Original Article

The Cost of Penicillin Allergy Evaluation

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What is already known about this topic? Unverified penicillin allergy leads to adverse clinical and economic consequences. Penicillin allergy evaluation is a simple procedure, typically performed by allergy specialists. Time-driven activity-based costing (TDABC) is an accurate method to estimate the cost.

What does this article add to our knowledge? Using TDABC, we identified that penicillin allergy evaluation costs $220 in the base case. In various univariable and multivariable sensitivity analyses, we identified a cost range of $40 to $537 for penicillin allergy evaluation.

How does this study impact current management guidelines? Penicillin allergy evaluation is inexpensive, even when considering operational challenges, such as infrequent or expanded testing. TDABC estimates of penicillin allergy evaluation can inform efficient clinical operations, the practice of cost-conscious care, and cost-effectiveness assessments.

BACKGROUND: Unverified penicillin allergy leads to adverse downstream clinical and economic sequelae. Penicillin allergy evaluation can be used to identify true, IgE-mediated allergy.
OBJECTIVE: To estimate the cost of penicillin allergy evaluation using time-driven activity-based costing (TDABC).
METHODS: We implemented TDABC throughout the care pathway for 30 outpatients presenting for penicillin allergy evaluation. The base-case evaluation included penicillin skin testing and a 1-step amoxicillin drug challenge, performed by an allergist. We varied assumptions about the provider type, clinical setting, procedure type, and personnel timing.
RESULTS: The base-case penicillin allergy evaluation costs $220 in 2016 US dollars: $98 for personnel, $119 for consumables, and $3 for space. In sensitivity analyses, lower cost estimates were achieved when only a drug challenge was performed (ie, no skin test, $84) and a nurse practitioner provider was used ($170). Adjusting for the probability of anaphylaxis did not result in a changed estimate ($220); although other analyses led to modest changes in the TDABC estimate ($214-$246), higher estimates were identified with changing to a low-demand practice setting ($268), a 50% increase in personnel times ($269), and including clinician documentation time ($288). In a least/most costly scenario analyses, the lowest TDABC estimate was $40 and the highest was $537.
CONCLUSIONS: Using TDABC, penicillin allergy evaluation costs $220; even with varied assumptions adjusting for operational challenges, clinical setting, and expanded testing, penicillin allergy evaluation still costs only about $540. This modest investment may be offset for patients treated with costly alternative antibiotics that also may result in adverse consequences. © 2017 American Academy of Allergy, Asthma & Immunology (J Allergy Clin Immunol Pract 2017;■:■-■)

Key words: *Hypersensitivity; Allergy; Beta-lactam; Resource; Skin test; Test dose; Challenge*

Ten percent of the US population reports an allergy to penicillin antibiotics.[1,2] However, most patients with reported penicillin allergy are determined not to be allergic after an allergy evaluation.[2-4] Unverified penicillin allergy results in patients receiving broader-spectrum antibiotics, as well as antibiotics that may be more toxic, less effective, and/or higher cost.[5,6] Furthermore, unnecessary use of β-lactam alternative antibiotics places patients at risk for adverse reactions, treatment failures, and health care–associated infections.[6-8]

For patients with self-reported immediate (ie, IgE-mediated) penicillin allergy histories, penicillin skin testing and/or drug challenges under medical observation can accurately distinguish

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Abbreviations used
CCR- cost to charge ratio
CPT- Current Procedural Terminology
E&M- evaluation and management
MGH- Massachusetts General Hospital
RCC- ratio of costs to charges
RVU- relative value unit
TDABC- time-driven activity-based costing
USD- US dollars

true allergy. Currently, most penicillin skin testing in the United States is performed using major determinant, or benzylpenicilloyl (PRE-PEN, ALK-Abelló, Hørsholm, Denmark), and dilutions of penicillin G. The negative predictive value of penicillin skin testing using these reagents is at least 95%.[2] Allergists may additionally skin test with ampicillin because side-chain–specific allergy to aminopenicillins has been documented.[9,10] Most practices follow a negative penicillin skin test result with an observed test dose challenge to amoxicillin, which increases the negative predictive value of the evaluation to almost 100%.[11]

Although penicillin allergy evaluation has been hypothesized to be a cost-effective intervention,[6] there have been no costing studies or cost-effectiveness analyses of penicillin allergy evaluation in patients with reported penicillin allergy. Time-driven activity-based costing (TDABC), a method developed by health care economists, estimates cost through the calculation of both time spent using a given resource and the per-unit cost of such resource.[12,13] Since its development, TDABC has been used effectively in health care settings to determine cost and identify value in oncology,[14] urology,[15] interventional radiology,[16] and surgery.[17-22]

To inform efficient clinical operations, encourage cost-conscious care, and enable cost-effectiveness research, we performed TDABC of penicillin allergy evaluation. We additionally compared TDABC estimates to estimates derived from 2 other common costing models: (1) the ratio of costs to charges (RCC) method and (2) the relative value unit (RVU) method.[12,13,23]

