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Review

The global prevalence of reported penicillin allergy: A systematic review and meta-analysis

Akish Luintel [a,*], Joseph Healy [b], Michael Blank [b], Aashika Luintel [c], Simon Dryden [a], Abhishek Das [d], Ara Darzi [a], Graham Cooke [e]

[a] Institute of Global Health Innovation, Imperial College London, UK
[b] Imperial College Healthcare NHS Foundation Trust, UK
[c] East and North Hertfordshire NHS Foundation Trust, UK
[d] Division of Infection and Immunity, University College London, UK
[e] Department of Infectious diseases, Faculty of Medicine, Imperial College London, UK

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SUMMARY

Objectives: Patients labelled with penicillin allergy (PenA) often receive broader spectrum antibiotics, associated with antimicrobial resistance and poorer outcomes. However, ~95% of patients are likely mis-labelled. Whilst de-labelling programmes are gaining momentum, they have been restricted to a few countries. Here, we address the global prevalence of PenA, to inform the wider potential impact for de-labelling programmes.
Methods: We conducted a systematic review and meta-analysis including all studies on adult PenA prevalence between January 2003 and June 2023. Data on PenA prevalence, allergy recording methods, healthcare setting, and country income were extracted. This study is registered on PROSPERO (CRD42023437718).
Results: 174 studies from 28 countries were included (18,352 screened). Global PenA prevalence was 9·4% (95% CI 8·4–10·4%). 92% of peer-reviewed publications were from high-income countries(HICs), with 72% from the UK, USA or Australia. HICs had higher PenA prevalence 9·9% (95% CI 8·8–11·0%), compared to middle-income countries (MICs), 4·4% (95% CI 2·8–6·2%), $p < 0.0001$. Primary care data was seldom reported (16% of studies), and the method of allergy recording significantly influenced reported prevalence.
Conclusions: Studies reporting PenA prevalence are skewed towards HICs and secondary care, with little data from Africa, most of Asia and South America. This highlights an unmet need to broaden epidemiological analysis in under-represented regions.

Introduction

Penicillins and related beta lactams represent over 40% of antibiotics covered by the WHO AWaRe classification[1] and are preferred first-line agents for over 95% of infections in WHO AWaRe antibiotic book.[2] However, many patients are precluded from their use due to self-reported penicillin allergy.[3] Patients labelled with penicillin allergy (PenA) are often prescribed combinations of second-line, broader spectrum antibiotics, which are more likely to be classified into the AWaRe; "watch" or "reserve" categories.[4] In addition, having a PenA label is associated with increased rates of healthcare-associated infections such as *Methicillin Resistant Staphylococcus aureus (MRSA)* and *Clostridioides Difficile (C. Diff)*.[5]

In practice, formal testing has shown that over 95% of patients labelled as PenA are mislabelled and will tolerate penicillins safely.[6,7] For these reasons, the WHO has endorsed antibiotic allergy assessment as a key antimicrobial stewardship activity.[8] Delabelling has gained traction in many areas of the world with guidance emerging in North America, Australia, Europe and Asia-Pacific regions.[9–12] However, data on the prevalence of reported PenA-labelled patients are limited[13,14] and are required to understand the need and impact of delabelling programmes. We sought to comprehensively characterise the global prevalence and distribution of reported PenA.

Methods

This systematic review and meta-analysis were conducted in accordance with the Preferred Reporting Items for Systematic Review and Meta-Analyses (PRISMA) guidelines (Appendix 1).[15] This

* Corresponding author.
E-mail address: aluintel@ic.ac.uk (A. Luintel).

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study is registered on PROSPERO (CRD42023437718). The search strategy was created in collaboration of the British Medical Association (BMA) library; exact search terms can be found in the supplementary material (Appendix 2).

Four authors (AL, JH, MB, AL) independently screened abstracts using COVIDENCE software. Duplicate data was marked by COVIDENCE and also by authors. Where there were conflicts, two authors discussed the material and if there was no consensus a third member would review to arbitrate.

Three authors (AL, MB and JH) independently reviewed the full texts. Where there were conflicts, consensus was reached through discussion. Four authors extracted the data and two were assigned to review each article, including assessment of the accuracy and quality of the data using the Joanna Briggs Institute Critical Appraisal checklist tool (Appendix 4).[16]

Selection criteria

MEDLINE, EMBASE and the COCHRANE database were searched for potentially relevant articles published between January 1, 2003, to June 1, 2023. A further search of the grey literature and any relevant references from the initial search were included.

