cost Effectiveness Refined (P-NICER) study of 975 hospitals and 1,534 ICUs provided the most comprehensive evaluation of infection prevention program structure and support in the United States after SENIC; it reported an average of 1.2 infection preventionists per 100 beds.[29] The authors concluded that the current recommendation of "0.8 to 1 infection preventionist per 100 hospital beds . . . are most likely out of date due to the complexity and responsibilities of infection prevention in hospitals today (p 97)" and staffing was "not consistent with published guidelines (p 98)."

Infection preventionist staffing standards are coming into focus throughout the globe; recent data suggesting that current recommendations may still be below actual labor needs.[30–34] Recently, Providence Health and Services, a large healthcare organization comprising 34 hospitals, performed a multifaceted evaluation including literature review, current infection prevention time allocation assessment, regional meetings with key stakeholders, and a quantitative needs assessment. These measures resulted in a staffing model developed to address priorities and gaps individualized to regions and hospitals. They concluded that the ideal benchmark should be 1 infection preventionist per 69 occupied beds if outpatient and long-term care (LTC) settings are included.[35] Unfortunately, hospital surveys often demonstrate poor "real world" adherence to staffing recommendations despite consensus regarding their impact on patient safety—a phenomenon also evident in the antibiotic stewardship literature. The barriers and progress in infection preventionist staffing and resource allocation serve as an ideal framework through which to view ASP development.

Surveys describing stewardship staffing and financial needs and barriers

A recent white paper on behalf of IDSA, SHEA, and PIDS recommends that compensation for ASPs be distinct from funds dedicated to infection prevention, with protected time afforded to antibiotic stewardship physicians and staff "appropriately scaled to facility size (p 998)."[12] Unfortunately, surveys of budding and active ASPs routinely cite insufficient financial resources, time, and staff as barriers to program success.[36–38] A 1999 survey of Emerging Infections Network (EIN) members—a network of US infectious diseases providers established by the CDC—found that 50% of respondents performed antimicrobial prior authorization but only 18% received remuneration for this effort (Table 2).[39] An accompanying commentary emphasized the value of this monitoring despite "little or no pay" and suggested that antibiotic stewardship physicians receive a global fee for "non-patient-care activities," which can be justified by an annual report to hospital administration.[40,41]

Following the 2007 IDSA/SHEA antibiotic stewardship guidelines, 52% of health professionals surveyed lacked an ASP; personnel shortages (55%) and financial considerations (35%) were cited as the top 2 barriers to program implementation,[42] which was confirmed in a separate 2009 survey with similar results.[43] A follow-up EIN survey in 2009 demonstrated only a modest increase ASP presence, with 25% of ASPs lacking physician involvement and only 52% of physicians receiving compensation for antibiotic stewardship activities.[44]

Pediatric ASPs have faced similar resource challenges. In a 2008 EIN survey, only 33% of pediatric facilities featured an ASP, and >50% of respondents cited funding and personnel insufficiencies as barriers to ASP implementation.[45] A subsequent 2011 survey of freestanding children's hospitals demonstrated similar results: 38% had a formal ASP and 36% were planning implementation. Identical support barriers were voiced among those without an ASP.[46] For existing ASPs, the median number of total FTE support was only 0.63 (median bed size, 295) even though total FTE support, particularly pharmacist FTE, correlated with the number of monitored antibiotics. More recently, the Sharing Antimicrobial Reports for Pediatrics Stewardship (SHARPS) collaborative reported data on their 36 participating hospitals with an overall antibiotic stewardship FTE of only 0.75 (median bed size, 284).[47]

In 2011, 5 years after California Senate Bill 739 mandated all state ACHs develop an ASP,[48] only 50% of facilities had complied with only 73% of physicians and 80% of pharmacists receiving any dedicated antibiotic stewardship FTE support.[49] Subsequent California legislation in 2014 (Senate Bill 1311) went further, requiring inpatient ASPs to have at least 1 physician or pharmacist leader.[50] Missouri passed a similar legislative mandate (Senate Bill 579), also requiring National Healthcare Safety Network (NHSN) antimicrobial use reporting though staffing and funding mechanisms were not clarified.[51]

The first NHSN survey accounting for antibiotic stewardship practices in the United States was conducted in 2014. Only 32% of the 4,184 ACHs surveyed provided antibiotic stewardship salary support despite both the 2014 and 2015 NHSN surveys demonstrating salary support to be an independent predictor for achieving all 7 CDC core elements.[52,53] The theme of limited resources for antibiotic stewardship continues to ripple through the movement's timeline, with particular impact on smaller, community hospitals.[44,54] Small community hospitals (<200 beds) represent 72% of US nonfederal hospitals, but only 31% of hospitals with <50 beds and 26% of critical-access hospitals (<25 beds) have an ASP featuring all 7 CDC core elements.[55–57] Despite these substantial barriers, successes have been demonstrated in the community setting by optimizing available resources.[54,57–60]

Even among *US News and World Reports* (USNWR) highest-ranking hospitals, a recently published 2016 survey reported that fewer than half of institutions (48%) have a dedicated ASP budget.[61] Most of these hospitals (65%) have ≤0.5 physician FTE, and 48% of programs feature only 0.51–1.0 pharmacist FTE. For surveyed ASPs with a budget, most fell within the range of $50,000–$250,000 per year. However, as an example, pediatric hospital ASP budgets ranged from $17,000 to $388,500 annually, without correlation to hospital size, which demonstrates the inconsistencies in hospital ASP funding.

International antimicrobial stewardship staffing

Much of the concrete guidelines for antibiotic stewardship resources have been provided by stewardship colleagues abroad (Table 3). Nevertheless, international ASPs still struggle to meet policy recommendations. The French Ministry of Health has mandated public reporting of each hospital's antibiotic policy since 2007.[62,63] Data from the 2007 antibiotic policy questionnaire produced a composite index (ICATB) to assess appropriate antimicrobial use.[64] In 2015, using the previously developed ICATB indices, a French AMR task force surveyed 65 French facilities to assess the human resources required to implement recommended ASP activities. Ultimately, they recommended 3.6 antibiotic supervisor FTE, 2.5 pharmacist FTE, and 0.6 microbiologist FTE per 1,000 acute-care beds—a dramatic increase from prior staffing targets.[65]

In 2011, the Australian Commission on Safety and Quality in Health Care required all hospitals to implement an ASP by 2013.[66] However, surveys in 2012 demonstrated that implementation was lagging with only 5% of hospitals in Victoria and 19% of Queensland hospitals reporting a dedicated ASP.[67,68] Lack of educational training in antimicrobial use and insufficient pharmacy resources were leading barriers.