METHODS

The TDABC method

Base case. We considered the base case of an outpatient penicillin allergy visit with an American Board of Allergy and Immunology–certified Allergist/Immunologist who, after taking the allergy history, ordered skin testing with major determinant and dilutions of penicillin G, as well as a 1-step amoxicillin 500 mg oral challenge for all patients whose skin test result was negative. To estimate the cost of the base case, we defined each step along the outpatient penicillin allergy evaluation pathway in a process map (Figure 1). We then identified the personnel, consumables, and space used for 30 unique patients presenting for penicillin allergy evaluation, a convenience sample of prospectively observed patients at Massachusetts General Hospital (MGH) Allergy Associates (Boston, Mass). Prior to their visit, the patients were deemed appropriate for a penicillin allergy evaluation appointment. Tested patients had immunologic reactions that were potentially IgE-mediated, but not anaphylactic in the last 5 years. We determined that 30 patients provided sufficiently stable time estimates by assessing personnel and space time descriptive characteristics (eg, means and SDs) for the first 25 patients compared with the final 5 patients. No significant time differences were observed, and the 30 patients comprised the sample.

We calculated capacity cost rates for each personnel type in 2016 US dollars (USD) per minute using regional and national compensation data that included salary, payroll taxes, and fringe benefits (eg, health insurance).[24-26] Regional and national averages, rather than actual MGH Allergy Associates compensation, were used to achieve more generalizable results. Allergists/Immunologists and other personnel were estimated to work 8.0 hours per day.[27] Within each work day, we assumed 5% idle or break time for physicians and 10% idle or break time for other personnel.[12,27] Twenty-one days of vacation, 6 days for educational time and sick/personal leave, and

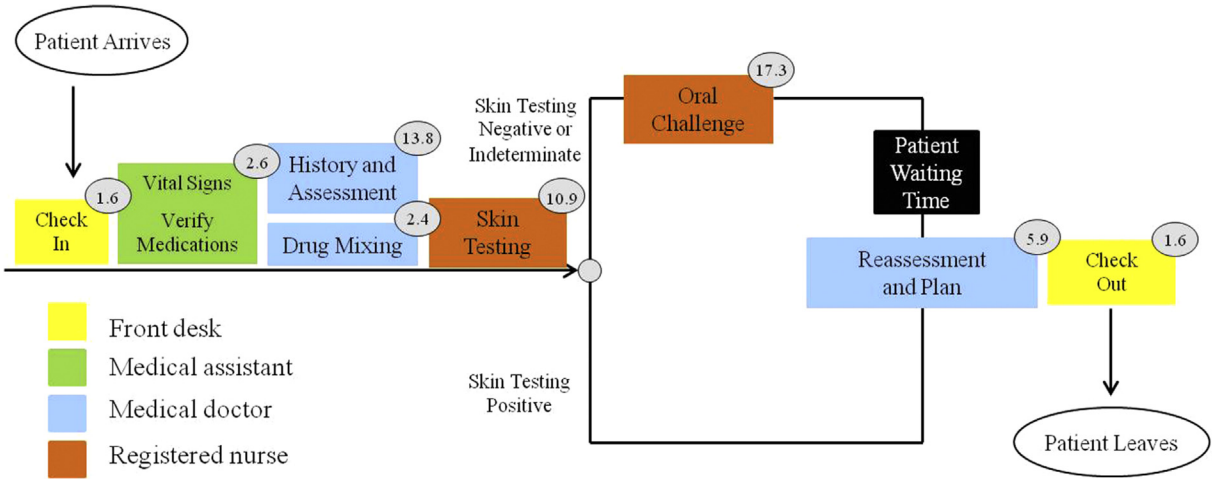


FIGURE 1. Outpatient penicillin allergy evaluation process map. The process map identifies all components of outpatient penicillin allergy evaluation including personnel type (indicated by color). The numbers in the gray circles indicate the mean measured time (in minutes) for each process for the 30 prospectively observed outpatients at MGH's Allergy Associates. Note that patient time is excluded from the process map, given that costing is performed from the health care system perspective. Patient time spent in the clinical examination room and the test room is included in space cost (Table III).

114 days for weekends/holidays were additionally accounted for by assuming 224 of a possible 260 workdays a year.[12]

Medical consumables used at each stage in the penicillin allergy evaluation pathway were costed according to the acquisition cost to MGH, except for drug costs, for which we used the average wholesale price.[28,29] For the base-case analysis, we assumed that demand for evaluation was high with clinic operations accommodating 4 penicillin allergy patients per day. Thus, for example, the clinician time spent preparing penicillin G dilutions and the cost of the penicillin G vial were split among 4 patients in the base case rather than being a per-patient cost.

Space costs were calculated using the mean time patients occupied the examination room and allergy testing space, a procedure space at MGH Allergy Associates where skin testing and drug challenges are performed under nursing observation, and measuring the square footage of each clinical space. Construction and renovation costs were incorporated by using the price per square foot. We assumed a 20-year, linear depreciation of the building with 15% annual maintenance, operating, and housekeeping costs.[23] Space availability was calculated using a 9-hour Monday through Friday clinical practice (143,100 available minutes annually).

