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ORIGINAL ARTICLE

Reducing penicillin allergy mislabelling: A one-day structured training program improves nurses' knowledge and self-reported confidence in allergy assessment and skin testing

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Abstract

Background: Penicillins are the most commonly prescribed antibiotics; however, penicillin allergy (PA) labels are highly prevalent and often inaccurate, leading to suboptimal antibiotic selection use. In Mainland China, PA mislabeling is exacerbated by inappropriate penicillin skin testing (PST) practices. Nurses play a crucial role in assessing and labeling suspected PA, but the lack of systematic, evidence-based training limits their ability to address mislabeling effectively.

Objective: To evaluate the impact of a structured one-day PA training course targeting nurses on their knowledge and self-reported confidence in PA assessment and skin testing practices.

Methods: A quasi-experimental pre- and post-test design was employed with 60 nurses in Mainland China who completed training course. Knowledge and self-reported confidence were assessed using a standardized 0–100 questionnaire (≥70=satisfactory) before training and at 1-month follow-up. Baseline results were also compared with those of nurses in Hong Kong.

Results: At baseline, overall knowledge did not differ significantly between Chinese Mainland and Hong Kong nurses, but Mainland nurses scored lower on PST–related practical knowledge questions (63.5 ± 32.9% vs. 56.6 ± 23.6%; $p = 0.031$). Following the training, there were significant improvements in both knowledge (64.3 ± 18.8 to 86.9 ± 9.9; $p < 0.001$) and self-reported confidence (72.0 ± 12.6 to 81.9 ± 8.7; $p < 0.001$). The proportion achieving a "satisfactory" score increased from 45.0% to 93.3% ($p < 0.001$).

Conclusion: A structured one-day training program significantly enhanced nurses' knowledge and confidence in PA assessment and PST. These findings support the integration of standardized, evidence-based PA training into nursing curricula, which may contribute to reducing mislabeling and promoting optimal antibiotic stewardship.

Key words: allergy, education, labelling, nurses, penicillin, practice, skin tests

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Introduction

Penicillins remain the most widely prescribed class of antibiotics and their appropriate use remains a cornerstone of antimicrobial stewardship.[1-3] Paradoxically, they are also the most commonly reported drug allergy, accounting for over half of all drug allergy labels in Mainland China and prevalence estimates ranging from 5-10% globally.[4-7] However, about 90% of reported penicillin "allergies" (PA) are found to be incorrect after clinical evaluation.[8-11] This pervasive mislabeling drives the unnecessary use of broader-spectrum antibiotics, contributing directly to adverse patient outcomes, including increased rates of multidrug-resistant organism (MDRO) infections.[12-18]

The high rate of PA mislabeling is closely related to both healthcare providers' misjudgment and widespread variation in clinical practices and policies for allergy assessment.[11,19,20] A particularly problematic practice in certain settings, including Mainland China, is the routine mandatory pre-emptive penicillin skin testing (PST) to all patients before any penicillin prescription, irrespective of clinical history.[21-24] In contrast to regions such as Hong Kong (Special Administrative Region of China), where PST is reserved for patients with a history of suspected PA, this universal approach lacks risk stratification and clinical context. Evidence indicates it yields a false-positive rate exceeding 99%, thereby systematically reinforcing inaccurate allergy labels.[25,26] Compounding this issue, the procedural execution of PST itself (including drug dilutions, intradermal injection volumes, and the interpretation of positive readings) often diverges from international, evidence-based standards, further undermining test reliability.[27,28] Within this context, nurses occupy a decisive role, as they perform and interpret over 95% of PSTs in China.[29] As the largest segment of the healthcare workforce, nurses are optimally positioned as essential agents for improving PA assessment and advancing antimicrobial stewardship.[30-33]

Despite this pivotal role, significant gaps persist in nurses' knowledge of evidence-based PA evaluation, documentation, and the appropriate use of diagnostic tools like PST. While innovative multidisciplinary and training programs such as the nurse-led Hong Kong Drug Allergy Delabeling Initiative (HK-DADI) and the AI-assisted drug allergy education courses for physicians have demonstrated success, no structured training framework currently exists to equip frontline nurses with standardized, risk-stratified competencies aligned with international best practices.[34-37]

To address this gap, we developed and implemented a structured, one-day training course specifically designed for nurses. Using a quasi-experimental pre- and post-test design, this study evaluates the program's impact on participants' knowledge, self-rated confidence in clinical decision-making, and willingness to adopt evidence-based, risk-stratified and procedurally standardized practices in real-world clinical settings.