An internet-based survey distributed to 660 hospitals in 67 countries by the European Society of Clinical Microbiology and Infectious Diseases (ESCMID) in 2012 sought to characterize global AS.[69] Respondents were mostly European from tertiary teaching hospitals (48%) with >500 beds (52%). National antibiotic stewardship standards existed in 52% of countries, dominated by Europe (81%), but formal ASPs were present in only 58% of hospitals, ranging from 67% in North America to 14% in Africa. The number of resource hours per week varied dramatically between countries; lack of funding and personnel were reported as the major barriers to implementation by all respondents.

In Canada, antibiotic stewardship has been required in ACHs since 2013.[70] Given the lack of clarity around necessary human resources required and the complexity of petitioning hospital administration, the Association of Medical Microbiology and Infectious Diseases Canada (AMMI) recently published a "business case" for ACH ASPs through expert consensus. They proposed 1 physician FTE, 3 pharmacist FTE, 0.5 administrative staff FTE, and 0.4 data analyst FTE per 1,000 ACH beds, with a minimum requirement of 0.1 physician FTE and 0.3 pharmacist FTE regardless of institutional size. Nevertheless, a recent survey of 97 organizations in Ontario found that only 50% of hospitals had designated antibiotic stewardship resources; teaching hospitals reported 0.57 physician FTE and 2.16 pharmacist FTE per 1,000 beds. Small community hospitals averaged only 0.006 pharmacist FTE and 0 physician FTE.[71]

In 2017, Pulcini[72] et al summarized the proposed minimum staffing standards by countries with mandatory hospital antimicrobial stewardship: Australia (4 FTE per 1,000 acute-care beds), Austria and Germany (2 FTE per 1,000 beds), Canada (4.9 FTE per 1,000 acute-care beds), France ("optimal" goal of 6.7 FTE per 1,000 acute-care beds), and The Netherlands (3 FTE for bed size >750).[65,70,72–75] This summary also commented that ASPs remain understaffed or nonexistent in most countries, with almost exclusive inpatient focus despite the fact that most global antimicrobial use originates in the outpatient environment. The 2017

Table 2. Selected Surveys Reporting Antimicrobial Stewardship Program Resources

First Author	Year Published	Respondents, No.	Population Surveyed	Respondents with ASP, %	Budgeted Support if ASP present, %	Factors associated with ASP	Top 2 Barriers Reported
United States, Inpatient							
Sunenshine[39]	2004	502	EIN	50 (preauthorization)	18	Teaching hospitals	...
Pope[42]	2009	357	SHEA membership	48	...	Pharmacy driven de-escalation and dose optimization	Personnel Financing
Hersh[45]	2009	147	Pediatric EIN	33	60 (pharmacist) 40 (physician)	...	Funding Time
Septimus[59]	2011	568	HealthTrust Purchasing Group	15 ("antimicrobial committee")	...	...	...
Johannsson[44]	2011	522	EIN	61	48	Less likely in community hospitals and <200 beds	Funding Personnel
Doron[43]	2013	406	Yankee and Premier Healthcare Alliance	51	...	Teaching hospitals and higher bed number	Staffing Funding
Abbo[144]	2013	82	Florida Hospital Association	55	35 (programs with >0.5 physician FTE)	Facilities >250 beds	Funding Personnel
Trivedi[49]	2013	223	California ACHs	50	73 (pharmacist) 80 (physician)	Less likely in rural areas and <200 beds	Staffing Funding
Newland[46]	2014	38	Children's Hospital Association[a]	38	42	Inpatient bed number and transplant patients	Funding Personnel
Pollack[52]	2016	4184	NHSN	39 (meeting all CDC core elements)	32	Major teaching hospitals and >200 beds	...
O'Leary[53]	2017	4569	NHSN	48 (meeting all CDC core elements)	...	Teaching status and >200 beds	...
Newland[47]	2017	36	SHARPS Pediatric Collaborative	...	83	...	...
Nhan[61]	2019	101	USNWR highest-ranking hospitals	82	48	...	...

Note. ASP, antimicrobial stewardship program; EIN, Emerging Infections Network; SHEA, Society for Healthcare and Epidemiology of America; ACH, acute-care hospital; NHSN, National Healthcare Safety Network; SHARPS, Sharing Antimicrobial Reports for Pediatric Stewardship; USNWR, United States News and World Report; FTE, full-time equivalent.

[a]Survey sent to freestanding children's hospitals that are members of Children's Hospital Assocation.

Table 3. Selected Antimicrobial Stewardship Program Staffing Proposals

First Author	Year Published	Group/Nation	Physician FTE(s)/100 Beds	Pharmacist FTE(s)/ 100 Beds	IT FTE(s)/ 100 Beds	Other FTE(s)/ 100 Beds	Total FTE(s)/ 100 Beds
United States, Inpatient							
Federal Register[90]	2016	CMS	0.08	0.2	0.04	...	0.32
Echevarria[88]	2017	VHA ASTF	0.25	1	...	...	1.25
Doernberg[36a]	2018	IDSA, SHEA, PIDS					
		100–300 beds	0.2	0.5	...	...	0.7
		301–500 beds	0.1	0.3	...	...	0.4
		501–1000 beds	0.08	0.27	...	...	0.35
		>1000 beds	0.1	0.3	...	...	0.4
Non-United States, Inpatient							
Duguid[73]	2011	Australia	0.1	0.3	...	...	0.4
Le Coz[65]	2016	France	0.36	0.25	...	0.06 (microbiologist)	0.67
de With[74]	2016	Germany/Austria	...	...	...	...	0.2
Plachouras[76]	2017	ECDC	...	...	...	...	0.2–0.6
Morris[70]	2018	Canada	0.1	0.3	0.04	0.05 (administrative)	0.49
Ten Oever[75]	2018	Netherlands	...	...	...	...	≈0.3[b]

Note. FTE, full-time equivalent; IT, information technology; CMS, Centers for Medicare and Medicaid Services; VHA, Veterans' Health Administration; ASTF, antimicrobial stewardship task force; IDSA, Infectious Diseases Society of America; SHEA, Society for Healthcare Epidemiology of America; PIDS, Pediatric Infectious Diseases Society; ECDC, European Centre for Disease Prevention and Control.
[a]Physician, pharmacist and total FTE/100 beds calculated from average bed size per given range (eg, 200 for 100–300 range, 400 for 301–500, 750 for 501–1,000) except for >1,000 beds, which was calcuated per 1,000 beds.
[b]Approximated from recommended range for "optimal staffing standards during the first few years of implementing an ASP" of 1.25 FTE per 300 beds to 3.18 FTE per 1,200 beds (ie, 0.27–0.42 FTE per 100 beds).