One-way sensitivity analyses. We performed 1-way sensitivity analyses to assess how assumptions about provider type, clinical setting, procedure type, and personnel timing impact TDABC estimates. Specifically, we (1) changed the procedure to include only a 2-step challenge (ie, no skin testing), which may be appropriate for low-risk patients[30-33]; (2) changed the clinical provider from an Allergist/Immunologist to a nurse practitioner, and considered both the scenarios of a minimally supervised nurse practitioner and a nurse practitioner supervised at every patient encounter; (3) changed drug compounding from an allergist-performed task to a task performed by a registered nurse; (4) added a resource adjustment to account for the rare but nonzero probability of causing resource-intensive anaphylaxis (3.2/1000), which was not observed in the 30 prospectively observed patients (see the Methods section in this article's Online Repository at www.jaci-inpractice.org); (5) added ampicillin as an additional skin testing reagent; (6) simulated a 2-step graded challenge after skin testing (an initial 30-minute period of observation followed by a 60-minute period of observation); (7) assumed a 50% increase in all personnel activity times; (8) simulated an inpatient penicillin allergy evaluation, with an allergy registered nurse skin tester and pharmacist-prepared drug, assuming 15 minutes for reagent preparation, safety checking, and labeling; (9) changed clinical volume to a low-demand setting (eg, multiuse drug consumables would not be reused); (10) included 20 minutes of provider time to perform clinical documentation; and (11) considered a 2-visit penicillin allergy evaluation (history and physical during the first visit followed by a second visit where testing was performed with limited clinician time).

Multiway sensitivity and scenario analyses. We performed multiway sensitivity analyses where we simultaneously varied the most influential 1-way sensitivity analyses. We also performed a minimum and maximum scenario analysis intended to reflect the lowest and highest plausible costs of the procedure, using results from the 1-way analyses.

The RCC model

To examine the sensitivity of our results to our methods used, we also examined an alternative costing approach in which we identified charges for the office visit and procedure codes used for penicillin allergy evaluation. We calculated the cost to charge ratio (CCR) for MGH Allergy Associates by using the total operating costs divided by the total gross charges from the last fiscal year. Because this internal CCR was similar to the published Massachusetts CCR for the fiscal year 2016 (0.505),[34] we used the published Massachusetts CCR to enhance generalizability. Using this adjustment, we calculated the base-case penicillin allergy evaluation patient. We also calculated different evaluation combinations, varying the evaluation and management (E&M) codes (none, follow-up, new, 2 visits) and procedures performed (skin testing, skin testing with ampicillin, 1-step challenge, 2-step challenge).

Procedure charges used Current Procedural Terminology (CPT) codes 95018 for skin testing and 95076 for ingestion challenges, the latter only considered for multistep challenges from 61 to 120 minutes in duration.[35] E&M codes assumed that new patients were level 4 (99204) and follow-up patients were level 3 (99213). Two-visit sensitivity analyses included 2 E&M codes: 1 new and 1 follow-up.

The RVU model

In a final methodologic approach, we identified work and facility—related RVUs for 2016 urban office visit and procedure codes used for penicillin allergy evaluation. We converted the RVUs using the 2016 Medicare conversion factor (35.8043).[36] To increase generalizability of these estimates, facility fees did not assume a hospital-based practice, which would incur an additional facility fee. We again recalculated the cost for the base-case penicillin allergy evaluation patient, as well as different combinations of E&M codes (none, follow-up, new, 2 visits) and procedures (skin testing, skin testing with ampicillin, 1-step challenge, 2-step challenge) using the same assumptions as the RCC model.

RESULTS

The TDABC method

Measured mean personnel times for each process (Figure 1) resulted in an estimated personnel cost of $98 (Table I), consumables cost of $119 (Table II), and space cost of $3 (Table III). The base-case penicillin allergy evaluation cost $220 in 2016 USD.

Assessing variations in 1-way sensitivity analyses led to different TDABC estimates (Figure 2). If skin testing were not performed, the cost was $84; $82 for personnel, less than $1 for consumables, and $2 for space. Using a nurse practitioner instead of an Allergist/Immunologist led to a cost of $170 to $192 depending on Allergist/Immunologist supervision: $48 to $71 for personnel, $119 for consumables, and $3 for space. Many 1-way sensitivity analyses did not change, or only modestly changed, the TDABC estimate: drug mixing performed by a registered nurse cost saved $6 ($214); adjusting for the probability of anaphylaxis cost $220; performing skin testing with ampicillin in addition to benzylpenicilloyl and penicillin G cost $226; a 2-step oral challenge after skin testing cost $227; and inpatient evaluation cost $220. If the penicillin allergy evaluation were performed in 2 separate visits, the estimate was $246, driven by $26 higher personnel costs. For a clinic with a low demand for penicillin allergy evaluation, the TDABC estimate was $268; increased cost estimates are due to higher personnel ($122) and consumables ($143) cost (see Table E3 in this

TABLE I. Analysis of personnel cost in base-case penicillin allergy evaluation

Staff member	Mean activity time (min)	Cost per minute ($)	Total cost ($)
Front desk	3.2	0.40	1.28
Medical assistant	2.6	0.33	0.87
Allergist/Immunologist	22.0	3.41	75.17
Registered nurse	28.2	0.73	20.63
Total personnel cost			97.96*

*Number in text was rounded to nearest $1.