Papers were included for full review if from the title or abstract, a prevalence of reported PenA was likely to be calculated from data in the study. We additionally included publications for full review in which 'beta-lactam allergy' were mentioned, given several of these had PenA label prevalence data nested within, that we could leverage for our study. We did not include studies that reported pan-beta-lactam allergy prevalence only in our meta-analysis.

To map the number of studies on PenA prevalence by geographical region, we included data from any study, including conference abstracts where PenA prevalence data existed. For studies including multiple geographic locations, each country was treated as a separate population for the distribution mapping, this allowed us to plot a distribution map of studies globally (Fig. 2). Additionally, we mapped studies on both PenA prevalence and pan beta-lactam allergy prevalence together, by geographical region (Appendix 8).

To calculate reported PenA prevalence, we restricted our analysis to include only peer-reviewed articles, thus excluding abstracts and conference presentations to ensure more robust data. Where sequential studies originated from the same cohort of patients with overlapping dates, the study with the largest sample size was chosen for the meta-analysis.

We included any data from within these peer-reviewed studies where reported PenA label prevalence could be calculated. This included data calculated from electronic health record systems(EHRS), drug charts, questionnaires and coded data from databases. We included all patients with reported PenA labels and did not distinguish between severity of allergy.

Case studies, case series and data from preprints were excluded. The search strategy excluded any papers primarily focussed on paediatric cohorts, though we did include several papers in which paediatric and adult populations were combined (as they could not be separated by the metadata provided in the paper). The included papers with relevant metadata are included in Appendix 3.

We excluded studies identifying 'true' PenA (confirmed by allergy testing) and those recording specific hypersensitivity reactions (such as DRESS, SJS, TEN), if these studies only tested individuals with an existing PenA label and no data were available for the non-PenA cohort.

Of note, we observed inter-study variability in the denominator against which PenA prevalence was calculated. For example, 107/125 studies (86%) used individual patients as the denominator, whilst 11/125 studies (9%), used procedure or condition (e.g. number of C-sections, surgeries, or patients with pneumonia). Six studies (5%) used hospitalisations as the denominator, and one study (1%) used emergency department presentations. For the primary analysis to calculate PenA label prevalence we included all these studies, though a sensitivity analysis on studies including the denominator 'individual patients' is shown in Appendix 7.

Data analysis

Our primary outcome was to determine the distribution and number of patients with reported PenA label in each study and the country and continent the study population originated.

Our secondary outcomes included assessment of reported PenA prevalence by i) study setting (primary versus secondary care), country income bracket (High, Middle, or Low-income country as defined by the World Bank), and method of allergy recording. Allergy recording was sub-categorised as follows; i) electronic health record systems e.g. medical records; 'EHRS', ii) 'Manual Chart Review', iii) 'Questionnaire', iv) Coding e.g. ICD-9 code and v) when the primary methodology mentioned chart review but did not ascribe this to electronic or manual we reported this as "EHRS/Chart Review", vi) where there was no mention of methodology this was marked down as "Unclear", and vii) "Other", where groups used more than one method of defining PenA labels.

The pooled prevalence of penicillin allergy and the 95% CI were calculated by applying a random-effects model (REML methodology),[17] using a double arcsine transformation.[18] This was undertaken on the "metafor" package on R studio. Heterogeneity was measured with the I^2 statistic. A sensitivity analysis was conducted stratifying prevalence by mode of data collection, continent/country, country income and primary care/secondary care.

Results

428 out of 18,352 studies identified in the search were reviewed in full. These included full-text articles and conference abstracts. 174 out of 428 studies (full text and abstracts), originating from 28 countries, included a reported PenA prevalence (Fig. 1).

Within 174 studies, 181 separate populations were represented, given some publications included multiple locations (Fig. 2). More than half were from North America (n= 106), followed by Europe (n=48), Oceania (n=20), Asia (n=5), Africa (n=1) and South America (n=1). The USA (n=95) represented 52% of populations, followed by the UK (n=18), and Australia (n=18) (Table 1). We completed an additional analysis with a similar heat map in Appendix 8 which included pan beta-lactam allergy.