European Centre for Disease Prevention and Control (ECDC) technical report proposed 0.5–1.5 FTE for antibiotic stewardship activities per 250 acute-care beds, citing the French and German recommendations.[76]

Comparing ASP FTE between individual countries is complicated by varying expectations and definitions of antibiotic stewardship activity in a given nation and by differing funding streams (eg, private vs national health system).[72,77,78] Importantly, much of the world's antimicrobial overuse occurs in low- and middle-income countries with scant resources for antibiotic stewardship.[79,80] The United Nations General Assembly high-level AMR meeting in 2016 inspired calls for a "Global Antimicrobial Conservation Fund" to provide transitional financial and technical support to build ASP capacity in the developing world.[81,82]

Unfortunately, most international stewardship literature—regardless of nation—does not comment on ASP team composition nor provide FTE data, leading some to propose that human resources be added to the reporting checklist for epidemiologic studies on AMR (STROBE-AMS).[83,84]

Proposed staffing ratios in the United States

Within the United States, the Veterans' Health Administration (VHA) has led the way in promoting antibiotic stewardship implementation and staffing requirements, creating the antibiotic stewardship initiative in 2010, followed by the National Antibiotic Stewardship Task Force (ASTF) in 2011.[55,85] In 2012, the VHA Healthcare Analysis and Information Group (HAIG) surveyed all 130 VHA facilities to characterize antibiotic stewardship structure and practices.[86] At the time, 38% of hospitals had an ASP defined as at least a physician and clinical pharmacist. In 2014, VHA Directive 1031 mandated every VHA facility implement antibiotic stewardship paired with annual ASP evaluations.[85,87] Following this directive, 89% of facilities had a defined ASP by 2015 (compared to 41% in 2011), with a 12% decrease in inpatient antimicrobial use compared to 2010.[87]

Next, the VHA ASTF partnered with the Clinical Pharmacy Practice Office, a national program that previously developed standardized clinical pharmacy staffing models, to create a staffing calculator based on time-in-motion tracking studies from 12 facilities in 2014 for both clinical interventions and program management activities.[88] The ASTF found that a median of 2.62 FTE (1.01 FTE per 100 occupied beds) were required. After excluding outliers, the group proposed 1 pharmacist FTE per 100 occupied beds (Fig. 2). Though not extrapolated from this study, the group also proposed 0.25 physician FTE per 100 occupied beds. They concluded that a minimum of 0.25 physician FTE and 0.5 pharmacist FTE should be allotted for hospitals with <100 beds. In 2017, VHA Directive 1131 required minimum physician and pharmacist FTE staffing in keeping with this study's findings based on facility complexity.[89]

A 2016 cross-sectional electronic survey of 244 members of IDSA, SHEA, and PIDS actively involved in antibiotic stewardship reported on "self-reported effectiveness" in relation to staffing levels, defined as demonstrating ≥1 of the following: cost savings, decreased antimicrobial use or decreased rate of multidrug-resistant organisms in the prior 2 years.[36] Multivariate analysis accounting for bed size showed a 1.48-fold increase in program

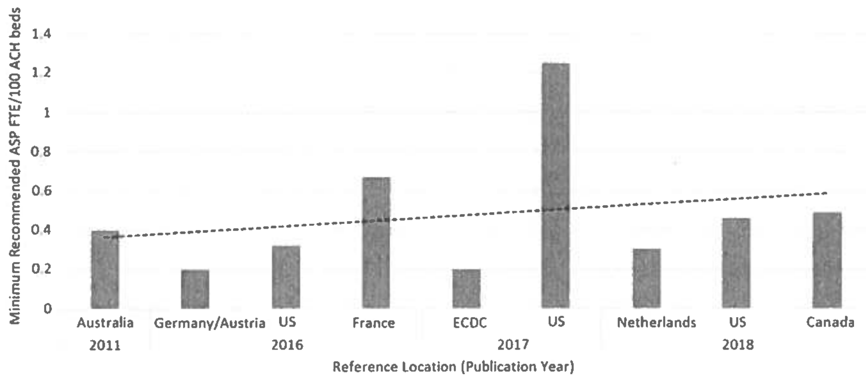

Fig. 2. Selected Antimicrobial Stewardship Program Staffing Proposals. ASP, Antimicrobial Stewardship Program; FTE, full-time equivalent; ACH, Acute Care Hospital; US, United States; ECDC, European Centre for Disease Prevention and Control.

effectiveness for every additional combined 0.5 FTE support. These authors proposed minimum combined FTE support of 1.4 FTE for hospitals with 100–300 beds, 1.6 FTE for 301–500 beds, 2.6 FTE for 501–1,000 beds, and 4 FTE for settings with >1,000 beds. Furthermore, they proposed a physician-to-pharmacy ratio of 1:3 for the "highest-value use of resources."

In 2016, the Department of Health and Human Services Centers for Medicare and Medicaid Services (CMS) stated, "(However, we believe that) the burden of implementing and maintaining an AS (program) includes the salaries of the qualified personnel needed to establish and manage such a (CAH) program (p 39474)." They suggested 0.1 physician FTE (preferably trained in infectious diseases), 0.25 pharmacist FTE, and 0.05 data analyst FTE for an average-sized hospital of ~124 beds.[90]

Antimicrobial stewardship team composition: Who "counts?"

Numerous studies and reviews have evaluated different permutations of a successful antibiotic stewardship team, including varied approaches to leadership, team composition, and antibiotic stewardship–specific training.[37,57,58,91–94] The 2012 SHEA, IDSA, and PIDS policy statement recommended that an ASP should include a physician, a pharmacist, a clinical microbiologist, and an infection preventionist.[6] The Joint Commission suggests a multidisciplinary ASP include an infectious disease physician, pharmacist(s), and infection preventionist(s) when available, They allow part-time, consulting, and even telehealth staff.[11] Most proposed FTE metrics refer to either physician or pharmacy personnel; minimal comment or data pertain to information technology (IT) and administrative support. In the previously mentioned 2016 resources survey, only 16% of surveyed programs had data analytics support (average FTE, 0.25) and only 13% featured administrative support (mean FTE, 0.16).[36] AMMI Canada formally recommended designated administrative and data analytic support, though a follow-up survey demonstrated that only 11% of established ASPs had such funding.[71] Despite the potential effectiveness and efficiency of antibiotic stewardship IT systems, resource allocation is often lacking, as is analytic support for the data generated.[37,95–97]

The open question of "who counts" when evaluating antibiotic stewardship staffing is especially important for smaller medical facilities.[54,57] The VHA and other authors have called for future studies to facilitate the recruitment of less "traditional" ASP personnel (including hospitalists, nursing staff and tele-ASPs), particularly for institutions where infectious disease specialists are simply not available, including many long-term care (LTC) settings.[12,85,92,98] Although a variety of staffing models exist, the importance of dedicated support for AS-specific activities cannot be overstated.