TABLE II. Analysis of consumables in base-case penicillin allergy evaluation

Supplies	Acquisition cost per pack ($)	Number in pack	Number used	Total cost ($)
Greer*Pick*	347.60	1000	4	1.39
BD SafetyGlide	6.78	25	5	1.36
Albumin saline with phenol	112.20	50	4*	2.24

Drugs	Average wholesale price ($)	Number in pack	Number used	Total cost ($)
Penicillin G Potassium 5 million units	14.47	1 vial*	0.25	3.62
PRE-PEN	110.00	1 vial	0.50	110.00
Amoxicillin 250 mg/5 mL	7.11	30 challenges†	0.03	0.47
Total consumables cost				119.08‡

*Distributed evenly over 4 patients under high volume assumption in base case.
†500 mg of amoxicillin.
‡Number in text was rounded to nearest $1.

TABLE III. Analysis of space costs in penicillin allergy evaluation

Cost	Clinical examination room	Testing room space
Square feet	92.25	34.10
Construction cost ($/ft^2)	248.00	248.00
Useful life-years	20	20
Maintenance, operating, housekeeping cost	15%	15%
Annual space cost ($/ft^2)	49.60	49.60
Availability (min)	143,100	143,100
Capacity cost rate ($/min/ft^2)	0.00035	0.00035
Mean time (min)	32.16	149.63
Space cost ($/patient)	1.03	1.79
Total space cost		2.82*

*Number in text was rounded to nearest $1.

article's Online Repository at www.jaci-inpractice.org). Assuming a 50% increase in all personnel times led to a cost estimate of $269, with the cost of personnel $147, consumables $119, and space $3. Including 20 minutes of Allergist/Immunologist documentation time led to the highest estimate among 1-way sensitivity analyses ($288), driven by the $68 increase in personnel cost.

Varying 2 or more assumptions simultaneously in multiway sensitivity analyses led to a more broad range of cost estimates (Figure 3). We identified that the lowest TDABC estimate scenario used a nurse practitioner clinical provider without direct supervision and did not perform the penicillin skin test ($40). The highest TDABC estimate ($537) included adjusting the scenario for the possibility of anaphylaxis, testing with ampicillin, increasing personnel time by 50%, having a low-demand setting, doing a 2-step oral challenge after skin test, incorporating 20 minutes of Allergist/Immunologist documentation time, and performing the evaluation over assessment and testing in 2 visits.

The RCC model

The cost of the base-case penicillin allergy evaluation using the RCC model was $829, which included the cost of a new visit E&M ($306) as well as the evaluation procedure ($523, Figure 4). Including ampicillin in the evaluation increased the cost by $58. Performing a 2-step challenge instead of a 1-step challenge increased the cost by $224; forgoing skin testing in favor of a 2-step challenge saved only $298. The cost of penicillin allergy evaluation using the RCC method ranged from $225 (no E&M, 2-step challenge only) to $1,247 (2 visits, penicillin skin test with ampicillin, 2-step challenge after skin testing).

The RVU model

The cost of the base-case penicillin allergy evaluation using the RVU model was $328, $218 from the E&M code and $110 from the CPT code (Figure 5). Including ampicillin in the evaluation increased the cost by $12. Performing a 2-step instead of a 1-step challenge increased the cost by $128; forgoing skin testing with a 2-step challenge resulted in a $19 higher cost. The cost of penicillin allergy evaluation using the RVU method ranged from $110 (no E&M, skin test, 1-step challenge) to $555 (2 visits, skin test with ampicillin, 2-step challenge after skin testing).

DISCUSSION

Using a TDABC approach, we found that the base-case penicillin allergy evaluation, penicillin skin testing, and a 1-step amoxicillin drug challenge performed by an allergy-boarded physician cost $220 in 2016 USD, with more than half of the cost attributed to consumables and about 45% attributed to personnel. Under alternative assumptions, we identified a cost range from $40 to $537 per penicillin allergy evaluation. Finally, we identified that the TDABC estimates were lower than estimates using the RCC model or the RVU model, the 2 most commonly used accounting-based costing methods; the maximum cost of the evaluation, considering all approaches and assumptions, was $1,247.