Reported PenA label prevalence

PenA label prevalence was derived from 124 full text articles (including letters and research notes; Table 1). We excluded six studies in which cohorts from the same site, similar authors and had overlapping time windows, to avoid the potential for duplicate counting. Two studies[19,20] had sample populations from more than one country, and we have treated these as independent samples. Thus, we included 118 studies, representing 125 patient populations with documented PenA label prevalence (Table 2).

Country prevalence varied from 0·16% (Latvia) to 12% (USA). This highlighted the heterogeneity in the type and quality of studies, outcomes, populations sampled and how penicillin allergy labels were found.

High income vs low- or middle-income countries

The vast majority of populations (115/125; 92%) were conducted in HICs, whilst the remainder derived from middle-income

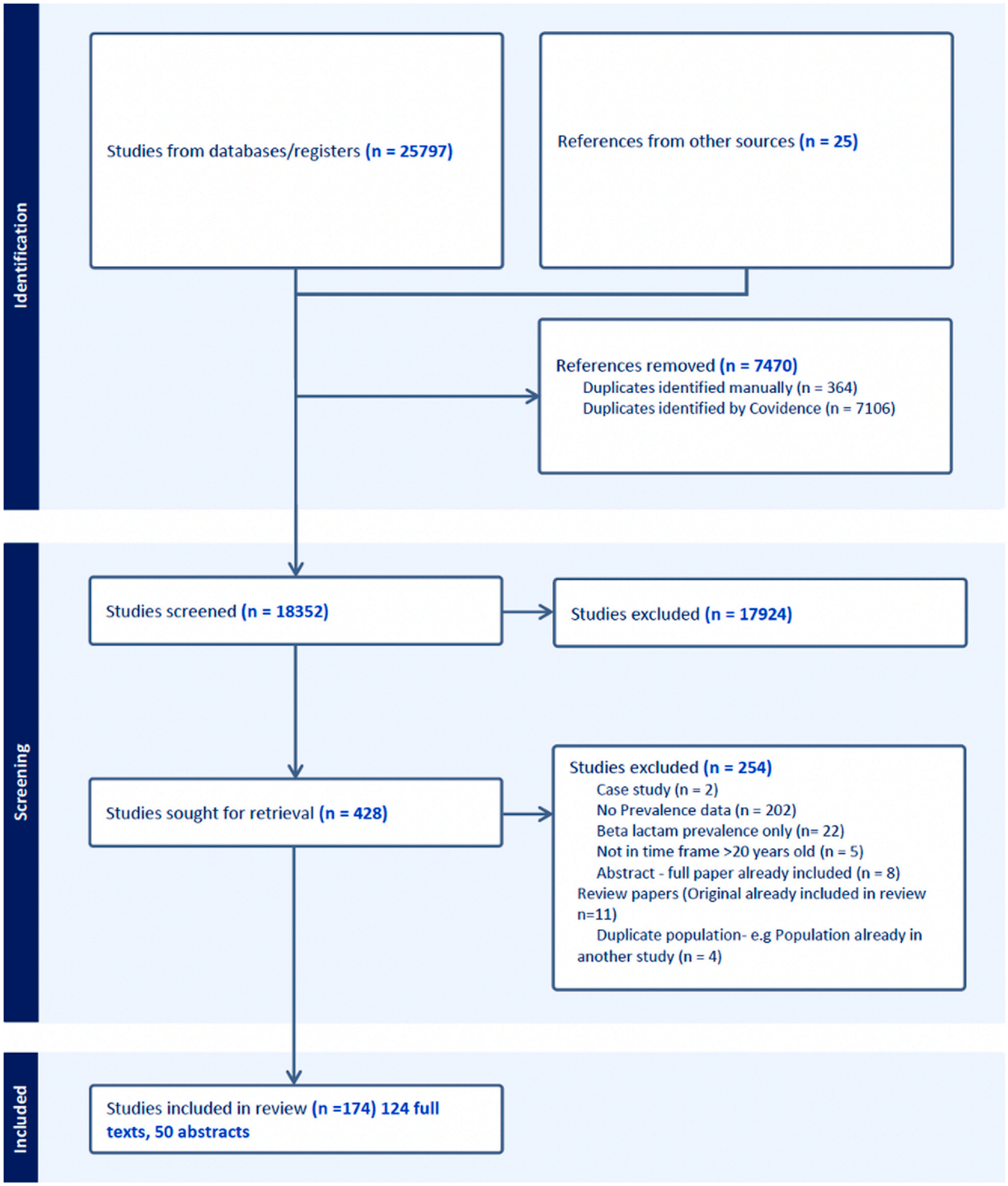

Fig. 1. PRISMA Flow diagram.

countries MICs (10/125; 8%). Among the MICs, Pakistan represented the only low-middle-income country (LMIC) for which penicillin allergy prevalence data were available. The rest of the data from MICs represented upper-middle-income countries. We could not find any studies from LICs that reported penicillin allergy prevalence.