Stewardship staffing outside the hospital

The 2012 SHEA, IDSA and PIDS policy statement asks for antibiotic stewardship to be a "fiduciary responsibility for all healthcare institutions across the continuum of care (p 322)."[6] In 2015, the CDC published its *Core Elements of Antibiotic Stewardship for Nursing Homes then the Core Elements of Outpatient Antibiotic Stewardship* in 2016.[99,100] Long-term care ASPs have been required by CMS since November 2017.[101] Most antimicrobial use and expenditure occurs outside the hospital (eg, clinics, emergency departments (ED), hemodialysis units and LTC facilities), and only one-third of outpatient prescriptions are appropriate.[102–104] Data on the prevalence of outpatient antibiotic stewardship activity are scant, clouding our understanding of true staffing needs.[85,105–108]

Outpatient stewardship staffing

Several reviews of evidence-based outpatient antibiotic stewardship interventions exist, but they do not provide guidance on funding mechanisms.[105,109,110] According to one reviewer, compared to inpatient strategy, it is difficult "to justify funding based on reductions in antibiotics expenditures or decreased length of stay (p 458)."[110] Although resource-intensive approaches such as provider feedback demonstrate impact and support outpatient ASP expansions, interventions often focus on educational awareness and IT decision support tools.[105,110–118] Various personnel models for outpatient antibiotic stewardship infrastructure have been suggested, including engaging, training, and incentivizing community pharmacists and public health department personnel and leveraging community collaborations and health systems.[85,110,119] Experts continue to call for research into outpatient ASPs with varying resources as well as "potential policies or incentives" to promote outpatient antibiotic stewardship.[120]

Long-term care stewardship staffing

A comprehensive 2016 review of LTC antibiotic stewardship found that <20% of nursing homes employ full-time physicians and that most medical directors spend only 8–12 hours per week providing direct patient care.[121] An early survey of Nebraska LTC facilities found that 60% had an ASP, though more recent surveys revealed only 23% in Michigan and 28% in Rhode Island where a paltry 15% received budgeted support with mean FTE allocations for physicians and infectious disease pharmacists of 0.02 and 0.01, respectively.[122–124] A variety of antibiotic stewardship approaches have been employed in LTC facilities to leverage limited available resources, including sharing antibiotic stewardship personnel.[121,125–129] Despite some success, staffing limitations often prohibit more reliable but resource-heavy interventions.[127]

Other considerations

Beyond setting size, location, and team composition, additional variables affecting appropriate stewardship staffing are worth considering but are rarely discussed.[12] Care complexity influences resource allocation for high-risk patient populations (eg, transplant recipients or burn patients) who are especially prone to prolonged antibiotic exposure and complications.[128] A 2015 survey of 71 solid-organ hematopoietic stem cell transplant centers in 32 states cited staffing challenges as a barrier for transplant antibiotic stewardship.[129] ASPs presumably require more resources in the "initiation" phase (particularly for IT support) compared to an established program in the "maintenance" phase of program development.[97] Data evaluating how complexity and intensity of care as well as the presence of specialty services are limited, but the effect of these variables on antimicrobial use and need for risk adjustment have been examined previously.[130–132] It follows that staffing ratios would similarly require calibration to reflect differing needs. Whether minimum requirements are tied only to occupied bed count or some other measure warrants further study. Elements of the NHSN's pioneering standardized antimicrobial administration ratio (SAAR) (eg, academic affiliation and ICU bed count) could be utilized for adjusting expected ASP staffing needs.[132,133]

Yet another call to action

The recurring theme in antibiotic stewardship staffing literature is insufficient financial and human resources. Spellberg et al[134] point out the temptation for institutions to "check the box" in response to regulatory requirements yet still understaff the true needs of a robust multidisciplinary ASP. The literature is replete with "real world" examples of this phenomenon in California, Canada, Australia, and beyond. As stated bluntly by Pulcini et al,[72] formal antibiotic stewardship staffing standards are needed and should be linked to sustainable funding mechanisms.

The general movement away from "fee for service" models toward reimbursement for quality of care presents an opportunity for a productive partnership between antibiotic stewardship and hospital administration.[135,136] Conditions of participation in Medicare were recently approved and include language to regulate and incentivize ASP development and references prior 2016 CMS staffing proposals.[137] Specific quality and staffing metrics (some with direct monetary incentives) are emerging in visible national organizations, including the Leapfrog Group, Agency for Healthcare Research and Quality and USNWR.[138] Leapfrog now relies on information collected from the NHSN survey, and the USNWR pediatric survey includes a minimum threshold of 0.4 FTE for pharmacy support, 0.3 FTE for medical director, and 0.2 FTE for analyst support dedicated to ASP.[139,140] Such incentives are likely to help ASPs "compete" for resource allocation in a given institution.[133]

Most inpatient ASP staffing proposals recommend a combined physician and pharmacist FTE of roughly 1 to every 100–250 occupied beds, with a suggested physician-to-pharmacist ratio of 1:3.[36,65,70,72,88] Therefore, a formal recommendation establishing a total of 1 FTE ASP support for every 250 beds, optimally with ~1 physician for every 3 pharmacists, offers a bare minimum expectation for inpatient facilities. Relying on even the most up-to-date staffing recommendations is fraught with limitations because the optimal stewardship FTE-to-bed ratio remains a "moving target." The minimum inpatient recommendation should evolve over time and with facility complexity, just as infection preventionist staffing expectations have matured since SENIC.

Stewardship resource standards are desperately needed for outpatient and LTC settings as well as for accompanying analytic and administrative support. Technology support is required to integrate ASP tools to enhance the vital human components of ASPs, and resources for software as well as support likewise deserve attention.[97] Further studies are needed to characterize human resource parameters for antibiotic stewardship across the healthcare continuum, which should both further refine inpatient standards and prompt yet another call to action for outpatient stewardship staffing benchmarks.[57,141,142]

Zahn et al[143] could not be more right in stating, "Physicians performing infection control and antimicrobial stewardship work should be compensated for these activities (p 355)." Stewardship staffing standards, analogous to evolving infection prevention recommendations, are necessary to provide appropriate resources for ASPs. Just as medical centers, providers, patients, and their families expect robust infection prevention activity to optimize safe and quality care, healthcare entities should sufficiently staff and fund antibiotic stewardship for both inpatients and outpatients to decrease the public threat of antibiotic resistance and adverse antibiotic exposure outcomes.

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MAJOR ARTICLE

Essential Resources and Strategies for Antibiotic Stewardship Programs in the Acute Care Setting

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Background. Antibiotic stewardship programs improve clinical outcomes and patient safety and help combat antibiotic resistance. Specific guidance on resources needed to structure stewardship programs is lacking. This manuscript describes results of a survey of US stewardship programs and resultant recommendations regarding potential staffing structures in the acute care setting.

Methods. A cross-sectional survey of members of 3 infectious diseases subspecialty societies actively involved in antibiotic stewardship was conducted. Survey responses were analyzed with descriptive statistics. Logistic regression models were used to investigate the relationship between stewardship program staffing levels and self-reported effectiveness and to determine which strategies mediate effectiveness.