Although we observed variation in TDABC estimates with different conditions related to provider type, clinical setting, procedure type, and personnel timing, the total cost of penicillin allergy evaluation never exceeded $540 in multiway sensitivity analyses. The only previously reported cost for penicillin allergy evaluation was estimated in the Kaiser Permanente health maintenance organization and was restricted to an assessment of cost for 1 penicillin skin test ($131).[6] This study's TDABC estimates of comprehensive penicillin allergy evaluation demonstrate that this intervention is neither resource-intensive nor costly. Indeed, the evaluation cost may well be offset by ultimate medication cost savings—not captured here—because the

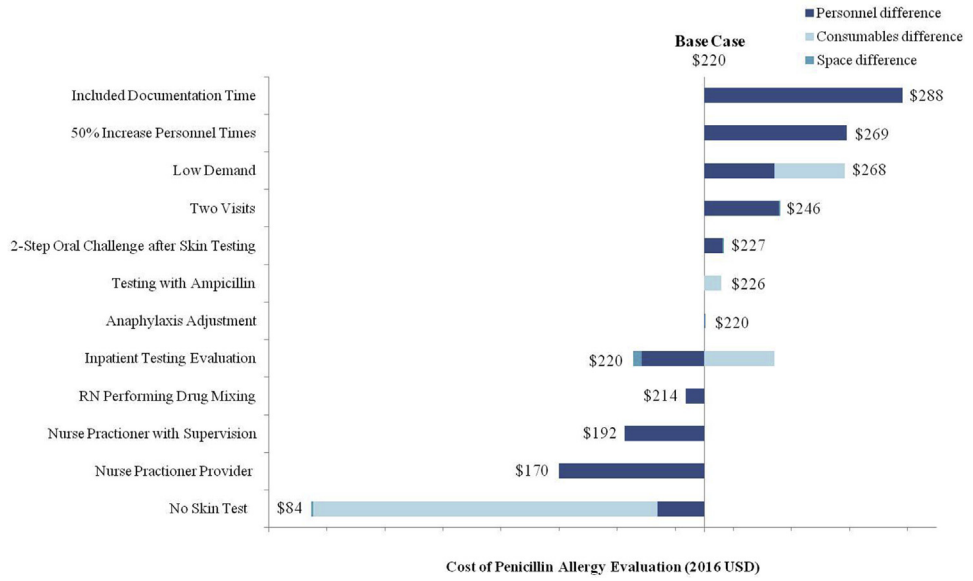


FIGURE 2. The cost of penicillin allergy evaluation using TDABC: Base-case and 1-way sensitivity analyses. This tornado diagram displays the TDABC estimates identified in different 1-way sensitivity analyses, compared with the base case, represented by the vertical line ($220). Bars to the left are analyses that demonstrate situations in which the evaluation is less costly than the base case, whereas bars to the right are analyses that demonstrate situations in which the evaluation is more costly than the base case. *RN*, Registered nurse.

