

# The Use of Telemedicine for Penicillin Allergy Skin Testing



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**What is already known about this topic?** Penicillin skin testing is increasingly used as a tool to evaluate penicillin allergy in patients with a reported history, given the significant clinical and financial consequences associated with the penicillin allergy label.

**What does this article add to our knowledge?** This is the first report that assesses and describes the use of real-time, interactive video conferencing or telemedicine to facilitate inpatient penicillin skin testing.

**How does this study impact current management guidelines?** This novel approach optimizes allergy/immunology resources with a high degree of patient satisfaction. The minimal technology and trained personnel required has the potential to enhance patient access to allergy services while optimizing available resources.

**BACKGROUND:** Penicillin skin testing (PST) is increasingly used as a tool to evaluate penicillin allergy in patients with a reported history. The limited availability of allergists, however, may be an impeding factor.

**OBJECTIVE:** We sought to assess the clinical utility of telemedicine to facilitate PST.

**METHODS:** Penicillin-allergic inpatients receiving systemic antibiotics were prospectively identified between April and August 2017. Qualifying patients underwent PST performed by a trained allergy/immunology physician assistant (PA). On completion of PST, a telemedicine consultation, through the use of real-time interactive video conferencing (Microsoft Lync 2013, Redmond, Wash), was performed remotely by an allergist. Patients were surveyed regarding their satisfaction with the telemedicine experience.

**RESULTS:** Fifty patients consented to PST through a telemedicine consultation. The average total time to complete a consultation was 128 minutes (standard deviation [SD]  $\pm$  33). Of this, the average PA travel time was 46 minutes (36%) with the remaining time spent on clinical services (82 minutes, 64%). The average physician telemedicine time per patient was 5 minutes (SD  $\pm$  2). Patients rated their experience as an average of

4.5 on a scale of 1 (highly unsatisfied) to 5 (highly satisfied). Of the 46 PST-negative patients, 33 were transitioned to a  $\beta$ -lactam antibiotic that reduced the use of vancomycin, metronidazole, aztreonam, aminoglycosides, and clindamycin ( $P < .05$ ). More than \$30,000 was saved throughout the study period.

**CONCLUSIONS:** Telemedicine is an effective and novel approach to facilitate PST in the inpatient setting and carries a high degree of patient satisfaction. This method has the potential to optimize and improve access to allergy/immunology resources. © 2018 American Academy of Allergy, Asthma & Immunology (J Allergy Clin Immunol Pract 2018;6:2033-40)

**Key words:** Telemedicine; Video conferencing; Penicillin allergy; Penicillin skin testing; Antimicrobial stewardship

Penicillin skin testing (PST) is increasingly advocated and used as a leading strategy to evaluate penicillin allergy in patients with a reported history.<sup>1-4</sup> The growing body of literature revealing the clinical and financial consequences associated with the penicillin allergy label has prompted national organizations from various subspecialties to promote the importance of this diagnostic tool to both health care clinicians and patients.<sup>1-4</sup> Moreover, multidisciplinary antibiotic stewardship guidelines formally recommend PST to reduce alternative antibiotic use that has been associated with multidrug resistant bacterial infections and *Clostridium difficile*, 2 “urgent threats” highlighted in the Centers for Disease Control and Prevention threat report.<sup>1,5</sup> Delabeling penicillin allergy in PST-negative patients has been associated with a reduction in health care utilization, as well as a decrease in exposure to second-line antibiotic therapy and associated adverse reactions.<sup>6-9</sup>

The limited availability of allergists, however, may be a barrier to PST application.<sup>10,11</sup> One potential strategy to improve patient access to health care is through the implementation of telemedicine, which is defined as the use of technology and its applications by health care providers to remotely evaluate, diagnose, and treat patients.<sup>12</sup> The use of telemedicine in

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**Abbreviations used**

AWP- Average wholesale price

EMR- Electronic medical record

PA- Physician assistant

PST- Penicillin skin testing

SD- Standard deviation

numerous subspecialties and settings has been found to be noninferior or superior to standard of care in the areas of patient satisfaction, diagnostic accuracy, and cost containment.<sup>10,13</sup> As such, the incorporation of meaningful and sustained use of telemedicine in allergy/immunology practice is highlighted and supported in a recent position statement from the American College of Allergy, Asthma, and Immunology.<sup>14</sup>

Prospective reports describing the implementation of real-time, interactive telemedicine within the allergy/immunology realm is currently limited to 2 studies evaluating outcomes in asthmatic children managed via this technology.<sup>14-16</sup> Presently, the role of telemedicine to assist with PST has not yet been demonstrated. Given the increased demand for PST at our institution driven by antimicrobial stewardship efforts, we sought to evaluate and describe the clinical utility of telemedicine to facilitate inpatient PST at a tertiary community teaching hospital.