When comparing prevalence rates, HICs exhibited significantly higher rates, with a prevalence of 9.9% (95% CI 8.8–11.0%), compared to MICs 4.4% (95% CI 2.8–6.2%), $p < 0.0001$.

Primary care vs secondary care

Data on penicillin allergy prevalence is highly skewed towards hospitalised rather than community cohorts (Table 2). Of 125 populations evaluated, only four were exclusively in primary care with a further 16 including mixed primary and secondary care populations. Nevertheless, comparison across healthcare settings demonstrated lower estimated prevalence in primary 6·5% (95% CI 0·2–20·5%) versus secondary care 10·2% (95% CI 9·2–11·3), $p < 0.0001$.

Fig. 2. Global distribution and number of studies where PenA label reported. Heat maps show number of studies (including abstracts) where PenA prevalence is reported.

Table 1
PenA prevalence studies by geographical location.

		Penicillin Allergy abstracts and full texts	Penicillin allergy full text only
Total number studies		174	124
Total sample populations		181	131
Continent/Country			
North America			
	USA[a]	95	63
	Canada	8	7
	Mexico	3	3
Europe			
	UK[a]	18	10
	Spain	5	3
	France	4	3
	Netherlands	3	2
	Portugal	2	2
	Belgium	2	2
	Denmark	2	2
	Norway[a]	2	2
	Turkey	1	1
	Estonia[a]	1	1
	Finland	1	1
	Hungary	1	0
	Ireland	1	0
	Italy[a]	1	1
	Latvia[a]	1	1
	Russia[a]	1	1
	Slovenia[a]	1	1
	Switzerland	1	1
Oceania			
	Australia	18	14
	New Zealand	2	1
Asia			
	China	3	3
	Saudi Arabia	1	1
	Pakistan	1	1
Africa			
	South Africa	1	1
South America			
	Colombia	1	1

[a] Country includes a study which included multiple populations in one study.

We noted that studies used different methods to define PenA labels (Table 3). The most common method of defining whether a patient was allergic was to use the allergy tab within their electronic health record system (EHRS) or a combination of EHRS and chart review of individual electronic records. This group comprised instances where EHRS was explicitly mentioned as the source of PenA labels, "EHRS" or where it was likely involved, "EHRS/Chart review", this included 75/125 (60%) study populations. We analysed the "EHRS" and "EHRS/Chart review" groups together and found a pooled prevalence of 11·3%(95%CI;10·3–12·4%).

Other methods included:

1. Questionnaire: Surveys taken directly from patients and therefore representative of how the patient labelled themselves, this was through manual/electronic/postal assessment, they had a pooled prevalence of 9·1% (CI 6·7-11·8%); n=22 study populations.
2. Manual chart review: Reviewing/auditing patients physical drug chart or medical notes, which was only used in five studies, showing a pooled prevalence result of 13·9% (CI 6·7-11·8%).
3. Coded data: Ten studies used exclusively coded data to define PenA labels, this included, ICD-9, ICD-10, ICPC codes and READ codes. In these studies, the pooled prevalence was lower than other methods 2·68% (95%CI; 1·6-4·0%).
4. Other methods: Studies where more than one method was used were defined as "Other", there were only one of these and therefore we excluded them from this sub analysis.
5. Unclear: Studies where we could not delineate the methodology into the above groups were put down as unclear and were excluded.

When comparing papers with coded data (which had the highest number of patient episodes n= 75,889,384 episodes) to those using EHRS (the most common method, n=20,456,029 episodes) there was a significant difference in the prevalence values ($p < 0.0001$, 95% CI: 8·76–8·78%).

Heterogeneity

The majority of analyses had an I^2 value of greater than 95%, see Table 2; this reflects the broad number of study settings,

Table 2
Prevalence of penicillin allergy by continent, country, income and setting.