Methods

This study employed a single-group, quasi-experimental design with pre- and 1-month follow-up post-tests, conducted at Guangdong Dermatology Hospital in China. All nurses enrolled in the structured, one-day PA training course were invited to participate. Eligibility for the final matched analysis required the provision of complete responses to both the pre-training and 1-month follow-up questionnaires. Ethical review exemption was granted for this study as it constituted a program evaluation of a training program, did not involve patient information, and utilized anonymous questionnaires as a standard component of course assessment.

The one-day training program was structured into two core components. The didactic lectures were delivered by experienced allergy clinicians and specialist nurses from Hong Kong and focused on essential knowledge, with a particular emphasis on international standards for evidence-based PST practices and interpretation. The second component was a hands-on practical session led by the same instructors, utilizing simulated model arms to facilitate realistic practice of both skin prick and intradermal testing techniques, which included a live demonstration followed by supervised skills practice.

Outcomes were measured using a series of anonymous, matched questionnaires developed with expert input and refined through a pilot test with five nurses, who conducted a pre-survey to ensure the clarity and comprehensibility of the questionnaire content (for details, please refer to **Supplementary Text 2**). The pre-training questionnaire collected demographic data and assessed baseline states using a 12-item multiple-choice knowledge test covering core penicillin allergy (PA) concepts (comprising 4 items on theory and 8 items on practical skills), which was designed by experienced allergy clinicians and covered content directly relevant to penicillin allergy delabelling (international standards, skin test interpretation, reaction types, and standardized procedures) to reflect nurses' baseline and 1-month follow-up knowledge and confidence in performing penicillin skin testing. A cut-off score of ≥ 70% (determined via contrasting groups validation: experienced vs. non-experienced nurses, 84.7% vs. 48.6%, $p = 0.007$) was established to define "satisfactory" performance on the knowledge test (see **Supplementary Text 1**). Additionally, a 4-item scale measured self-rated confidence in various aspects of PA testing, ranging from 0 ('not confident') to 5 ('very confident').

The immediate post-course questionnaire re-administered course feedback items. The 1-month follow-up questionnaire re-evaluated both knowledge and self-reported confidence. To provide a benchmark for the baseline data, the pre-training knowledge scores of the Mainland Chinese nurses were also compared with those from a reference cohort of nurses in Hong Kong who had completed the same questionnaire.

In procedure, the pre- and immediate post-course questionnaires were administered in paper form at the course venue. The 1-month follow-up was conducted remotely. To enable matching while preserving anonymity, participants created a unique, anonymous code for all surveys.

Sample size calculation was performed using the G*power application version 3.1, with a total of 54 participants required to detect a medium effect size of 0.50 with a power of 0.95 and a two-sided significance level of 0.05. Data from matched responses were analysed using SPSS version 24.0. The 0-5 scores were converted to a 0-100 scale by dividing by 5 and multiplying by 100 to express them as percentages, and both knowledge and confidence scores were reported accordingly. Changes in knowledge scores and confidence scores from pre- to 1-month follow-up were analysed using paired-sample t-tests. An independent samples t-test was used to compare baseline knowledge scores between the Mainland Chinese and Hong Kong nurse cohorts. The change in the proportion of participants achieving a satisfactory knowledge score (≥ 70%) was assessed using McNemar's test. All tests were two-sided, with a p-value < 0.05 deemed statistically significant.

Results

A total of 66 nurses completed the one-day training, among whom six had incomplete or unmatched questionnaires at follow-up points, resulting in a final sample of 60 nurses in Mainland China (effective response rate: 90.9%) who completed all associated questionnaires. The baseline characteristics of the participants, compared to a reference cohort from Hong Kong, are detailed in **Table 1**. The Mainland cohort was predominantly female (59/60, 98.3%), with a median age of 32 years (Range: 18–46) and a median of 10 years (Range: 1–27) of nursing experience. The vast majority (55/60, 91.6%) reported extensive experience in performing PST, with over half (38/60, 63.3%) having conducted more than 50 tests in their career. Among nurses with significant testing volume, the self-reported estimated positive PST rate in the Mainland cohort was 22% (Range: 17.6–26.6%). In contrast, while the Hong Kong reference cohort (n = 12) was generally older and more experienced (median age: 40 years; median experience: 15 years), they reported performing far fewer PSTs, with 91.6% (11/12) having conducted fewer than 10 PST and encountering a lower self-reported estimated positive rate (11%).