## MATERIALS AND METHODS

### Study design and patient population

Rochester Regional Health comprises 5 acute- and 8 long-term care medical facilities throughout western and central New York, which in total contain 3384 patient beds. The largest acute-care facility within the system is Rochester General Hospital, a 528-bed tertiary community medical center and 1 of 2 facilities system-wide that has allergy/immunology consultative services. There is one Rochester Regional Health-employed allergy/immunology group that employs 4 full-time and 2 part-time allergists. A total of 3 allergy/immunology offices are located in the community at a distance ranging from 4 to 8 miles, equivalent to a 20- to 30-minute commute, from Rochester General Hospital. Therefore, allergy/immunology physicians travel to the hospital for inpatient consultations, generally before or after a full day of outpatient appointments.

We conducted a prospective observational study between April and August 2017 at Rochester General Hospital to assess the clinical utility of telemedicine for PST. Inpatients  $\geq 18$  years of age with a documented history of penicillin allergy and receiving systemic antibiotic therapy were screened via a report generated by the electronic medical record (EMR) (Hyperspace; Epic Systems Corporation, Verona, Wis). Qualifying patients were approached for consideration of study participation. Patients for whom a formal consultation for PST was requested, patients receiving high-risk antibiotics (ie, fluoroquinolones, clindamycin, vancomycin) as defined by our institutional antimicrobial stewardship team, and patients receiving second-line antibiotics for susceptible bacterial infections (eg, intravenous vancomycin for the treatment of methicillin-susceptible *Staphylococcus aureus*) were prioritized for study inclusion. Patients were deemed ineligible for participation if they were pregnant, unable to consent, or if their presentation was deemed high risk by the allergy/immunology attending physician (ie, penicillin reaction occurred during the hospitalization when the patient was screened). All telemedicine consultations required

approval from the primary team and written patient consent, as approved by the investigational review board.

### Penicillin allergy skin testing

A thorough penicillin allergy history was obtained by a pharmacist using a penicillin allergy history algorithm, as previously reported (Figure 1).<sup>8</sup> Qualifying patients underwent skin testing performed by a trained allergy/immunology physician assistant (PA). The skin prick test was initially administered on the volar forearm using the Quintip testing device (Hollister-Stier, Spokane, Wash) with benzylpenicilloyl polylysine (Pre-Pen; ALK, Round Rock, Tex) as the major determinant, penicillin G 10,000 U/mL as the minor determinant, histamine 6 mg/mL as the positive control, and sodium chloride 0.9% as the negative control.<sup>3</sup> Negative skin prick testing was followed by intradermal testing administered on the upper arm with the same materials except with a histamine concentration of 0.02 mg/mL. The major and minor determinants were performed in duplicate. Patients were observed for 15 minutes after both the skin prick and intradermal test. Skin test results were measured in millimeters (mm). A positive test result for each step was defined as a wheal  $\geq 3$  mm compared with the sodium chloride control.<sup>3</sup> Patients receiving medications with antihistaminic properties received an intradermal histamine control before skin prick and intradermal testing. Skin testing was performed if the histamine control resulted in a wheal  $\geq 5$  mm. A one-time challenge dose of amoxicillin 500 mg was administered for patients not transitioned to a penicillin-based antibiotic during their hospital stay.

Immediately after the completion of skin testing by the PA, a telemedicine consultation, as described below, was remotely performed by the allergist. Through the use of real-time interactive technology, the allergist verbally and visually confirmed the penicillin allergy history and intradermal PST result, which was then discussed with the patient. The risks and benefits of the subsequent penicillin-based drug challenge were further reviewed with the patient who was then given the opportunity to ask questions with the allergist before the completion of the telemedicine consultation.

### Technology and telemedicine

Rochester General Hospital has an established and robust telemedicine department that assisted with the implementation of this project. Real-time interactive video conferencing or telemedicine was conducted using a Windows (Microsoft, Redmond, Wash) laptop computer and/or a phone (approved for Android and iOS) via Microsoft Lync 2013. This software limits access to institutional employees with valid network domain accounts using standard 256-bit data encryption. In the rare circumstance where wireless coverage within the hospital was weak or nonexistent, resulting in an unsuccessful connection, the investigators were permitted to use mobile cellular connectivity supporting the same application (Skype for Business connecting to the Microsoft Lync 2013 framework) and encryption (256 bit). Quality synchronous video and voice exchange occurred between devices.