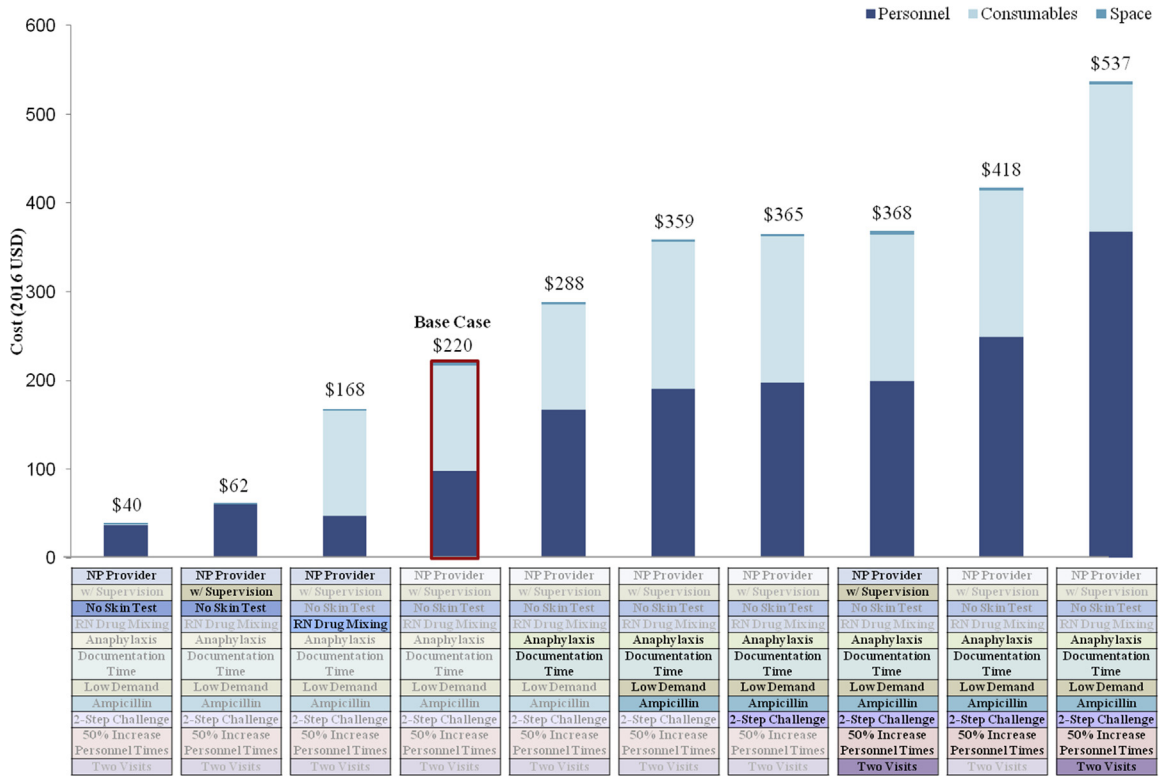
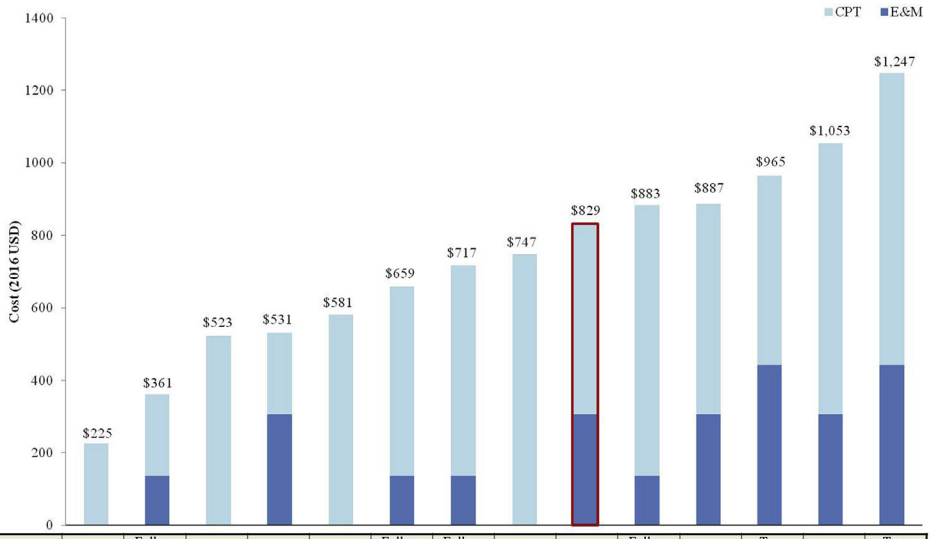
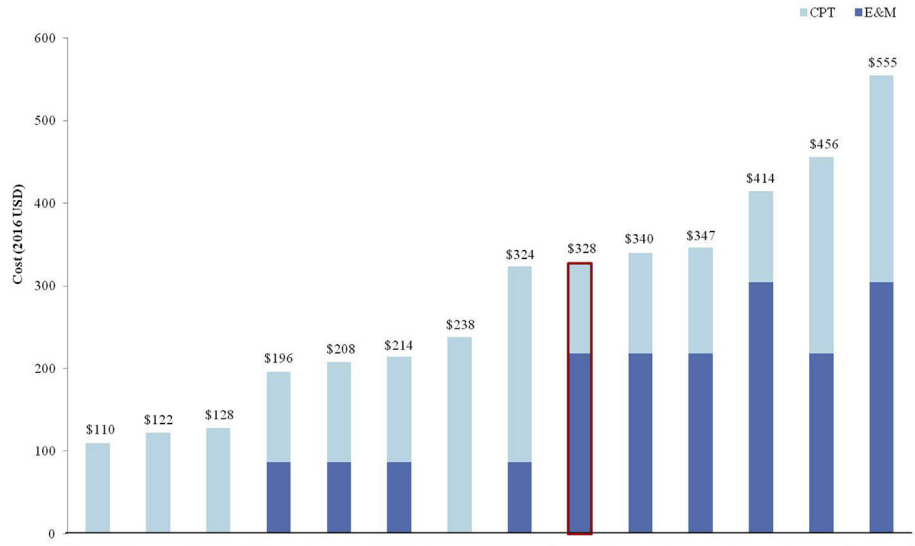


FIGURE 3. The cost of penicillin allergy evaluation using TDABC: Base-case, 2-way, and multiway sensitivity analyses. This bar graph displays the TDABC estimates identified in 2-way and multiway sensitivity analyses. Assumptions varied are shown brightly beneath the horizontal axis. *NP*, Nurse practitioner; *RN*, registered nurse.



E&M	None	Follow Up	None	New	None	Follow Up	Follow Up	None	New	Follow Up	New	Two Visits	New	Two Visits
Skin Testing	None	None	Yes	None	Yes+Amp	Yes	Yes+Amp	Yes	Yes	Yes	Yes+Amp	Yes	Yes	Yes+Amp
Challenge Steps	2	2	1	2	1	1	1	2	1	2	1	1	2	2

FIGURE 4. The cost of penicillin allergy evaluation: The RCC model. This bar graph demonstrates the different costs for various combinations of visits (E&M, dark blue) and procedures (CPT, light blue) in penicillin allergy evaluation using the RCC model. The base case, outlined in red, costs $829. Two-visit analyses include both a new and follow-up E&M. *Amp*, Ampicillin.