Group	Country	Income Economies	Study population	Total population	Penicillin allergy label	Prevalence (% with 95%CI)	I^2 (%)
North America			70	43,219,562	2,970,556	11·5 (10·3–12·8%)	100
	USA[a]	High	61	43,093,145	2,960,093	12·0(10·7–13·4%)	100
	Canada	High	6	124,610	10,352	10·0(7·4–13·0%)	97
	Mexico	Upper Middle Income	3	1807	111	5·4(1·6–11·1%)	66·9
Europe			33	52,942,260	1,313,480	5·7(4·1–7·4%)	100
	UK[a]	High	9	3,103,268	192,835	11·3(7·9–15·2%)	
	France	High	3	2226	178	7·8(4·4–11·9%)	59·7
	Netherlands	High	2	214,399	2264	2·5(0–85·0%)	99·9
	Spain	High	3	36,867,335	981,797	3·6(1·5–6·5%)	98·2
	Portugal	High	2	11,482,771	10,2912	2·8(0·0–82·0%)	98·4
	Belgium	High	2	1,011,096	22,993	5·9(0–100%)	99·5
	Denmark	High	2	1961	135	7·3(0–58·9%)	94
	Norway[a]	High	2	6190	285	4·6(3·3–6·1%)	0
	Turkey	Upper Middle Income	1	1267	22	1·7(1·1–2·6%)	N/A
	Estonia[a]	High	1	51,936	1320	2·5(2·4–2·7%)	N/A
	Finland	High	1	211	23	10·9(7·0–15·9%)	N/A
	Italy [a]	High	1	1749	7	0·4(0·02–0·08%)	N/A
	Latvia[a]	High	1	572	9	0·2(0·07–0·03%)	N/A
	Russia[a]	High	1	2763	53	1·9(1·4–2·5%)	N/A
	Slovenia[a]	High	1	2272	57	2·5(1·9–3·2%)	N/A
	Switzerland		1	192,244	8590	4·5(4·4–4·6%)	N/A
Oceania		High	15	151,607	10,780	11·0(9·0–13·1%)	99·1
	Australia	High	14	149,072	10,506	11·1(8·9–13·3%)	99·1
	New Zealand	High	1	2535	274	10·8(9·6–12·1%)	N/A
Asia			5	173,794	8147	5·5(1·8–10·9%)	99·5
	China	Upper Middle Income	3	171,472	7951	6·1(1·7–12·9%)	99·7
	Saudi Arabia	High	1	2022	193	9·6(8·3–10·9%)	NA
	Pakistan	Low Middle Income	1	3	300	1·0(0·2–2·9%)	NA
Africa							
	South Africa	Upper Middle Income	1	48	1166	4·1(3·1–5·4%)	NA
South America							
	Colombia	Upper Middle Income	1	60,978	2479	4·1(3·9–4·2%)	NA
Low/Upper MIC		Middle income	10	236,990	10,614	4·4(2·8–6·2%)	98·8
High Income countries		High income	115	96,312,377	4,294,876	9·9(8·8–11·0%)	100
Primary Care			4	174,985	2,780,916	6·5(0·2–20·5%)	100
Secondary Care			105	4,061,802	92,820,154	10·2 (9·2–11·3%)	100
Mixed Care			16	948,297	68,703	5·1(2·7–8·1%)	99·9
World			125	96,549,367	4,305,490	9·4(8·4–10·4%)	100

In the included peer-reviewed studies, worldwide pooled prevalence of PenA prevalence was 9·4% (95% CI; 8·4-10·4%). Most populations included in our meta-analysis were from North America, of which the USA contributed the most (n=61), Europe (n=33), Oceania n=15 (Australia n=14), Asia (n=5), African (n=1) and South America (n=1).
[a] Country includes a study which included multiple populations in one study.

Table 3
Recording of PenA labels.