### Data collection

Data regarding patient demographic characteristics, hospital service, potentially interfering medications, antibiotic therapy (ie, indication, duration, pre- and post-PST regimen, direct cost per day), and skin test results were obtained from the EMR. The historical penicillin reaction and impression of the telemedicine process were collected during the patient interview pre- (reaction history) and post-PST (impression). Patients completed a

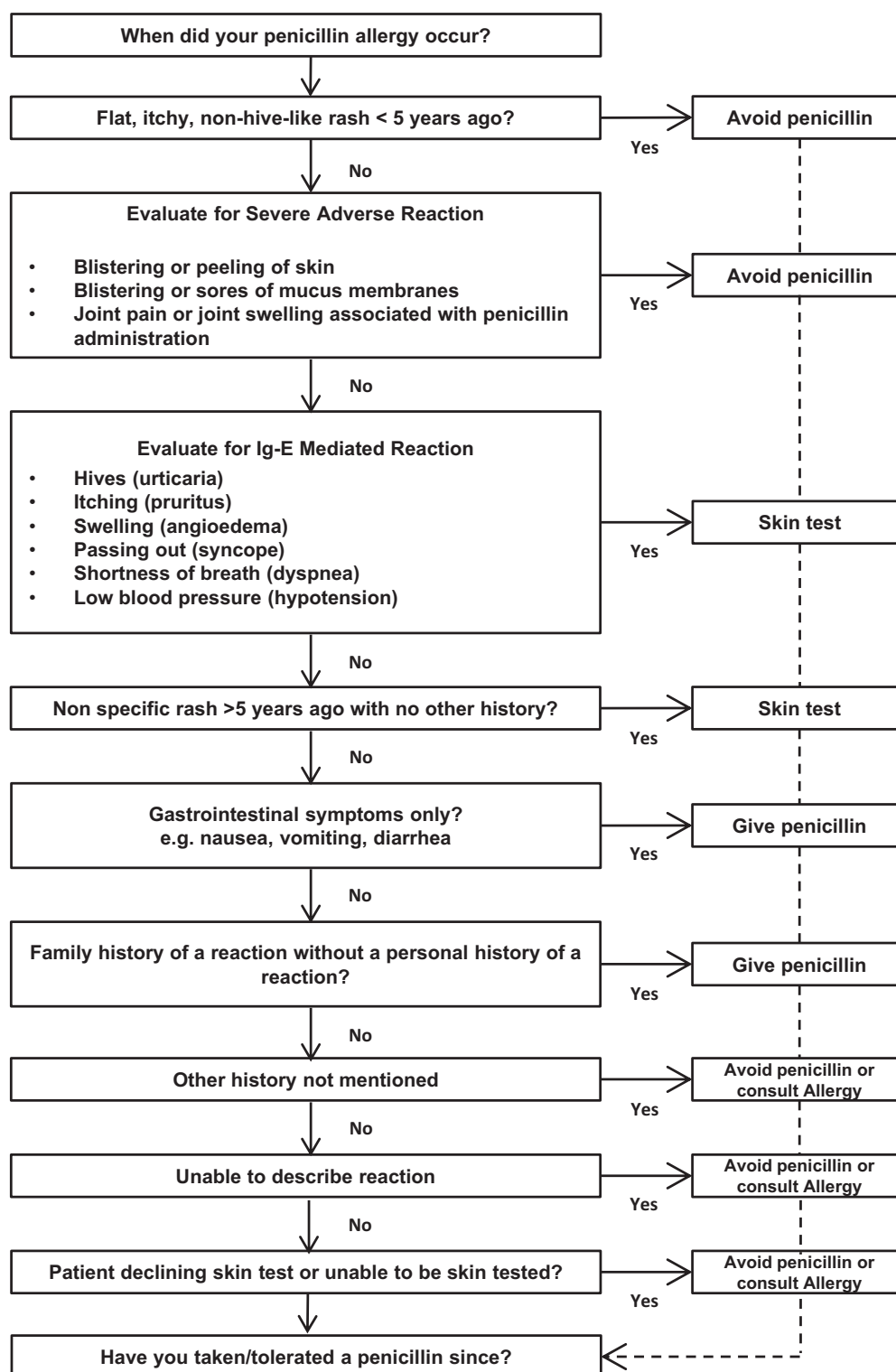


**FIGURE 1.** Penicillin allergy history algorithm. This tool was used to obtain a standardized penicillin allergy history with a suggested management strategy.

3-question satisfaction survey that was distributed and collected after the completion of the telemedicine consult. In addition, patients received a 2- to 4-week follow-up phone call to assess the tolerability of their outpatient  $\beta$ -lactam antibiotic, if applicable.