E&M	None	None	None	Follow Up	Follow Up	Follow Up	None	Follow Up	New	New	New	Two Visits	New	Two Visits
Skin Testing	Yes	Yes+Amp	None	Yes	Yes+Amp	None	Yes	Yes	Yes	Yes+Amp	None	Yes	Yes	Yes+Amp
Challenge Steps	1	1	2	1	1	2	2	2	1	1	2	1	2	2

FIGURE 5. The cost of penicillin allergy evaluation: The RVU model. This bar graph demonstrates the different costs for various combinations of visits (E&M, dark blue) and procedures (CPT, light blue) using the RVU model. The base case, outlined in red, costs $328. Two-visit analyses include both a new and follow-up E&M. *Amp*, Ampicillin.

average wholesale price for β-lactam antibiotics is generally less than that of β-lactam alternative antibiotics.[29] Previous studies comparing drug costs in patients labeled as penicillin-allergic, compared with those without the penicillin allergy label, found the total inpatient cost of antibiotics for patients labeled as penicillin-allergic from $11 to $582 higher.[37-41] Furthermore, through removal of an erroneous penicillin allergy label, some patients may avert unnecessary costly clinical outcomes such as

adverse reactions, treatment failures, and health care–associated infections, outcomes that cost from $3,023 to $14,629 2016 USD per event.[6-8,42-46] Considering the reasonable cost identified, and all the potential benefits, penicillin allergy evaluation should not be seen as a barrier for patients with an indication for a β-lactam antibiotic; ultimately, it is likely to be both clinically beneficial and cost-saving.

The lowest TDABC estimate of $40 was achieved through the use of an independent nurse practitioner provider and performing a 2-step graded challenge only (no skin testing). With more than 25 million Americans reporting a penicillin allergy history and only about 5000 Allergist/Immunologists in the United States, any widespread evaluation program would require involvement of nonallergist providers, such as nurse practitioners and physician assistants.[2,47] Our findings therefore emphasize the potential role of nurse practitioners, and other advanced providers, in expanding care delivery and lowering health care costs. Even when accounting for the supervision of a physician who understands how to appropriately prescribe, perform, and interpret the testing, the cost increase was not large ($22). A medical doctor provider performing a 2-step graded challenge only (no skin testing) cost $84, $136 (62%) less than the base case. The identified cost savings with forgoing the skin test were greater in this study than reported in a previous study that identified a reduction by $69 (35% lower) if no skin test was performed.[48] Although complete evaluation with skin testing is preferred, especially for patients with higher risk allergy histories, oral challenge only can be considered for patients with mild allergy histories or when there are no personnel trained to perform and interpret skin test results. Indeed, through the use of challenge-only evaluations, 818 Canadian children with histories of amoxicillin allergy were safely challenged to amoxicillin without skin testing, and in that study saved their health system $182,393 compared with full skin testing with oral challenge.[31]

Accurately measuring the cost of health care is important to guide efficient clinical operations and the practice of cost-conscious medical care.[13] Identifying and using valid costs in health care provides a common currency for clinicians and administrators to identify cost- reduction and process-improvement opportunities. Through assessing true costs, redundancies may be identified, equipment may be more efficiently used, and benchmarking across clinicians, facilities, and institutions becomes possible.[13] To our knowledge, TDABC methods have not been applied previously to allergy practices to guide cost-reduction or value-improvement opportunities. By considering the variation in TDABC estimates of penicillin allergy evaluation, allergy clinics may identify their optimal testing practice, such as one that maintains clinical outcomes with lower costs (eg, uses nurses for drug compounding, uses challenge-only procedures, batches penicillin allergy evaluations into a single day in the week, deploys nurse practitioner providers, and/or hires a scribe to perform clinical documentation). Accurate cost estimates additionally enables cost-effectiveness research. To date, cost-effectiveness analyses in drug hypersensitivity have been limited to genetic testing in severe cutaneous adverse reactions and desensitization in aspirin hypersensitivity.[49-54]

We found that the RCC method valued the cost of penicillin allergy evaluation $609 (>250%) more than the TDABC method. This higher cost estimate was expected given that the RCC methodology relies on aggregate data for assessing costs, and assumes that indirect resource costs are the same for each E&M or CPT code.[23] The RVU method, which achieved similar estimates to the TDABC estimate, still overvalued the cost for the base case by $108 (49%). Although the RVU method often provides a more accurate assessment of work than does the RCC method, the RVU method presupposes that indirect resource costs are proportional to patient volume; some economists and costing experts disagree with the subjective method of RVU value assignment (ie, physician specialty panels/surveys rather than by an objective measurement of resource use).[12]

Although TDABC provides a good estimate of cost from measurable resources, it does not include all costs related to health care delivery. For example, our analysis did not include the cost of services such as access to information technology support and other ancillary services, such as billing and human resources. We also did not include supervision costs for all personnel (eg, nursing supervisor, clinic administrator, and teaching of housestaff). Although the former was excluded because it was too technically challenging to accurately estimate, the latter exclusion was intentional because there is tremendous variability in clinical personnel across practice types and sites. We justified this exclusion after determining that, in our practice, supervision costs by a nursing supervisor and clinic administrator resulted in $5 more per patient visit. Although we used averages for salaries and drug prices in the TDABC analysis, many costs are variable by region in the United States. The base case accounted for skin testing with benzylpenicilloyl (PRE-PEN, ALK-Abelló) and dilutions of penicillin G, and ampicillin skin testing was considered in sensitivity analyses. Skin testing with minor determinant mix was excluded from the analysis, given that minor determinant mix is not commercially available and is laborious to compound. Although we were able to use observed data for many of the sensitivity analyses, simulated estimates were necessary for scenarios not observable in our practice environment (eg, registered nurse and pharmacist drug compounding time). TDABC estimates cost from the perspective of the health care system; we did not consider costs from the societal perspective, which would need to account for the patient's time spent at the penicillin allergy evaluation appointment. Finally, the TDABC methodology assumes that the resources and infrastructure exist to provide the evaluation. Although this is true for general allergist-offered penicillin allergy evaluation, in the case of large-scale penicillin allergy evaluations, additional infrastructure would be required.