Baseline knowledge and self-reported confidence were compared between the Mainland cohort and the Hong Kong reference group (**Table 2**). No significant difference was found in total knowledge scores (Mainland: 64.3 ± 18.8% vs. Hong Kong: 68.0 ± 23.0%; p = 0.060). However, Hong Kong nurses scored significantly higher on PST-related practical knowledge questions (Hong Kong: 63.5 ± 32.9% vs. Mainland: 56.6 ± 23.6%; p = 0.031). In terms of self-report confidence, Hong Kong nurses reported significantly higher confidence in diagnosis (75.0 ± 12.4% vs. 63.0 ± 19.3%; p = 0.015), labelling/delabelling (83.3 ± 16.7% vs. 61.3 ± 22.1%; p < 0.001), and in composite self-report confidence scores (82.1 ± 8.4% vs. 72.0 ± 12.6%; p = 0.003).

Table 1. Baseline demographics and experience of participating nurses, compared to reference Hong Kong cohort.

	Participating Nurses (n = 60)	Hong Kong Cohort (n = 12)
Sex		
Female	59 (98.3)	5 (83.3)
Age		
Median (Range)	32.00 (18–46)	40.00 (38–48)
Years of experience in nursing		
Median (Range)	10.00 (1–27)	15.00 (2–25)
Lifetime number of tests if ever performed		
Fewer than 10 times	5 (8.3)	11 (91.6)
11–50 times	17 (28.3)	—
51–100 times	26 (43.3)	1 (8.3)
More than 100 times	12 (20.0)	—
Estimated prevalence of positive PST	22% (17.6–26.6)	11% (5.6–18.8%)

Table 2. Baseline knowledge and self-reported confidence scores of participating nurses, compared to reference Hong Kong cohort.

	Baseline		*p*-value
	Mainland (n = 60)	Hong Kong (n = 12)	
Knowledge			
Participants with satisfactory scores (≥ 70/100)	27/60 (45.0%)	6/12 (50.0%)	0.755
Composite knowledge score (%)	64.3 ± 18.8	68.0 ± 23.0	0.060
- Theory (%)	80.0 ± 18.9	76.9 ± 21.6	0.071
- PST-related practical knowledge (%)	56.6 ± 23.6	63.5 ± 32.9	0.031
Practice (self-reported confidence)			
Composite practice score (%)	72.0 ± 12.6	82.1 ± 8.4	0.003
- Evaluation (%)	80.4 ± 14.9	81.7 ± 13.4	0.785
- Diagnosis (%)	63.0 ± 19.3	75.0 ± 12.4	0.015
- Labelling/delabelling (%)	61.3 ± 22.1	83.3 ± 16.7	0.001
- Managing reactions following testing (%)	83.0 ± 14.6	88.3 ± 13.4	0.246

Following training, participating nurses demonstrated significant improvements in all assessed domains (**Table 3**, **Figure 1**). Total knowledge scores increased from 64.3 ± 18.8% to 86.9 ± 9.9% ($p < 0.001$). The proportion of nurses achieving a satisfactory score (≥ 70%) rose from 45.0% (27/60) to 93.3% (56/60) ($p < 0.001$). Notably, scores in PST-related practical knowledge showed the greatest magnitude of improvement, from 56.6 ± 23.6% to 85.8 ± 12.0% ($p < 0.001$). Similarly, confidence scores also improved significantly with composite scores increased from 72.0 ± 12.6% to 81.9 ± 8.7% ($p < 0.001$). Significant gains were observed in confidence related to evaluation, diagnosis, and labelling/delabelling (all $p < 0.001$). Confidence in managing reactions following testing was high at baseline and showed a non-significant increase (83.0 ± 14.6% to 93.5 ± 9.5%; $p = 0.064$).

Participant feedback was overwhelmingly positive (**Figure 2**). The vast majority of nurses (93.3%, 56/60) rated the overall course quality as "excellent," and 85.0% (51/60) agreed the content was highly relevant to daily practice. Nearly all participants (96.7%, 58/60) indicated they would recommend the course to colleagues, and 86.7% (52/60) believed it would positively influence their future clinical practice. Furthermore, 61.7% (37/60) felt it was necessary to update their institutional PST guidelines based on the course content.

Table 3. Baseline and 1-month follow-up knowledge and self-reported confidence scores among Mainland nurse participants.