Travel time to and from the hospital, in-person and telemedicine consultative time, and the number of unsuccessful telemedicine connections were independently recorded by the PA for each patient encounter.

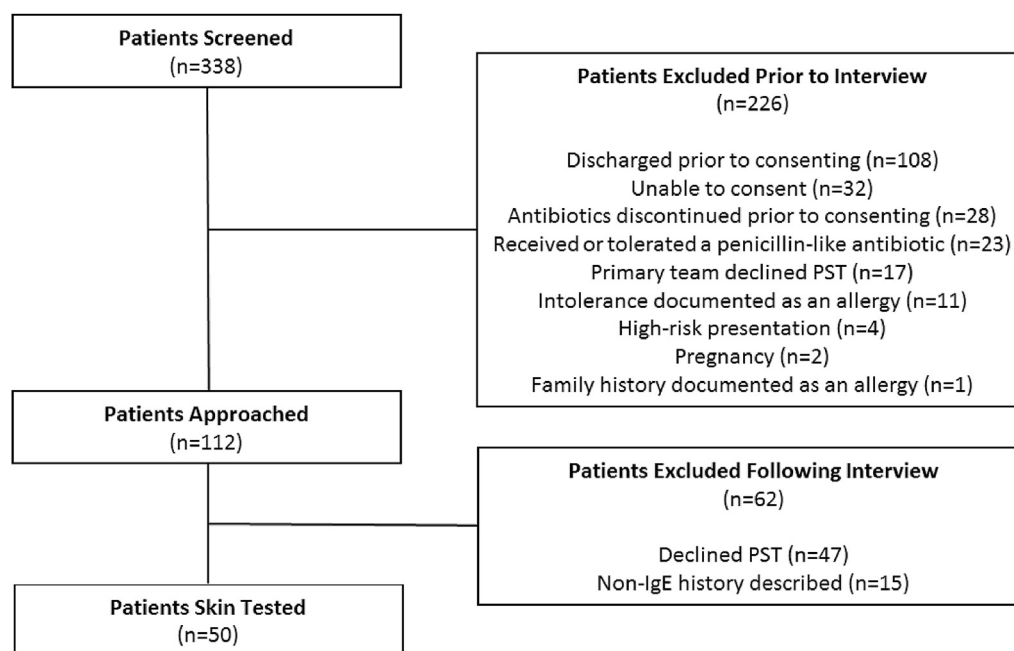


**FIGURE 2.** Patients assessed for penicillin skin testing via telemedicine. *PST*, Penicillin skin testing.

### Cost analysis

To estimate the potential impact of PST on direct antibiotic expenditures, we subtracted the average wholesale price (AWP) per day of antibiotic therapy after PST from the AWP per day of antibiotic therapy before PST.<sup>17</sup> This value was then multiplied by the total duration of antibiotic therapy in days administered after PST. The cost of PST and corresponding supplies, estimated to be approximately \$340 per PST kit (based on region-specific prices), was factored into our cost analysis.<sup>18</sup>

We also estimated the potential economic benefit of telemedicine by replacing allergist time with PA time. At the time of this study, the national mean annual salary of a PA was \$102,090 or \$49.08 per hour compared with the national mean annual salary of an allergist of \$257,000 or \$123.56 per hour.<sup>19-21</sup>

### Outcome measurements and data analysis

The primary study objective was to assess the clinical utility of telemedicine for inpatient PST with regard to technical and clinical efficiency, as well as patient satisfaction. The secondary objective was to evaluate the impact of PST on antibiotic selection and cost avoidance. Statistical analyses were performed using IBM SPSS Statistics V24 for Windows (IBM, Armonk, NY). Descriptive statistics, including measures of central tendency, were used to summarize the days of antibiotic therapy for each antibiotic class. Total antibiotic days of therapy were compared based on the difference between 2 Poisson rates; pre- and post-groups were compared over a 120-day time period using the Poisson means test.

### RESULTS

Of the 338 patients screened for inclusion over the study period, a total of 50 patients consented to PST through a telemedicine consult (Figure 2). The majority of our study cohort included Caucasian women between the ages of 46 and 68 years with a reported nonspecific rash or hives to penicillin that

occurred  $\geq 10$  years from the interview date (Table I). Historical reactions to penicillin are detailed in Table II, with the most common reported reactions of nonspecific rash (26%), hives (24%), and angioedema (18%). Approximately 1 in 4 patients also reported a concomitant cephalosporin allergy (Table II).