Through a comprehensive TDABC analysis, we estimated that the cost of penicillin allergy evaluation is $220, and identified a range from $40 to $537 under different assumptions. Using other common costing methods, the RCC model and the RVU model, penicillin allergy evaluation costs more, but never exceeded $1,247. Given the modest cost of evaluation, and the potential downstream clinical and economic benefits, penicillin allergy evaluation should be encouraged by medical providers and covered, indeed, encouraged, by United States insurance plans. However, given the number of patients in the United States with an unverified penicillin allergy, testing demand could easily overcome the supply of Allergists/Immunologists to perform these evaluations. Given these impending challenges, it may be necessary to educate an expanded workforce to achieve large-scale testing.

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METHODS

To adjust for the cost of anaphylactic reactions that result from penicillin allergy evaluation, we first determined the probability of an anaphylactic reaction during penicillin allergy evaluation using weighted averages across 4 previous studies (3.2 per 1000; Table E1).[E1-E4] We then used TDABC to retrospectively cost the last 30 anaphylactic reactions treated at MGH Allergy Associates, using documentation times on anaphylaxis sheets, which included the initial time the patient presented/was assessed, each time vital signs were taken and/or physical examination performed, and the patient discharge time. Personnel times were estimated on the basis of interviews with nursing and physicians, as follows: registered nurse (7.5 minutes for intake history and physical, 5 minutes for each set of vital signs/examination/check in) and medical doctor (5 minutes initial history and physical and 2 minutes discharge examination). Personnel cost was the capacity cost rate multiplied by personnel time (Table E2). Consumables were calculated using the sum of the mean consumables used for the 30 cases (Table E2). Space cost used mean patient time observed for reaction (discharge time minus presentation time) multiplied by the allergy testing space capacity cost rate (Table E2).

TABLE E1. The probability of an anaphylactic reaction that results from penicillin allergy evaluation: Weighted average from peer-reviewed literature

Probability	n	Probability	Reference
Probability of systemic reaction during penicillin allergy evaluation	1710	.0012	E1
Probability of IgE-mediated reaction during penicillin allergy evaluation	500	.008	E2
Probability of IgE-mediated reaction during drug challenges	123	0	E3
Probability of anaphylactic reaction during outpatient drug challenges	497	.006	E4
Weighted average	2830	.0032	E1-E4

TABLE E2. TDABC for anaphylactic reactions (n = 30)

Personnel	Staff member	Mean activity time (min)	Cost per minute ($)	Total cost ($)
Assessment	Allergist/Immunologist	7.0	2.60	18.20
Assessment	Registered nurse	20.7	0.73	15.15
Total personnel cost				33.35

Consumables	Average wholesale price ($)	Number in pack	Mean used per patient	Total cost per patient ($)
Adrenalin 1 mg/mL 1:1000	15.00	1 vial	0.57	8.50
Proair albuterol sulfate 90 μg	60.02	200 puffs (100 doses)	0.43	0.26
Fexofenadine 60 mg	0.60	1 tablet	0.70	0.42
Cetirizine 10 mg	0.37		0.90	0.33
Diphenhydramine 25 mg oral solution (12.5 mg/5 mL)	1.71	Each	0.20	0.34
Diphenhydramine 25 mg tablets	0.06	Each	0.17	0.01
Famotidine 20 mg	2.42	Each	0.07	0.16
Prednisone 5 mg tablets	0.73	Each	2.67	1.95
Total consumables cost				12.0

Space	Testing room space
Mean minutes used	97.83
Capacity cost rate ($/min)	0.0118
Total space cost	1.16

TABLE E3. Analysis of consumables in penicillin allergy evaluation for a low-demand setting

Supplies	Acquisition cost per pack ($)	Number in pack	Number used	Total cost ($)
Greer*Pick*	347.60	1000	4	1.39
BD SafetyGlide	6.78	25	5	1.36
Albumin saline with phenol	112.20	50	4	8.98

Drugs	Average wholesale price ($)	Number in pack	Number used	Total cost ($)
Penicillin G Potassium 5 million units	14.47	1 vial	1 vial	14.47
PRE-PEN	110.00	1 vial	1 vial	110.00
Amoxicillin 250 mg/5 mL	7.11	30 challenges*	1 bottle	7.11
Total consumables cost				143.31†

*500 mg of amoxicillin.
†Number in text was rounded to nearest $1.

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