Results. Two-hundred forty-four respondents from a variety of acute care settings completed the survey. Prior authorization for select antibiotics, antibiotic reviews with prospective audit and feedback, and guideline development were common strategies. Eighty-five percent of surveyed programs demonstrated effectiveness in at least 1 outcome in the prior 2 years. Each 0.50 increase in pharmacist and physician full-time equivalent (FTE) support predicted a 1.48-fold increase in the odds of demonstrating effectiveness. The effect was mediated by the ability to perform prospective audit and feedback. Most programs noted significant barriers to success.

Conclusions. Based on our survey's results, we propose an FTE-to-bed ratio that can be used as a starting point to guide discussions regarding necessary resources for antibiotic stewardship programs with executive leadership. Prospective audit and feedback should be the cornerstone of stewardship programs, and both physician leadership and pharmacists with expertise in stewardship are crucial for success.

Keywords. antibiotic stewardship; antimicrobial stewardship; resources; effectiveness; survey.

Antibiotic resistance threatens human health and safety on a global scale and is a key priority of the Centers for Disease Control and Prevention (CDC) and the World Health Organization [1–4]. Antibiotic stewardship programs (ASPs), designed to promote appropriate use of antibiotics, are a major component of the strategy to combat antibiotic resistance, and regulatory bodies such as the Joint Commission [5] in the United States have established standards outlining requirements for ASPs in the acute care setting. These requirements provide important incentives for hospitals to implement ASPs, which have been shown to decrease antibiotic resistance and improve quality of care [6–8]. There is a growing body of evidence supporting the beneficial impact of ASPs in the acute care setting; however, further practical guidance on staffing ratios and resources needed to carry out these recommendations will enhance available information [9–12]. Compared to the United States, European guidelines provide concrete full-time equivalent (FTE)–to-bed ratios, though translating this guidance to the US hospital structure is challenging [13–15].

In April 2016, the Infectious Diseases Society of America (IDSA), along with members of the Society for Healthcare Epidemiology of America (SHEA) and the Pediatric Infectious Diseases Society (PIDS), convened a joint task force to identify resources to assist infectious diseases (ID) specialists interested in initiating and sustaining ASPs. The group consisted of 13 physicians from a variety of backgrounds, including academia and the private sector. The group designed and distributed an electronic survey of ASPs within the United States to better understand existing structures, activities, resources, and gaps.

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This paper describes our survey results and potential staffing structures for the implementation and sustainability of successful ASPs across diverse acute care hospital settings.

METHODS

Survey

A cross-sectional survey of members of IDSA, SHEA, and/or PIDS actively involved in antibiotic stewardship was conducted. Inclusion criteria required membership in at least 1 of the 3 societies with patient care, epidemiology, or administration listed as a primary responsibility. Exclusion criteria were (1) degrees other than doctor of medicine (MD), bachelor of medicine, bachelor of surgery (MBBS), doctor of osteopathic medicine (DO), or doctor of pharmacy (PharmD); (2) trainee status; (3) members outside the United States; (4) employment affiliation listed as industry, public health, or other business; or (5) no affiliated facility listed. To avoid duplicates, the resultant lists were grouped by institution to identify the most appropriate member, as determined by title. Physicians were chosen over pharmacists when both were available. The list was then sorted by state to avoid duplications and to identify cases where members indicated their institution in different ways (eg, UCSF vs UC San Francisco). The list was manually searched to further identify duplicates.

A 73-question electronic survey was developed and distributed via email (Qualtrics, Provo, Utah; see Supplementary Material File 1). Respondents were instructed to forward the survey to the stewardship lead at their institution if they had not been correctly identified. Only 1 response per hospital was accepted. No incentives were provided for participation. Respondents working in stewardship at >1 hospital or as part of a health system were instructed to answer the questions for the hospital where they spent the majority of their time. Survey responses were collected from 29 June to 3 August 2016, with regular reminders sent out to nonresponders.

Definitions

Definitions for cascade reporting of antibiotics, computerized decision support, antibiotic time-out, formulary restriction/prior authorization, and prospective audit and feedback (PAF) are taken from the IDSA/SHEA guidelines for implementation of antimicrobial stewardship and the CDC Core Elements of Hospital Antibiotic Stewardship Programs [9, 16]. Technology add-on was defined as a computer program apart from or in addition to the main electronic medical record that is designed to aid with antibiotic stewardship. The Clinical and Laboratory Standards Institute definition for antibiogram [17] was used.

Analysis

Survey results were analyzed using Stata SE version 14.2 software (StataCorp LP, College Station, Texas), using descriptive statistics to summarize responses. Comparisons among groups were performed using Pearson χ^2 test for categorical variables and 1-way analysis of variance for continuous variables.

Logistic regression analysis was performed to evaluate whether combined physician and pharmacist FTE support was associated with the ability of a program to demonstrate effectiveness. The main outcome was ASP effectiveness, defined as a positive survey response to at least 1 of the following: demonstrated cost savings, decreased antibiotic utilization, or decreased rate of multidrug-resistant organisms (MDROs) within the past 2 years. The main predictor was a continuous measurement of summed physician and pharmacist FTE, hereafter referred to as combined FTE. Stepwise regression analysis with a priori *P* value cutoffs for retention in the multivariable model was conducted. Bed size was locked in the model a priori. Sensitivity analyses included 2 models: the first using forward and backward selection with the same variables but without forcing bed size into the model, and the second retaining all covariates without stepwise selection. Marginal probabilities of effectiveness were calculated for levels of combined FTE and were graphed with 95% confidence intervals.

A second logistic regression analysis, using identical covariates and effectiveness outcomes, evaluated the impact of pharmacist FTE and physician FTE separately, defined as continuous variables.

A third logistic regression analysis was designed to determine which stewardship strategies act as mediators of the relationship between combined FTE and ASP effectiveness. A sensitivity analysis included all strategies listed above, plus use of a technology add-on.

Determination of Proposed Recommended FTE-to-Bed Ratio

Using the results of the survey responses for the number of existing FTE positions paired with the number of FTE perceived by respondents to be needed, the Task Force developed a consensus recommendation for a minimum FTE-to-bed ratio proposed to staff an ASP adequately in the acute care setting.

Prototype Program

A subgroup of the Task Force defined attributes of a prototype ASP and compared FTE support for programs overall and by attribute. This analysis is presented in Supplementary Material File 2.