The average total time to complete a telemedicine consultation for PST was approximately 128 minutes per patient (standard deviation [SD]  $\pm 33$ ). A substantial component (46 minutes  $\pm 6$ , 36%) was attributed to travel to and from the hospital with the remaining time (82 minutes  $\pm 26$ , 64%) spent interviewing the patient, administering the skin test, videoconferencing, and completing the EMR consult note. The average physician time spent to complete the telemedicine consult was approximately 5 minutes per patient (SD  $\pm 2$ ). Therefore, the average total physician time replaced by PA time was 123 minutes per patient (SD  $\pm 32$ ). An unsuccessful connection requiring back-up occurred in 1 patient (2%).

The results of the patient satisfaction survey are displayed in Table III. One patient left against medical advice before completing the questionnaire, leaving a total survey count of 49. On a Likert scale of 1 (poor) to 5 (excellent), patients rated their overall impression of telemedicine for PST as an average of 4.4 (SD  $\pm 0.79$ ). When asked to rate the statements "Overall I was very satisfied with my telemedicine encounter" and "I would have preferred to discuss PST with the allergy doctor in person," patients indicated on a scale of 1 (strongly disagree) to 5 (strongly agree) an average satisfaction score of 4.5 (SD  $\pm 0.54$ ) and an average preference for an in-person encounter score of 2.7 (SD  $\pm 0.96$ ).

Of the 50 patients who completed skin testing, 46 (92%) had negative PST results. The remaining 4 patients were PST-positive (2 patients to penicillin G [PCN G]: wheal 5 mm, flare 15 mm; 1 patient to PCN G: wheal 5 mm, flare 10 mm; 1 patient to PCN G: wheal 4 mm, flare 10 mm). There were no

**TABLE I.** Demographic characteristics of the study population

| Variable                           | n = 50  |
|------------------------------------|---------|
| Average age in years (±SD)         | 58 (16) |
| Female sex, n (%)                  | 31 (62) |
| Race, n (%)                        |         |
| Caucasian                          | 42 (84) |
| Hispanic                           | 6 (12)  |
| Black                              | 2 (4)   |
| Primary service, n (%)             |         |
| Internal medicine                  | 30 (60) |
| General surgery                    | 7 (14)  |
| Critical care                      | 3 (6)   |
| OB/GYN                             | 2 (4)   |
| Observation                        | 2 (4)   |
| Vascular surgery                   | 2 (4)   |
| Cardiothoracic surgery             | 1 (2)   |
| Orthopedic surgery                 | 1 (2)   |
| Plastic surgery                    | 1 (2)   |
| Urology                            | 1 (2)   |
| Antibiotic indication, n (%)       |         |
| Skin/soft tissue infection         | 12 (24) |
| Bloodstream infection/endocarditis | 11 (22) |
| Respiratory tract infection        | 11 (22) |
| Intra-abdominal infection          | 10 (20) |
| Bone/joint infection               | 2 (4)   |
| Urinary tract infection            | 2 (4)   |
| Empiric                            | 2 (4)   |

OB/GYN, Obstetrics/gynecology; SD, standard deviation.

patients with a nonreactive histamine control although potentially interfering scheduled medications were noted in a total of 13 patients (26%). Antibiotic regimens were modified in 33 of the 46 patients with negative PST results: 27 patients (59%) were transitioned from a non- $\beta$ -lactam to a  $\beta$ -lactam antibiotic regimen; 5 patients (11%) were transitioned from a cephalosporin to a penicillin-based antibiotic; and 1 (2%) patient was transitioned from a carbapenem to a penicillin-based antibiotic. Total antibiotic days of therapy before and after PST in PST-negative patients are displayed in Figure 3. After PST, we observed a significant reduction in aztreonam ( $P < .001$ ), aminoglycoside ( $P < .031$ ), clindamycin ( $P < .001$ ), metronidazole ( $P < .002$ ), and vancomycin ( $P < .001$ ) days of therapy, whereas penicillin-based and cephalosporin (first- and second-generation) antibiotic usage significantly increased ( $P \leq .001$ ). A total of 386 days of second-line antibiotics were avoided, including aztreonam, 66 days; vancomycin, 153 days; fluoroquinolones, 41 days; clindamycin, 112 days; and aminoglycosides, 14 days, respectively. No adverse reactions occurred during skin testing or the amoxicillin challenge and no adverse reactions were reported during the 2- to 4-week follow-up phone call. Of note, 43 of the 46 PST-negative patients received the amoxicillin test dose or a penicillin-based antibiotic. Of the remaining 3, 1 patient refused, 1 patient was discharged before the challenge, and 1 patient agreed to follow up as an outpatient after discussion with the allergist given her complicated past medical history.