	Number of populations	Prevalence (%)
EHRS	61	11·3
EHRS/Chart review	14	95%CI(10·3–12·4%)
Manual Chart review	5	13.9 95%CI (10·0–18·3%)
Questionnaire	22	9·1 95% CI (6·7–11·8%)
Coded- ICD-9/10 codes	8	2·68
Coded- ICPC codes	1	95% CI(1·6–4·0%)
Coded- READ codes	1	
Other	1	
Unclear	12	

populations, methodologies, and the general tendency of prevalence studies to have high heterogeneity. This is not unexpected as a review of prevalence meta-analysis illustrated the median I^2 value in studies was 96·9%. This is because; i) large sample sizes in national studies will cause precise estimates with small confidence intervals (CI) meaning that when meta-analysis is performed their CI will not overlap, ii) by the nature of comparison of proportional data we observe a more diverse estimate.[21]

Discussion

This study represents the first comprehensive effort to map the distribution and prevalence of PenA labels globally. Our study highlights i) a significant gap in knowledge of prevalence in much of the world especially outside HICs ii) that prevalence estimates are determined by the methodology of recording of PenA, and iii) there are only few studies conducted in primary care.

Mapping PenA prevalence globally

We observed that the majority of studies reporting PenA labels originated from three HIC countries; USA, Australia and the UK, with over 50% of studies originating from the USA alone. Notably, as has been described previously, we found very little data from outside high-income countries,[13] and we only found a single study published from a LMIC and none from LICs. Cognisant that some studies reported on beta-lactam allergy,[22] rather than PenA specifically, we replotted a map including both PenA and beta-lactam allergy together in Appendix 8. This provided only one extra country (Albania) and 22 additional studies altogether (11 of whom were from the USA), and we observed little additional difference in the maps. As for PenA prevalence alone, large regions, including Africa and much of Asia and South America, remain with little data.

We acknowledge that focusing solely on the number of studies may not provide an accurate representation of quality of data from that region. For example, a single study from Hong Kong included close to the entire population, providing a highly accurate prevalence estimate,[22] whilst other nations, including Germany, progressed to the development of national de-labelling guidelines, despite this study not being able to find prevalence data from that

area. This may be because they rely on trends from neighbouring countries or have the prevalence data outside published studies.[23]

Estimating reported PenA prevalence

Our results align with previous estimates, with a pooled prevalence of 9·4% which range from 5–15% cited in most review articles and published papers.[3,24,25] We found prevalence varied dependent on i) country income bracket ii) methodology of recording allergies and iii) healthcare setting.

Prevalence by income of country and geography

We found that LMICs had lower prevalence rates compared to HICs, with no data from LICs. It may be that PenA labels might have a lower burden in LMICs or certain continents (e.g. Africa, Asia, South America) and therefore are less researched or reported on. In support of this, the sole publication from Africa was from South Africa by *Day et al.* illustrated a prevalence of PenA labels of 4.12%,[26] whilst a study in Chinese patients reported prevalence of beta-lactam allergy labels of 2.0% with a sample size of over 7 million.[27] Similarly, research in Vellore, India noted an overall antibiotic allergy label of 3% implying a lower rate of reported PenA.[28] These studies indicate potentially lower prevalence rates outside Western HICs. However, with so few studies from these areas, expansion of data is critical, prior to drawing further conclusions.

Whilst we did not specifically analyse English-speaking countries as a single group, we observed that HICs where English is the primary language (such as the UK, USA, Australia, and Canada) had prevalence levels of 10% or higher. In contrast, no other countries reached this level. Based on these observations, we speculate that reported PenA may be influenced by language, ethnicity, or cultural factors (e.g. how patients or healthcare professionals report allergy as opposed to adverse drug reactions in certain settings).

Methodology of Pen A Label recording

Within our dataset, we highlight several potential variables that drive variance in reporting or documentation of allergy status, principle among them is the method of documentation, which is lower when data are extracted from datasets using coding e.g. ICD-10, rather than data from specific allergy modules of the EHRS or manual chart review/questionnaires. This has been described in the literature before, where coding may not be completed as comprehensively as a chart that may be used for direct care.[29] We reason this maybe because EHRS/manual charts are used for direct patient care and therefore are completed and reviewed regularly.

In addition, we theorise lower prevalence in coded data is partially attributable to the fact that free text entries in records are not captured in coded format.[30] For instance, *Krebs et al.* observed[20] significant differences in reported PenA prevalence between Estonia and the UK. In Estonia, using ICD codes alone, the prevalence was 0·01%, however upon further investigation using ATC codes and searching for "penicillin allergy" in free text fields of EHRS, the prevalence increased to 2.5%.[20] Moreover, the UK reported a prevalence of 15,782/386,564 (4·08%) patients using ICD codes and 139,437/ 2,350,803 (5·93%) using READ codes.[20,25] These differences in prevalence illustrate the variance both in between different coding systems (e.g. READ vs ICD) and different methodologies (e.g. EHRS, Coding, free text etc), and highlight the importance of using the correct coding system dependent on country sampled.