RESULTS

Survey Demographics

Two hundred forty-four of 1989 (12%) invitees (189 physicians, 52 pharmacists) completed the survey. Table 1 illustrates the characteristics of the respondents' ASPs. ASPs had been present for a median of 5 years (interquartile range, 1–10 years). Respondents came from 43 states. Most practiced stewardship at academically affiliated hospitals (46%) or major academic centers (21%). Of the physicians, 55 (29%) worked in private

Table 1. Characteristics of Antibiotic Stewardship Program Setting and Scope (N = 244)

Characteristic	No. (%)
Location	
Northeast	56 (23.0)
Midwest	63 (25.8)
South	62 (25.4)
West	60 (24.6)
Unknown	3 (1.2)
No. of hospitals where respondent works	
1	158 (64.8)
2	50 (20.5)
≥3	36 (14.8)
No. of beds at primary hospital	
<100	15 (6.2)
100–300	91 (37.3)
301–500	82 (33.6)
501–1000	45 (18.4)
>1000	11 (4.5)
Primary hospital's teaching status	
Major academic medical center	71 (29.1)
Academic affiliation	114 (46.7)
Nonteaching	54 (22.1)
Other	5 (2.1)
Primary hospital's specialty services	
Level 1 trauma center	89 (36.5)
Burn unit	36 (14.8)
Solid organ transplant program	84 (34.4)
Bone marrow transplant program	66 (27.1)
Primary hospital part of a health system	191 (78.3)
System- vs hospital-level ASP	
Hospital-level stewardship	93 (48.7)
Mixed system- and hospital-level stewardship	79 (41.4)
Stewardship centralized at health system level	19 (10.0)
Noninpatient settings covered by ASP	
Outpatient	35 (14.3)
Emergency department	135 (55.3)
Long-term care facility	21 (8.6)
ASP provides telestewardship	30 (12.3)

Abbreviation: ASP, antibiotic stewardship program.

practice, 129 (68%) as employees of healthcare systems, and 52 (28%) as salaried academic employees. One hundred fifty-nine (84%) took care of adults, with the remainder split between pediatricians (10%) and those trained in both medicine and pediatrics (6%). While almost all physician respondents were ID board certified or eligible (99%), only 44% of pharmacists were ID residency trained, with another 27% of those without residency training having a certificate in antibiotic stewardship. Respondents' ASPs were generally led by physicians (56%) or co-led by physicians and pharmacists (36%). Nineteen programs (8%) lacked accountable physician leaders.

Leadership Commitment

One-hundred eighty-four (75%) respondents reported a written stewardship policy at their main institution, while 57% of physicians (107/189) and 73% of pharmacists (38/52) noted stewardship as part of their job description. Table 2 shows current physician and pharmacy FTE support at sampled programs along with additional FTEs that respondents felt were needed to operate effectively. A combined sum of FTE is reported for each size hospital.

Nearly all programs (97%) reported the presence of electronic medical records, and 156 (64%) reported having information technology add-ons to assist with stewardship, with the most common ones being Theradoc (Premier, Inc), Epic ICON (Infection Control) module, Sentri7 (Wolters Kluwer), and MedMined (Becton Dickinson). Data analytics support was available at 40 programs (16%), with an average FTE of 0.25. Administrative support for ASPs was available in 32 programs (13%), with mean FTE of 0.16.

Action

Broad Interventions

Most ASPs reported performing prior authorization for select antibiotics (81%) and antibiotic reviews with PAF (84%), while a minority of programs reported having computerized decision support systems at the time of antibiotic prescription (32%) or an antibiotic time-out (33%). There was a significant increase in the proportions of programs reporting PAF with increasing combined FTE. Only 27 (60%) programs in the <0.5 combined FTE category reported performing PAF as compared to 48 (86%) in the 0.5 to <1.0 category, 74 (90%) in the 1.0–1.5 category, and 57 (93%) in the >1.5 category ($P < .001$).

Pharmacists performed PAF 72% of the time, with attending ID physicians participating 22% of the time. Accordingly, physician respondents reported spending on average 4.5 hours per week doing PAF while pharmacists reported 19.5 hours. The most common strategy for selecting patients for PAF was based on selected target antibiotics (79% of programs performing PAF). Other common strategies for identifying patients on whom to intervene included laboratory-based (eg, drug levels, microbiology [48%]) and guideline-based triggers (eg, duration for indication [35%]). The numbers of patients reviewed and on whom feedback was provided rose with increasing FTE ($P = .003$ and $P = .01$, respectively). Most programs (71%) reported providing feedback on ≤15 patients per day. Recommendations were documented in the chart by 81 (39%). When conflicts occurred, most programs (57%) defer to the primary service. However, 29 programs (14%) mandate consultation, and another 37 (18%) have no official policy. Only 5 programs (2%) report the ASP has authority to override the primary service.

Of the 179 programs (73%) who had local antibiotic guidelines for common clinical conditions, those for pneumonia (92%), surgical prophylaxis (86%), urinary tract infection (68%), and skin and soft tissue infection (66%) were popular. Pharmacy-driven interventions, including automatic dose

Table 2. Full-time Equivalent (FTE)–to-Bed Ratio: Existing and Needed FTEs Reported by Programs (N = 244)

	Bed Size				
FTE	<100 (n = 15)	100–300 (n = 91)	301–500 (n = 82)	501–1000 (n = 45)	>1000 (n = 11)
Existing MD FTE	0.27 (0–0.87)	0.24 (0–1.2)	0.26 (0–1.0)	0.37 (0–1.0)	0.46 (0.2–1.4)
Additional MD FTE needed	0.11 (0–0.8)	0.15 (0–1.0)	0.15 (0–1.0)	0.19 (0–1.5)	0.42 (0–2.4)
Total combined MD FTE	0.38 (0–1.4)	0.39 (0–1.7)	0.41 (0–2.0)	0.56 (0–2.1)	0.88 (0.2–2.8)
Existing PharmD FTE	0.61 (0–2.0)	0.63 (0–2.0)	0.89 (0–3.0)	1.2 (0–2.0)	1.5 (0.5–3.1)
Additional PharmD FTE needed	0.28 (0–2.0)	0.32 (0–1.4)	0.31 (0–2.0)	0.52 (0–2.5)	1.18 (0–7.0)
Total combined PharmD FTE	0.89 (0.2–4.0)	0.95 (0–2.8)	1.20 (0–4.0)	1.69 (0–4.5)	2.68 (0.8–9.0)
Total MD and PharmD overall FTE	1.27 (0.3–5.4)	1.34 (0–3.3)	1.61 (0–6.0)	2.24 (0.43–5.5)	3.56 (1.5–11.8)

Data are presented as mean (range).

Abbreviations: FTE, full-time equivalent; MD, doctor of medicine; PharmD, doctor of pharmacy.

adjustment, pharmacokinetic monitoring, and intravenous to oral conversions, were common across all sizes of hospital and did not vary significantly by FTE (data not shown).

Microbiological Interventions

Antibiograms were produced by 243 programs (99%), and 125 (51%) performed cascade reporting of antibiotic susceptibilities. Rapid diagnostics were widely available, with 153 (63%) using respiratory viral panels, 116 (48%) rapid diagnostic testing of blood specimens (any platform), and 114 (47%) rapid identification of *Staphylococcus aureus*. Procalcitonin testing was available at 128 (53%) hospitals. There were no notable differences in availability of microbiology interventions based on FTE support (data not shown). Rapid viral testing and rapid testing of blood cultures were significantly more common ($P = .001$ and $P = .005$, respectively) at larger hospitals.