The direct impact of PST on antibiotic cost savings was calculated to be approximately \$23,000 in the 33 patients where

**TABLE II.** Penicillin allergy characteristics of the study population

| Characteristic                                | n = 50  |
|-----------------------------------------------|---------|
| Historical penicillin allergy reaction, n (%) |         |
| Rash                                          | 13 (26) |
| Hives                                         | 12 (24) |
| Angioedema                                    | 9 (18)  |
| Unknown                                       | 6 (12)  |
| Anaphylaxis                                   | 5 (10)  |
| Shortness of breath                           | 2 (4)   |
| Itching                                       | 2 (4)   |
| Loss of consciousness                         | 1 (2)   |
| Reported time since initial reaction, n (%)   |         |
| 1 to <5 y                                     | 3 (6)   |
| $\geq 5$ to <10 y                             | 4 (8)   |
| $\geq 10$ y                                   | 43 (86) |
| Concurrent antibiotic allergies, n (%)        |         |
| Cephalosporins                                | 12 (24) |
| Sulfa                                         | 11 (22) |
| Fluoroquinolones                              | 7 (14)  |
| Clindamycin                                   | 5 (10)  |
| Macrolides                                    | 3 (6)   |
| Other*                                        | 3 (6)   |
| Tetracyclines                                 | 2 (4)   |

\*Nitrofurantoin, telithromycin, rifampin.

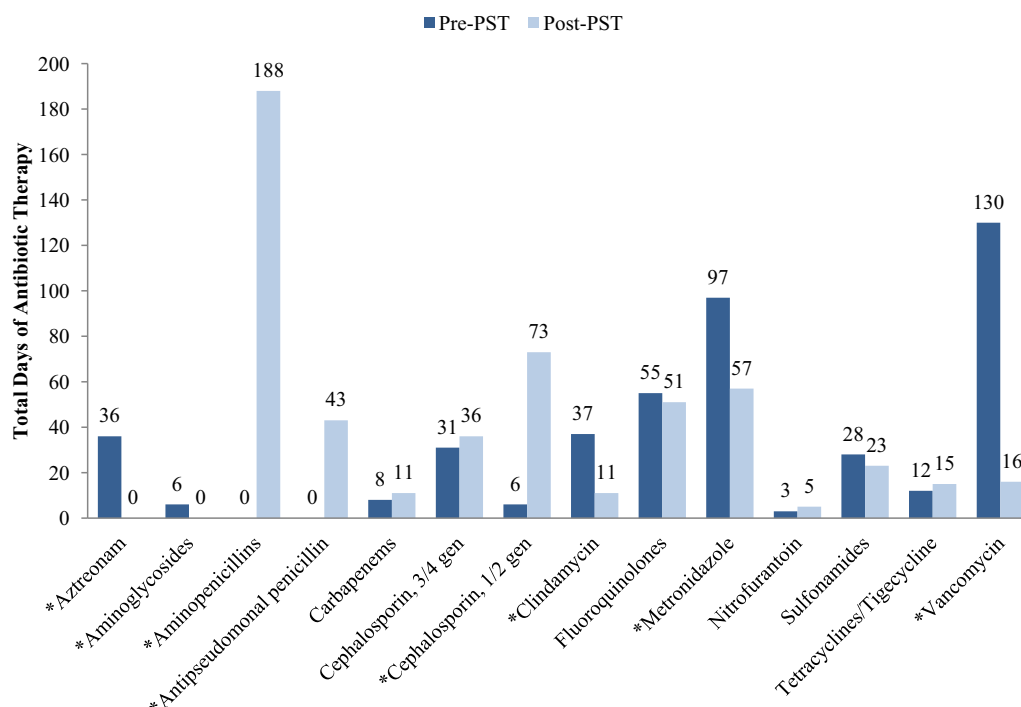
antibiotic therapy was modified after PST. This corresponds to approximately \$360 per patient after factoring in the cost of supplies. The majority of our cost avoidance stemmed from transitioning 11 patients receiving aztreonam (AWP approximately \$120-240 per day) to a  $\beta$ -lactam antibiotic regimen (AWP approximately \$5-60 per day). In addition, 1 patient required 6 weeks of antibiotic therapy for the treatment of a polymicrobial bone/joint infection, per Infectious Diseases recommendations, and was transitioned from tigecycline (AWP approximately \$375 per day) to a penicillin-based antibiotic regimen (AWP approximately \$10-60 per day) after a negative skin test result. From the standpoint of the telemedicine consult personnel used, the average total physician time replaced by PA time was 123 minutes per patient. In our cohort of 50 patients, this translates to approximately \$152 per consult or \$7600 total. If considering all aspects of the economic analysis, including the direct impact on PST on antibiotic cost savings per patient (approximately \$360) and physician time saved in dollars per patient (\$152), the total cost savings or avoidance was approximately \$510 per patient.