	Mainland nurse participants		*p*-value
	Baseline	1-month follow-up	
Knowledge			
Participants with satisfactory scores (≥ 70/100)	27/60 (45.0%)	56/60 (93.3%)	< 0.001
Composite knowledge score (%)	64.3 ± 18.8	86.9 ± 9.9	< 0.001
- Theory (%)	80.0 ± 18.9	93.7 ± 21.6	< 0.001
- PST-related practical knowledge (%)	56.6 ± 23.6	85.8 ± 12.0	< 0.001
Practice (self-report confidence)			
Composite practice score (%)	72.0 ± 12.6	81.9 ± 8.7	< 0.001
- Evaluation (%)	80.4 ± 14.9	87.0 ± 10.5	< 0.001
- Diagnosis (%)	63.0 ± 19.3	75.7 ± 17.3	< 0.001
- Labelling/delabelling (%)	61.3 ± 22.1	71.3 ± 16.1	< 0.001
- Managing reactions following testing (%)	83.0 ± 14.6	93.5 ± 9.5	0.064

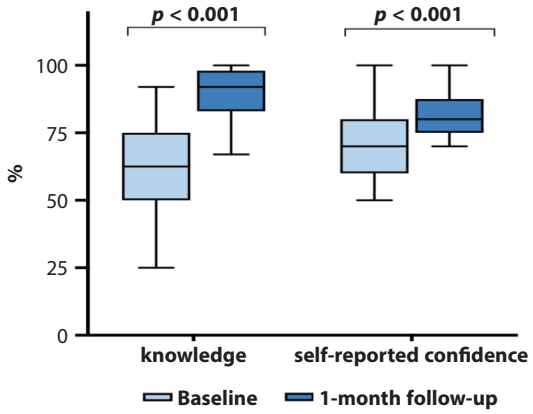

Figure 1. Change in knowledge and self-report confidence scores from baseline to 1-month follow-up (n = 60).

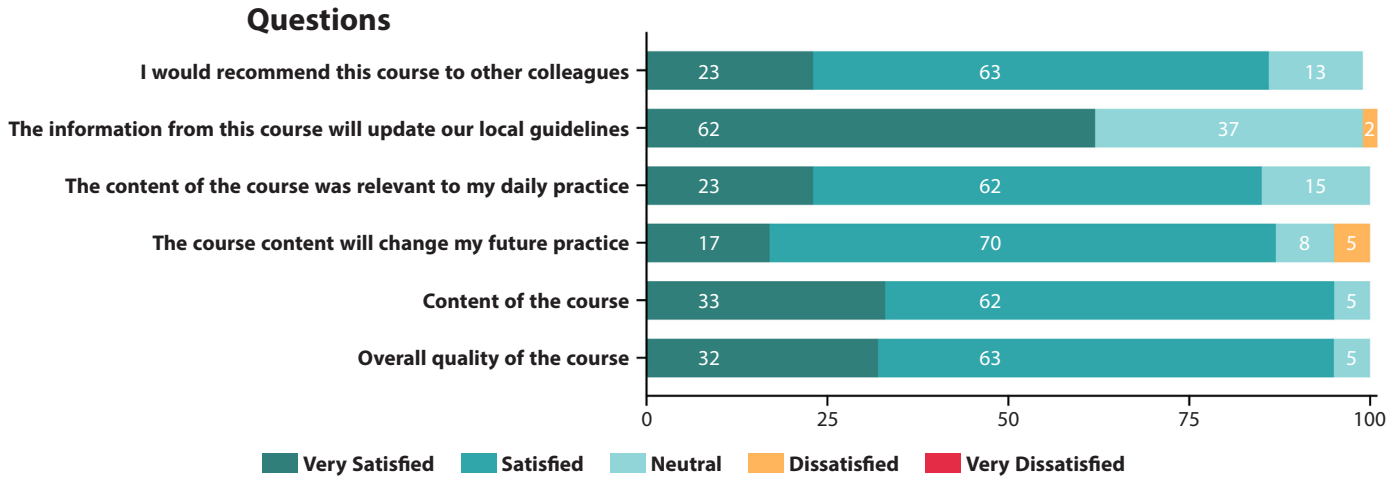

Figure 2. Post-course evaluation by participating nurses (n = 60).