Tracking and Reporting

Two-hundred thirty-nine (98%) programs reported monitoring at least 1 metric, including 66 (27%) who endorsed reporting to the National Healthcare Safety Network's Antimicrobial Use and Resistance option. The majority of reports (79%) were prepared by pharmacists with a minority prepared by physicians (11%) or data analysts (5%). These reports were most frequently presented at pharmacy and therapeutics (79%) and/or infection control (57%) committees and were infrequently presented to front-line clinicians (25%).

Outcomes

Two hundred eight (85%) programs reported demonstrating some measure of effectiveness in the past 2 years. More specifically, 164 programs (67%) reported cost savings, 168 (69%) reported decreased antibiotic utilization, and 49 (20%) reported a decrease in rates of drug-resistant organisms. In a multivariate model using stepwise selection of confounders including bed size, there was a consistent dose-response relationship between combined FTE and ability to demonstrate effectiveness in any domain (Table 3). Each 0.50 increase in combined FTE availability resulted in a 1.48-fold increase in the odds of demonstrating effectiveness (95% confidence interval, 1.06–2.07). This finding remained significant when the outcome of interest was limited only to demonstrating decreased antibiotic use, a metric more reliably related to ASP efforts (data not shown), as well as 2 sensitivity analyses utilizing different rules for covariate

Table 3. Predictors of Ability to Demonstrate Effectiveness

			Sensitivity Analysis 1	Sensitivity Analysis 2
Variable	Univariate OR (95% CI)	Primary aOR (95% CI)	aOR (95% CI)	aOR (95% CI)
Combined PharmD and MD FTE, 0.50 increase	1.60 (1.17–2.20)	1.48 (1.06–2.07)	1.50 (1.09–2.06)	1.42 (1.00–2.02)
Bed size				
0–300	0.78 (.36–1.73)	1.04 (.46–2.38)	…	0.95 (.39–2.33)
301–500	Reference	Reference	…	Reference
>501	1.75 (.58–5.27)	1.20 (.38–4.32)	…	1.09 (.29–4.07)
ASP technology add-on	2.57 (1.25–5.28)	2.04 (.96–4.32)	2.05 (.98–4.32)	2.23 (1.01–4.98)

The primary multivariate model used forward and backwards stepwise selection with bed size categories locked into the model; sensitivity analysis 1 used forward and backwards stepwise selection with no variables locked into the model; sensitivity analysis 2 locked all covariates into the model, including bed size, training of the ASP team, age of the ASP program, presence of an ASP policy, member of a health system, teaching status, presence of a burn unit, presence of a trauma unit, solid organ transplantation and bone marrow transplantation, and ASP technology add-on availability.

Abbreviations: aOR, adjusted odds ratio; ASP, antibiotic stewardship program; CI, confidence interval; FTE, full-time equivalent; MD, doctor of medicine; OR, odds ratio; PharmD, doctor of pharmacy.

selection. Availability of a technology add-on was a strong predictor in univariate models of ability to demonstrate effectiveness, though it fell short of statistical significance in multivariate models. Figure 1 shows the likelihood of demonstrating effectiveness based on combined FTE status.

Table 4 shows the impact of increasing physician and pharmacist FTE separately on the ability to demonstrate effectiveness. While there was an increased numerical odds of effectiveness with increasing physician FTE, this was not statistically significant. The effect of increasing pharmacist FTE on effectiveness was significant for both the primary model and the first sensitivity analysis but fell just shy of statistical significance for the second sensitivity analysis, with each 0.50 increase in FTE resulting in a 58% increase in the odds of a program being effective.

Potential mediators of effectiveness are shown in Table 5. PAF appears to be the strongest mediator of ASP success. For a program with all of these actions plus technology add-ons, the probability of being able to demonstrate effectiveness is 93% if the combined FTE support is a mean 1.1, rising to 98% at a combined FTE level of 3.5.

Education

Overall, 229 programs (94%) provided education to at least 1 group of stakeholders, most commonly physicians (87%) or pharmacists (77%), and less often to nurses (40%) or patients (9%).

Barriers

One hundred fifty-one (62%) programs somewhat or strongly disagreed with the statement "the financial resources for my program are adequate." The most commonly cited barriers to implementation of a successful ASP were lack of time (66%), financial resources (63%), and information technology issues (61%). Only 18 programs (7%) reported no barriers. In programs lacking PAF, the most common barrier was lack of physician and/or pharmacist time (84%). Another 58% reported lack of ID or stewardship expertise as a barrier, while 42% noted that implementation of such a program did not appear to be an institutional priority.

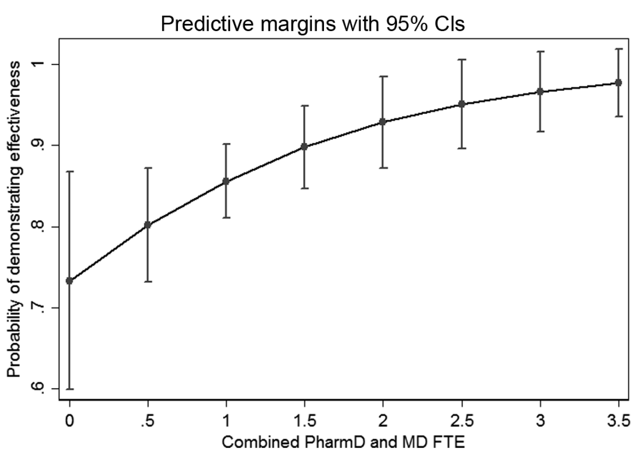

Figure 1. Predicted effectiveness based on staffing levels. A program having 0 full-time equivalent has no financial support for antibiotic stewardship program physician or pharmacist staff but may still perform stewardship activities. Abbreviations: CI, confidence interval; FTE, full-time equivalent; MD, doctor of medicine; PharmD, doctor of pharmacy.

DISCUSSION

In a survey of diverse ASPs from various geographical areas, we found an independent relationship between physician and pharmacist FTE and self-reported effectiveness of ASPs. This relationship was mediated mostly through the ability of programs with higher levels of staffing, specifically pharmacist support, to perform PAF. This finding aligns with a recent CDC study that found an association between salary support and the ability of an organization to have a comprehensive ASP [18]. Importantly, even programs with positive outcomes perceive understaffing, and nearly all respondents desired additional FTE support for both pharmacists and physicians. From the results of this survey, we have developed a proposed FTE-to-bed ratio that could be used as a starting point to guide discussions with executive leadership when developing and augmenting ASPs (Table 6) [19]. The intent of this research is to provide useful benchmarks for those currently engaged in ASP programs or those who are working to establish well-resourced ASPs and may inform business plan development. From this ratio, a hospital-specific cost based on salary and benefits could be estimated and, based on this, financial effectiveness goals set for the program. Further evaluation of this ratio in a variety of settings is warranted.