## DISCUSSION

Telemedicine is an innovative modality that can be used to enhance access to allergy/immunology services. To our knowledge, ours is the first report that describes the use of telemedicine for PST to allow for real-time patient interaction with an allergist located off-site. We also describe a method that uses readily available technology to maximize resources without sacrificing patient satisfaction. As demonstrated in previous PST studies in which face-to-face consultations were used, we showed that telemedicine consultations served to delabel penicillin allergy in the majority of patients evaluated, subsequently allowing for antibiotic therapy optimization according to national and local guidelines.<sup>7,8,22,23</sup>

**TABLE III.** Patient satisfaction survey scores (n = 49)

| Question                                                                                           | Poor              | Fair     | Neutral | Good    | Excellent      | Average rating |
|----------------------------------------------------------------------------------------------------|-------------------|----------|---------|---------|----------------|----------------|
| What is your overall impression of telemedicine consult for penicillin skin testing? n (%)         | 0 (0)             | 2 (4)    | 3 (6)   | 18 (37) | 26 (53)        | 4.4            |
| Statement                                                                                          | Strongly disagree | Disagree | Neutral | Agree   | Strongly agree | Average rating |
| Overall I was very satisfied with my telemedicine encounter, n (%)                                 | 0 (0)             | 0 (0)    | 1 (2)   | 21 (43) | 27 (55)        | 4.5            |
| I would have preferred to discuss penicillin skin testing with the allergy doctor in person, n (%) | 6 (12)            | 11 (22)  | 26 (53) | 4 (8)   | 2 (4)          | 2.7            |

**FIGURE 3.** Total days of antibiotic therapy before and after PST in PST-negative patients, n = 46. An increase in aminopenicillin, antipseudomonal penicillin, and first- and second-generation cephalosporin days of therapy was noted after PST, whereas aztreonam, aminoglycoside, clindamycin, metronidazole, and vancomycin days of therapy were decreased. \*Antibiotic usage before PST versus after PST met statistical significance,  $P < .05$ . PST, Penicillin skin testing.

Our multidisciplinary approach substantially reduced physician travel and clinical time by more than 2 hours per inpatient consult, which is equivalent to the time it would take for a Rochester Regional Health allergist to see 3 new patients or 6 follow-up patients. The allergist was able to simultaneously oversee telemedicine inpatient PST while providing a full day of outpatient care that serves to maximize allergy/immunology physician expertise. Although ours was a pilot project, we anticipate an extension of this method to other facilities in our health care system where allergy/immunology consultation services are not currently available. This may be a model for similar health care systems.

Despite reduced physician involvement in the PST consultation, our telemedicine approach received favorable inpatient satisfaction scores. In our cohort of 49 survey respondents,  $\geq 90\%$  indicated that they had a positive impression of telemedicine for PST and were overall very satisfied with their

encounter. Numerous patients indicated that outpatient appointment travel distance and time was challenging and a potential barrier to outpatient testing, which is likely to lead to attrition. Our approach allows these patients the convenience of an inpatient evaluation. Moreover, some patients expressed comfort with inpatient testing in the rare event of a serious adverse reaction to the skin test determinants or the oral amoxicillin challenge.

As in other published studies, second-line antibiotic exposure was significantly reduced after PST.<sup>7,8,22,23</sup> Approximately 12 second-line antibiotic days of therapy were avoided per each patient transitioned to a  $\beta$ -lactam antibiotic, with the greatest impact on intravenous vancomycin, clindamycin, aminoglycosides, metronidazole, and aztreonam. In addition to the most commonly recognized adverse reactions seen with intravenous vancomycin (nephrotoxicity and ototoxicity) and with clindamycin (gastrointestinal intolerance), these antibiotics have been

associated with an increased risk of vancomycin-resistant *Enterococcus* species colonization and *C. difficile* infections.<sup>24-29</sup> Further reason to support transition to  $\beta$ -lactam antibiotics includes treatment superiority in various clinical settings (eg, invasive methicillin-susceptible *S. aureus* infections; several sexually transmitted infections; surgical prophylaxis) compared with non- $\beta$ -lactam antibiotics.<sup>30-33</sup> Transitioning patients from second-line antibiotics to a penicillin-based antibiotic may theoretically reduce the risk of developing multidrug-resistant bacterial infections and/or colonization and may improve patient outcomes.