Discussion

This study presents the first targeted educational intervention aimed at improving PA assessment and PST competencies among nurses with a particular focus on China. The findings demonstrate that a structured, one-day training program can yield significant improvements at 1-month follow-up in both theoretical knowledge and self-report confidence.[38,39]

In Mainland China, nurses serve as the primary operators of PST and the frontline assessors of suspected PA. They are responsible for all stages of the test, including its preparation, administration, and documentation.[40,41] Despite this central role, their training has historically been based on local non-evidenced-based protocols (such as performing universal pre-emptive PST) rather than on internationally recognized guidelines.[21,28] This practice gap is evident in our baseline results. Although overall knowledge scores were similar between Mainland and Hong Kong nurses, the Mainland cohort scored significantly lower on practical, PST-related questions and reported markedly less confidence in diagnostic and delabeling tasks.[28] Furthermore, the estimated positive PST rate reported by Mainland nurses (22%) was substantially higher than both the Hong Kong reference (11%) and global averages, suggesting that current nursing PST practices may contribute to an environment of over-testing and false-positive interpretations.[4-7] This discrepancy also highlights a systemic issue in which clinical procedures have become misaligned with current international standards,[24,42] thereby perpetuating the cycle of penicillin allergy mislabeling and the subsequent reliance on broader-spectrum antibiotics.[43]

Our training program was designed to directly address this practice gap by aligning curricular content with international best practices. The significant post-course improvements, particularly in the practical domains where baseline deficits were most pronounced, confirm that nurses are both receptive and responsive to evidence-based training. Notably, the overwhelmingly positive evaluations indicated strong endorsement, with a clear majority of participants (61.7%) recognizing the necessity of updating their institution's PST guidelines based on the course content. The demographics are comparable to general nurse population in Mainland China.[44] According to behavioral change theory, this concurrent shift in knowledge, confidence, and professional intention constitutes a critical precursor to sustained practice change.[45] Therefore, this educational model represents a viable and scalable first-line strategy for initiating systemic reform.

Several limitations must be acknowledged. First, the study was conducted with a single cohort from one institution, which may limit the generalizability of the findings. Second, while we measured improvements in knowledge and practice, the assessment of practice change relied on self-reported confidence rather than direct observation of clinical behaviour.[46] Third, the follow-up period was short; the long-term retention of knowledge and its translation into sustained practice improvement require further investigation. Future studies should employ multicentre designs, incorporate objective measures of clinical behaviour (such as audit of PST practices and delabeling rates), and include longer-term evaluations to fully establish the intervention's impact on patient-level and stewardship outcomes.

In conclusion, this study provides evidence that a concise, internationally-aligned educational program can effectively equip Mainland Chinese nurses with the foundational knowledge and confidence required for evidence-based PA assessment. Integrating such standardized training into nursing professional development represents a critical step towards standardizing PST practices, which is essential for reducing inappropriate allergy labels, improving antibiotic prescribing, and formally establishing nurses as key contributors to antimicrobial stewardship.