Like any effective program, the right number of qualified individuals for the volume of the organization is critical. The results of this survey demonstrate the integral role of the pharmacist in effective stewardship programs and argue for enhancement in the pipeline of stewardship and ID-trained pharmacists with leadership skills and attitudes to plan, do, study, and act toward improving the use of antibiotics and effectively change behaviors in healthcare settings. Furthermore, a named physician leader responsible for the outcome of the program is necessary for interfacing with the C-suite and other physician/provider groups as well as helping to navigate priority-setting for the organization. It is the conclusion of our group that a physician-to-pharmacist ratio of approximately 1:3 allows for the highest-value use of resources. There are creative ways to distribute these FTEs, especially in small hospitals and complex health systems.

Given the effectiveness of PAF described in this survey, this would be a reasonable starting activity for developing ASPs or those needing to prioritize activities. Although the data are mixed, consistent with our findings, a recent trial suggests that PAF is superior to formulary restriction with prior authorization

Table 4. Effect of Individual Physician and Pharmacist Support on Ability of a Program to Demonstrate Effectiveness

Variable	Univariate OR (95% CI)	Primary aOR (95% CI)	Sensitivity Analysis 1 aOR (95% CI)	Sensitivity Analysis 2 aOR (95% CI)
MD FTE, 0.50 increase	1.79 (.79–4.05)	1.23 (.52–2.89)	1.25 (.55–2.84)	1.22 (.51–2.93)
PharmD FTE, 0.50 increase	1.77 (1.20–2.60)	1.58 (1.02–2.43)	1.58 (1.06–2.35)	1.48 (.97–2.28)
Bed size				
0–300	0.78 (.36–1.73)	0.90 (.38–2.15)	…	0.97 (.39–2.40)
301–500	Reference	Reference	…	Reference
>501	1.75 (.58–5.27)	1.38 (.42–4.50)	…	1.13 (.27–4.66)
ASP technology add-on	2.57 (1.25–5.28)	2.08 (.97–4.46)	2.03 (.96–4.27)	2.20 (1.00–4.85)
Part of a health system	0.54 (.20–1.46)	0.46 (.16–1.31)	…	0.48 (.16–1.45)
Burn unit	0.67 (.27–1.68)	0.46 (.16–1.30)	…	0.38 (.11–1.29)

The primary multivariate model used forward and backwards stepwise selection with bed size categories locked into the model; sensitivity analysis 1 used forward and backwards stepwise selection with no variables locked into the model; sensitivity analysis 2 locked all covariates into the model, including bed size, training of the ASP team, age of the ASP team, presence of an ASP policy, member of a health system, teaching status, presence of a burn unit, presence of a trauma unit, solid organ transplantation and bone marrow transplantation, and ASP technology add-on availability.

Abbreviations: aOR, adjusted odds ratio; ASP, antibiotic stewardship program; CI, confidence interval; FTE, full-time equivalent; MD, doctor of medicine; OR, odds ratio; PharmD, doctor of pharmacy.

with respect to appropriate and guideline-concordant antibiotic use [9, 20]. Given the strong association of technology add-ons with self-reported effectiveness, these programs should be considered in conjunction with an existing ASP. Having access to a technology add-on enhances the ASP but does not replace the manpower required to perform effective PAF and run a successful program.

Several important limitations to this survey should be noted. First, there was a low response rate of 12%. It is unknown whether the nonrespondents were not affiliated with ASPs or just declined to participate; it is unlikely that there are 1900 people doing stewardship in the United States, so many of the nonrespondents may not have been affiliated with ASPs. Because we relied on membership of ID-enriched societies, there was a selection bias for programs employing ID physicians, which do not exist at all hospitals. As a result, there were limited responses from smaller community hospitals, including rural and critical access hospitals. However, our sample did include programs of a variety of sizes and type with representation from all geographical regions. Another limitation is the reliance on self-reported effectiveness; whether this reflects true effectiveness is undefined as we did not validate the responses. In addition, we did not quantify the degree and significance of reported effectiveness, nor did we inquire about the impact of other interventions on *Clostridium difficile* infection and MDRO rates. However, our finding of increasing FTE associated with effectiveness held up even when effectiveness was limited to decreased antibiotic use, a metric less likely affected by other cointerventions such as improved environmental cleaning, hand hygiene campaigns, or new pharmacy purchasing contracts. Last, the survey was designed to inquire about stewardship practices on an institutional level and it asked respondents to focus on the hospital where they spent the most time. Therefore, it is difficult to draw conclusions on staffing recommendations for ASPs that cover >1 hospital or an entire health system.

In the setting of new regulations, repeating this survey in the future will help monitor the changing landscape. Ideally, a repeat survey would be expanded to a larger and more representative population and will have better metrics for measuring success. As ASPs expand outside acute care settings, understanding resources needed to run effective programs in these environments will also be critical. In summary, we have

Table 5. Mediators of the Relationship Between Full-time Equivalent Support and Effectiveness of a Program

Variable	Univariate OR (95% CI)	Primary aOR (95% CI)	Sensitivity Analysis aOR (95% CI)
Combined PharmD and MD FTE, 0.50 increase	1.60 (1.17–2.20)	1.36 (.98–1.90)	1.30 (.94–1.81)
Antibiotic time-out	1.59 (.71–3.56)	1.58 (.68–3.67)	1.60 (.68–3.77)
Cascade reporting	0.82 (.40–1.66)	0.68 (.32–1.46)	0.70 (.33–1.51)
Restricted formulary with prior authorization	1.01 (.41–2.48)	0.81 (.31–2.14)	0.80 (.29–2.16)
Institutional guidelines	1.70 (.80–3.59)	1.35 (.59–3.07)	1.32 (.58–3.02)
Prospective audit and feedback	4.88 (2.21–10.79)	3.92 (1.66–9.30)	3.82 (1.60–9.13)
ASP technology add-on	2.57 (1.25–5.28)	…	1.97 (.91–4.22)

The primary model includes the actions of a prototype program. The sensitivity analysis includes these actions plus presence of an ASP technology add-on.

Abbreviations: aOR, adjusted odds ratio; ASP, antibiotic stewardship program; CI, confidence interval; FTE, full-time equivalent; MD, doctor of medicine; OR, odds ratio; PharmD, doctor of pharmacy.

Table 6. Minimal Full-time Equivalent Support Recommended by Bed Size

Variable	Bed Size			
	100–300	301–500	501–1000	>1000
Pharmacist	1.0	1.2	2.0	3.0
Physician	0.4	0.4	0.6	1.0
Total	1.4	1.6	2.6	4.0

For hospitals with <100 beds, there were limited data to make recommendations.

provided initial recommendations for staffing, structure, and attributes of acute care ASPs, which can be used by hospitals developing and sustaining ASPs.

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 copyedited and are the sole responsibility of the authors, so questions or comments should be addressed to the corresponding author.

Notes

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