Direct cost savings was also demonstrated with our approach. The AWP of aztreonam is approximately \$120-240 per day, 10 times more expensive than preferred  $\beta$ -lactam antibiotics. Transitioning patients off aztreonam largely contributed to our antibiotic cost avoidance analysis, determined to be approximately \$360 per patient transitioned to a  $\beta$ -lactam antibiotic after PST. This calculation is similar to other estimates, although a wide range has been reported.<sup>8,23,34,35</sup> Offering PST via telemedicine in patients receiving high-risk or expensive antibiotics for the treatment of  $\beta$ -lactam-susceptible bacterial infections may therefore be a high-yield intervention for programs with limited resources. Indirect costs such as pharmacist therapeutic drug monitoring time, nursing drug administration time, serum concentration sampling time, and laboratory costs to analyze concentrations were not evaluated. Similarly, additional physician-patient contact hours and, therefore, additional revenue generated by using this method were not evaluated. A greater cost savings may have been realized if indirect costs were considered. In addition, the short duration of this pilot study does not take into account future cost savings from use of more appropriate antibiotics in subsequent hospitalizations.

It is notable that approximately 10% of patients were excluded during the screening process because of their demonstrated tolerance to a penicillin-based antibiotic. This included either documentation of tolerance in the EMR penicillin allergy reaction field and/or the receipt of a penicillin-based antibiotic during the screening process. It is also worth noting that 42% of patients approached for study consideration declined participation. The majority of these patients had limited prior knowledge of PST and the benefits testing could provide them. Allergy field documentation, penicillin allergy delabeling, and health care provider and patient education have been identified as opportunities for future interventions, which may include a standardized approach to collecting an allergy history, direction on updating allergy fields in the event of penicillin-based antibiotic tolerance, and patient educational materials.<sup>36</sup> Minimizing documentation errors and educating patients and health care practitioners are imperative from a public health and cost perspective.

Although our data are encouraging, several limitations should be considered. First, we evaluated the use of this technology in a small sample of patients, many who were prioritized for inclusion based on the infectious diagnosis and use of high-risk antibiotics. Therefore, patient selection bias may have occurred; however, this method may more accurately represent real-world application and triaging of PST in a hospital setting. Second, we acknowledge that there are multiple approaches to cost analysis, and ours does not encompass all potential savings of PST. Ours specifically considers travel time between our clinics and hospital,

as well as time to administer the skin test by a PA. We used a PA out of an abundance of caution for patient safety in this pilot project. Cost and time analyses may vary at other centers with different proximity between facilities and the type and efficiency of the personnel (ie, registered or licensed practical nurse; pharmacist; infectious diseases fellow) administering the skin test. Furthermore, we acknowledge that considerable time, especially pertaining to travel, could potentially be saved if multiple patients were evaluated daily, or if a trained representative was located onsite. We also recognize the limited allergist time spent conducting the telemedicine consultation at an average of 5 minutes; however, this is likely reflective of our multidisciplinary study design that incorporates pharmacist and PA discussion with patients about the penicillin allergy evaluation and testing before the allergist telemedicine encounter. In addition, the consent process encompasses much of the discussion surrounding the risks and benefits of PST. Outside of the study setting, we expect allergist telemedicine time spent to increase. Lastly, this method may be challenging in patient populations that are hard-of-hearing or require the assistance of a foreign language interpreter.

Limitations from the generalizability perspective should also be considered. From the patient safety perspective, trained allergy personnel should perform and oversee the PST telemedicine consultation. Institutions that do not have access to allergists may be limited in its application; however, our design has tremendous potential to connect institutions to resources that can assist with PST training, implementation, and service delivery. We acknowledge that there are potentially multiple methods to use telemedicine to facilitate penicillin allergy evaluations, which may include a store and forward model. However, our goal was to preserve the interaction between the patient and allergist in this particular study because the culture at our institution relies on allergy/immunology involvement in penicillin allergy evaluations. Future telemedicine approaches should be customized to institutional specific cultures and goals. In addition, an institution to which telemedicine is deployed must have the technology infrastructure to securely support the use of video conferencing to comply with data protection and patient confidentiality standards. In our experience, we did not observe significant connectivity issues; however, a back-up connection should be available in the event of a suboptimal or interrupted connection.

Less than 0.1% of the world's estimated 25 million penicillin-allergic patients undergo PST annually.<sup>37</sup> As a result of recent efforts by antimicrobial stewardship governing bodies, the appeal for PST continues to rise, requiring the development of creative strategies to meet the increased demand. The use of telemedicine is one such novel strategy and demonstrates efficiency, patient satisfaction, and cost-effectiveness in the inpatient setting. By virtue of its ability to minimize logistical and personnel demands, the use of telemedicine to assist with PST has the potential to enhance patient access to allergy services while optimizing available resources.

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