References

1. Mabilat C, Gros MF, Van Belkum A, et al. Improving antimicrobial stewardship with penicillin allergy testing: a review of current practices and unmet needs. JAC Antimicrob Resist. 2022;4(6):dlac116.
2. Castells M, Khan DA, Phillips EJ. Penicillin Allergy. N Engl J Med. 2019; 381(24):2338–2351.
3. Li PH, Blumenthal KG. Tackling the burden of β-lactam allergy labels. The Lancet Infectious Diseases. 2025;25(8):834–835.
4. Shi W, Low MC, To JC, et al. Disparities in Drug Allergy Labeling in China: Half of All Labels Are Attributed to b-Lactams. J Investig Allergol Clin Immunol. 2025:0.
5. Li PH, Yeung HHF, Lau CS, Au EYL. Prevalence, Incidence, and Sensitization Profile of beta-lactam Antibiotic Allergy in Hong Kong. JAMA Netw Open. 2020;3(5):e204199.
6. Chiang V, Kan AKC, Saha C, Au EYL, Li PH. Identifying the most at-risk age-group and longitudinal trends of drug allergy labeling amongst 7.3 million individuals in Hong Kong. BMC Med. 2024;22(1):30.
7. Luintel A, Healy J, Blank M, et al. The global prevalence of reported penicillin allergy: A systematic review and meta-analysis. J Infect. 2025; 90(2):106429.
8. Siew LQC, Li PH, Watts TJ, et al. Identifying Low-Risk Beta-Lactam Allergy Patients in a UK Tertiary Centre. J Allergy Clin Immunol Pract. 2019;7(7):2173–2181 e2171.
9. Li PH, Siew LQC, Thomas I, et al. Beta-lactam allergy in Chinese patients and factors predicting genuine allergy. World Allergy Organ J. 2019;12(8):100048.
10. Li TS, Hui HKS, Kan AKC, et al. Prospective Assessment of Penicillin Allergy (PAPA): Evaluating the performance of penicillin allergy testing and post-delabelling outcomes among Hong Kong Chinese. Asian Pac J Allergy Immunol. 2023.
11. Mak HWF, Yeung MHY, Wong JCY, Chiang V, Li PH. Differences in beta-lactam and penicillin allergy: Beyond the West and focusing on Asia-Pacific. Front Allergy. 2022;3:1059321.
12. Blumenthal KG, Peter JG, Trubiano JA, Phillips EJ. Antibiotic allergy. Lancet. 2019;393(10167):183–198.
13. Chan SCW, Yeung WWY, Wong JCY, et al. Prevalence and Impact of Reported Drug Allergies among Rheumatology Patients. Diagnostics (Basel). 2020;10(11).
14. Li PH, Chung HY, Lau CS. Epidemiology and outcomes of geriatric and non-geriatric patients with drug allergy labels in Hong Kong. Hong Kong Med J. 2021;27(3):192–197.
15. Copaescu AM, Vogrin S, James F, et al. Efficacy of a Clinical Decision Rule to Enable Direct Oral Challenge in Patients With Low-Risk Penicillin Allergy: The PALACE Randomized Clinical Trial. JAMA Intern Med. 2023;183(9):944–952.
16. Mak HWF, Chan ETS, Yim JSH, et al. Validation of the Chinese drug hypersensitivity quality of life questionnaire: Role of delabeling. Asia Pac Allergy. 2023;13(1):3–9.
17. Ahmed S, Sandoe JAT. A rapid literature review of the impact of penicillin allergy on antibiotic resistance. JAC Antimicrob Resist. 2025; 7(1):dlaf002.
18. Fu M, Hu L, Han K, et al. The burden of beta-lactam allergy labels in health care: a systematic review and meta-analysis. Lancet Infect Dis. 2025;25(8):896–908.
19. Li PH, Pawankar R, Thong BYH, et al. Disparities and inequalities of penicillin allergy in the Asia-Pacific region. Allergy. 2023;78(9): 2529–2532.
20. Wang L, Chen S, Lin L, et al. Breaking the barrier: Transforming the diagnosis and management of penicillin and cephalosporin allergy in China. Int J Infect Dis. 2025;160:108076.
21. Shi W, Wang L, Chen S, Li PH, Luo X. Mandatory Preemptive Skin Testing and Its Impact on Penicillin Allergy Labeling Across Different Healthcare Settings in Mainland China and Hong Kong. Allergy. 2025.
22. Jiang X, Xiao H, Zhang H, Xu F, Jia Q, Meng J. High false-positive results from routine penicillin skin testing influencing the choice of appropriate antibiotics in China. J Hosp Infect. 2023;134:169–171.
23. Tang MM, Fok JS, Thong BY, et al. Diagnostic procedures & practices in drug allergy/hypersensitivity: a survey of 13 Asian countries. Asia Pac Allergy. 2020;10(4):e36.
24. Jiang Z, Zhang H, Xiao H, Xiao X, Meng J. Negative impact of penicillin allergy labels on antibiotic use in hospitalized patients in Chinese Mainland. World Allergy Organization Journal. 2022;15(8):100677.
25. Li PH, Xu F, Shi W, et al. Prospective Multiregional Evaluation of Protocol-Based Penicillin Allergy Delabeling in China: Real-World Outcomes Challenge Mandatory Preemptive Skin Testing Policies. J Allergy Clin Immunol Pract. 2025.
26. Shenoy ES, Macy E, Rowe T, Blumenthal KG. Evaluation and Management of Penicillin Allergy: A Review. JAMA. 2019;321(2): 188–199.
27. Zembles T, Mitchell M, Alqurashi W, Castells M, Phillips EJ, Vyles D. Skin Testing for Penicillin Allergy: a Review of the Literature. Curr Allergy Asthma Rep. 2021;21(3):21.
28. Shi W, Liu N, Huang JX, Xiao H, Meng J, Li PH. Penicillin Allergy in China: Consequences of Inappropriate Skin Testing Practices and Policies. Clin Exp Allergy. 2025;55(8):625–633.
29. Ji D, Hu B, Chen Z, et al. Assessment of penicillin allergy evaluation practices among clinicians in China: a nationwide cross-sectional survey. BMJ Open. 2025;15(10):e101780.
30. DING X-L, SUN Z-M, YAO Z-Y, ZHANG H-J. Health care workers' cognition status towards allergy reactions to com-monly used antimicrobial agents. Chinese Journal of Infection Control. 2024:284–290.
31. Thurman Johnson C, Ridge LJ, Hessels AJ. Nurse Engagement in Antibiotic Stewardship Programs: A Scoping Review of the Literature. J Healthc Qual. 2023;45(2):69–82.
32. Carter EJ, Greendyke WG, Furuya EY, et al. Exploring the nurses' role in antibiotic stewardship: A multisite qualitative study of nurses and infection preventionists. Am J Infect Control. 2018;46(5):492–497.
33. Broom A, Broom J, Kirby E, Scambler G. Nurses as Antibiotic Brokers: Institutionalized Praxis in the Hospital. Qual Health Res. 2017; 27(13):1924–1935.
34. Kan AKC, Hui HKS, Li TS, et al. Comparative Effectiveness, Safety, and Real-World Outcomes of a Nurse-Led, Protocol-Driven Penicillin Allergy Evaluation From the Hong Kong Drug Allergy Delabelling Initiative (HK-DADI). J Allergy Clin Immunol Pract. 2023;11(2):474–480 e472.
35. Wong JCY, Kan AKC, Chik TSH, et al. Prospective, Multicenter, Head-to-Head Comparison Between Allergists Versus Nonallergists in Low-Risk Penicillin Allergy Delabeling: Effectiveness, Safety, and Quality of Life (HK-DADI2). J Allergy Clin Immunol Pract. 2024;12(7): 1801–1808 e1802.
36. Lucas M, Mak HWF, Lee JTY, Kulkarni R, Chan SSC, Li PH. Impact of a drug allergy education course for non-specialists: Findings from ADAPT-A randomized crossover trial. Allergy. 2024.