These findings underscore the impact of methodology on reported prevalence rates and emphasise the importance of using appropriate data collection methods specific to each country's healthcare system. We prefer the use of EHRS or manual chart review/questionnaires to measure prevalence, as these records directly influence patient care and are likely to affect prescribing and physician behaviour and therefore should be more accurate.

Healthcare setting

Our data highlight that prevalence varies significantly by healthcare setting, with few studies from primary care. Possible explanations are (i) data is readily available in the EHRS of hospitals (ii) PenA being managed by secondary care physicians (e.g. allergists) and (iii) a large number of studies were looking at the effect of PenA on surgical outcomes (n= 28/124 studies; see Appendix 6 for groupings) (iv) that certain countries have less primary care than secondary care and are seen directly by specialities.

However, given the significant number of antibiotics prescribed in primary care, our data illustrate that primary care is underrepresented in the literature. Efforts to prevent unnecessary labelling or to remove incorrect labels, once applied in primary care, should be prioritised. This shift in focus could potentially lead to more effective strategies for managing penicillin allergy and improving antibiotic stewardship practices.

Limitations

Our study has several important limitations. Firstly, PenA label prevalence is often not explicitly mentioned in the title or abstract of many studies, which could introduce selection bias. To minimise this, we reviewed both abstracts and peer-reviewed papers in our set time frame, covering 18,352 articles. Secondly, we included a diverse range of studies with 48 different cohorts of patients (see Appendix 6). Although this diversity presented challenges, we mitigated this with the sheer size of the number of studies included, with the majority (n=39) on general populations or patients seen by internal medicine.

The denominator for PenA label prevalence varied across studies and included hospitalisations, procedures, and admissions. We found that studies with hospitalisations had lower rates of reported PenA prevalence,[31] which is contrary to what we would expect (as we would expect patients with allergy to be hospitalised more). Despite this limitation, we believe it does not significantly affect the overall distribution of countries represented or the prevalence estimates, and we completed a sensitivity analysis of this issue which is provided in Appendix 7.

Additionally, although the inclusion criteria specified adult patients, some studies included both adults and children; removing these studies would reduce the breadth of our analysis, and in many of these texts it was implicit the majority of patients were adults.

Finally, many of these studies were conducted for other purposes, for example, one study by *Nyssen* et al., which audited H. Pylori treatment, included study populations from Russia, Slovenia, Italy, Latvia, Estonia, Norway, Spain. Although it provided the only PenA label prevalence data for some of these countries, the study was not designed to assess PenA label prevalence and therefore, the result may be less reliable.[19] Despite this, these studies offered data where none may have existed. We have completed a risk of bias assessment with the Joanna Briggs Institute assessment (see Appendix 4).

Conclusions

In summary, our study provides valuable insights into global PenA label prevalence and demonstrates the lack of data in large parts of the world, especially in LICs and LMICs. Moreover, we highlight the lack of studies from primary care settings and that the methodology of PenA recording significantly influences prevalence estimates.

Further work on understanding epidemiology of PenA labels in LICs and LMICs should be done to understand whether PenA

delabelling could form a part of stewardship activity in these settings. Differences in prevalence data may help reveal an understanding of why self-reported spurious PenA labels are so high in certain settings, and not in others.[13] More generally, work should be done in primary as well as secondary care even in HICs, especially given the number of antibiotics prescribed here.

Given, the WHO have identified that PenA de-labelling is a key part of antimicrobial stewardship activity,[8] equitable access to de-labelling programmes first requires in depth review of the baseline prevalence data to improve prescribing and reduce antimicrobial resistance worldwide.

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Author contributions

AL, GC, AWD and SD conceptualised the study. AL developed the methodology. AL, JH, MB, AL conducted data extraction and curation. AL and JH verified the underlying data. AL and SD undertook data analyses. AL and AD wrote the original draft. All authors contributed to the review. All authors had access to the data and accept responsibility for the publication.

Data availability

All data can be made available to approved researchers and enquiries should be directed to aluintel@ic.ac.uk.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at doi:10.1016/j.jinf.2025.106429.

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