37. Mak HWF, Meng J, Chung FKL, et al. Bridging Global Disparities in Drug Allergy Through AI-Assisted Training for Non-Specialists: Findings From the Multinational ADAPT-2 Course. Clinical & Experimental Allergy. 2026;n/a(n/a).
38. Weddle G, Goldman J, Myers A, Newland J. Impact of an Educational Intervention to Improve Antibiotic Prescribing for Nurse Practitioners in a Pediatric Urgent Care Center. Journal of Pediatric Health Care. 2017;31(2):184–188.
39. Gillespie E, Rodrigues A, Wright L, Williams N, Stuart RL. Improving antibiotic stewardship by involving nurses. American Journal of Infection Control. 2013;41(4):365–367.
40. Danielis M, Regano D, Castaldo A, Mongardi M, Buttiron Webber T. What are the nursing competencies related to antimicrobial stewardship and how they have been assessed? Results from an integrative rapid review. Antimicrob Resist Infect Control. 2022;11(1):153.
41. Olans RD, Nicholas PK, Hanley D, DeMaria Jr A. Defining a role for nursing education in staff nurse participation in antimicrobial stewardship. The Journal of Continuing Education in Nursing. 2015; 46(7):318–321.
42. Barker S, Daniels L, Chang YS, et al. Allergy education and training for physicians. World Allergy Organ J. 2021;14(10):100589.
43. Zhou J, Ma X. A survey on antimicrobial stewardship in 116 tertiary hospitals in China. Clinical Microbiology and Infection. 2019;25(6):759. e759–759.e714.
44. Lu H, Hou L, Zhou W, et al. Trends, composition and distribution of nurse workforce in China: a secondary analysis of national data from 2003 to 2018. BMJ Open. 2021;11(10):e047348.
45. Ajzen I. From Intentions to Actions: A Theory of Planned Behavior. In: Kuhl J, Beckmann J, eds. Action Control: From Cognition to Behavior. Berlin, Heidelberg: Springer Berlin Heidelberg; 1985:11–39.
46. Shorrock ST, Williams CA. Human factors and ergonomics methods in practice: three fundamental constraints. Theoretical Issues in Ergonomics Science. 2016;17(5-6):468–482.

Supplementary Text 1. Validation of Cut-off Score for Satisfactory Performance.

A cut-off score of ≥ 70% was established to define "satisfactory" performance on the 12-item multiple-choice knowledge test covering core PA concepts, using the "contrasting groups" method (S1). To validate this threshold, a separate cohort of 12 nurses, none of whom had participated in the main training course, were recruited. This validation cohort (**Table S1**) consisted of two distinct groups: six experienced allergy nurses actively practicing penicillin allergy (PA) evaluation, and six nurses without practical experience in PA assessment. All participants completed the same 12-item quiz.

Across the entire validation cohort, the overall mean score was 66.67 ± 23.57%, with 6/12 nurses (50.0%) scoring ≥ 70%. The experienced nurses achieved a mean score of 84.7 ± 14.4%, while the non-experienced nurses achieved a mean score of 48.6 ± 15.2% (p = 0.007). When applying the 70% cut-off, 5/6 experienced nurses (83.3%) achieved a satisfactory score, compared to 1/6 non-experienced nurses (16.6%; p = 0.08). Based on the clear separation in mean performance between these two contrasting groups, and a review of the individual score distributions, a score of 70% was selected as an appropriate and empirically validated cut-off to distinguish Mainland Chinese nurses with satisfactory foundational knowledge in drug allergy assessment from those requiring further education.

Table S1. Comparison of experienced nurses vs non-experienced nurses (n = 12)

Group	n	Mean % ± SD	*p*	≥ 70% score (n, %)	*p*
Experienced nurses	6	84.7 ± 14.4	0.007	5/6 (83.3%)	0.080
Non-experienced nurses	6	48.6 ± 15.2	—	1/6 (16.6%)	—

Reference

S1. Norcini JJ. Setting standards on educational tests. Med Educ. 2003;37(5):464-469.

Supplementary Text 2.

Knowledge Test: Core Concepts in Penicillin Allergy

1. **The primary aim of allergy skin testing is to investigate for:**
   A. Type I hypersensitivity reactions
   B. Type II hypersensitivity reactions
   C. Type III hypersensitivity reactions
   D. Type IV hypersensitivity reactions

2. **When will immediate drug hypersensitivity reactions usually occur after drug administration?**
   A. 1-2 hours
   B. 6-8 hours
   C. 8-12 hours
   D. 12-24 hours

3. **Which of the following tests is considered the gold standard to confirm or exclude drug allergy?**
   A. Clinical history
   B. Skin testing
   C. Drug-specific IgE
   D. Drug provocation testing

4. **Which of the following is the LEAST USEFUL in assessment of suspected drug allergy:**
   A. Drug dosage
   B. Previous drug exposure
   C. Route of administration
   D. Family history of drug allergy

5. **What are reasons why at present many patients are incorrectly labelled with penicillin allergy?**
   A. Skin tests are mostly useful for immediate-type reactions only
   B. The skin test reagents used in our country only contain benzylpenicillin
   C. Positive and negative controls are not routinely used
   D. All of the above

6. **According to international recommendations, the standard injection volume for intradermal tests is:**
   A. 0.02 ml
   B. 0.1 ml
   C. 0.5 ml
   D. 1 ml

7. **What approximate proportion of penicillin allergy patients are missed we penicilloyl-polylysine (PPL) + minor determinant mixture (MDM) are not included in skin testing?**
   A. 1-5%
   B. 10-20%
   C. 50-60%
   D. 70-80%

8. **According to international recommendations, which of these are criteria for a positive intradermal tests?**
   A. An induration diameter increase of ≥ 3 mm accompanied by redness/itching
   B. Slight pallor at the injection site
   C. Patient reports a stinging sensation
   D. Redness around the papule measuring 1 cm

9. **Which of the following statements is TRUE?**
   A. A positive penicillin skin test definitely confirms that the patient is allergic to penicillin.
   B. Patients with a history of positive skin tests should never be tested again
   C. Skin testing (with or without provocation tests) should be repeated if the patient's history is not suggestive of genuine allergy
   D. If a patient's skin test result is negative, this definitely confirms the patient is not allergic to penicillin

10. **Which test is recommended as the first step of penicillin skin testing?**
    A. Skin prick test
    B. Intradermal test
    C. Skin patch test
    D. Provocation test

11. **Which is the most appropriate time to perform skin test when drug allergy is suspected?**
    A. Anytime
    B. Immediately following the index reaction
    C. At least one month following the index reaction
    D. Never

12. **Which of the following are situations should skin testing not be performed?**
    A. Patient has taken an anti-histamine the day before testing.
    B. Patient has a family history of severe cutaneous adverse reaction to penicillin
    C. Patient is pregnant.
    D. Patient has ongoing infection.

Supplementary Text 2. (Continued)

Confidence Test: Self-Rated Confidence in Penicillin Allergy

1. **How confident do you feel in evaluating patients with suspected drug allergy?**
   A. Not confident
   B. lightly confident
   C. Somewhat confident
   D. Confident
   E. Very confident

2. **How confident do you feel in accurately diagnosing a positive penicillin allergy test result?**
   A. Not confident
   B. lightly confident
   C. Somewhat confident
   D. Confident
   E. Very confident

3. **How confident do you feel in labelling or delabelling suspected drug allergy?**
   A. Not confident
   B. lightly confident
   C. Somewhat confident
   D. Confident
   E. Very confident

4. **How confident do you feel in managing patients presenting acutely with suspected drug allergy?**
   A. Not confident
   B. lightly confident
   C. Somewhat confident
   D. Confident
   E. Very confident