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FROM GENOTYPE TO PRESCRIPTION: PHARMACIST-LED IMPLEMENTATION OF PHARMACOGENOMICS IN ROUTINE CLINICAL PRACTICE A NARRATIVE REVIEW

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ABSTRACT

Pharmacogenomic testing has a guideline base, a falling unit cost and, since 2023, one large multinational trial behind it. What it lacks is a routine delivery route. This narrative review examines the evidence that pharmacists can supply that route, drawing on implementation studies, randomised trials, economic evaluations and scoping reviews identified by structured searching in November 2026. Actionable genotypes are close to universal: 91% of 9,589 patients in one preemptive programme carried at least one, and modelling from Dutch and United Kingdom dispensing data places an actionable drug-gene interaction at 19.1-23.6% of first prescriptions for the drugs concerned. Pharmacist-led services have been shown to be feasible in hospitals, community pharmacies and primary care, with prescribers accepting 70.5-91.8% of recommendations in the better-documented programmes. Outcome evidence is thinner. The PREPARE trial (n = 6,944) reported an odds ratio of 0.70 for clinically relevant adverse drug reactions, yet the same reduction appeared in participants with no actionable result, which weakens a causal reading. Two small randomised trials of pharmacist-delivered testing against an untested comparator favour the intervention; both are open to bias from unblinded assessment, commercial involvement or short follow-up. The studies were too heterogeneous in design and endpoint to pool. The pathway loses most of its value at two points outside the pharmacist's direct control: transfer of the recommendation to the prescriber and durable recording of the result. Economic evidence supports single drug-gene tests more firmly than pharmacist-delivered panels. Routine adoption now depends on reimbursed consultation time, shared records with decision support, and a blinded, individually randomised trial of the pharmacist-led model.

Keywords: pharmacogenetics; pharmacogenomic testing; pharmacists; community pharmacy services; medication therapy management; decision support systems

1. Introduction

Adverse drug reactions fill hospital beds. In a prospective audit of 1,187 medical admissions to one English teaching hospital over a single month, 218 patients (18.4%) had an adverse drug reaction, and reactions caused or contributed to 16.5% of all admissions; the affected patients were taking a mean of 10.5 medicines against 7.8 in those without a reaction, and 40.4% of reactions were judged avoidable [1]. Inherited variation in drug-metabolising enzymes, transporters and immune genes explains part of that harm, and it is the part that can be known before the first dose is taken.

The knowledge already exists in usable form. Two guideline bodies, the Clinical Pharmacogenetics Implementation Consortium (CPIC) and the Dutch Pharmacogenetics Working Group (DPWG), publish drug-by-drug prescribing recommendations keyed to genotype [2,3]. A joint report of the Royal College of Physicians and the British Pharmacological Society in 2022 counted more than 40 medicines for which a genetic cause of variable response is established and called for testing to be embedded across the National Health Service [4]. Yet a guideline that tells a clinician what to do with a result says nothing about who orders the test, who explains it to the patient, who converts a diplotype into a dose, and who makes sure the answer is still visible when the next drug is prescribed five years later. CPIC guidance is deliberately silent on whether and whom to test [5].

That gap between a validated recommendation and a changed prescription is an implementation problem, and it is the subject of this review. The argument advanced here is that pharmacists are the profession best placed to close it, that the published record shows they can run every step of the pathway they control, and that the weakest links are the two steps they do not control: the prescriber's decision to act and the health record's capacity to remember. The review maps the delivery models that have been tested, weighs the outcome and economic evidence without overstating it, and identifies what would have to change for pharmacist-led pharmacogenomics to become ordinary practice.

2. Scope and methods

This is a narrative review, not a systematic one, and no protocol was registered. Literature was identified in November 2026 through web-based searches of PubMed-indexed and open-access sources using combinations of the terms pharmacogenomic, pharmacogenetic, pharmacist, community pharmacy, medication review, implementation, clinical decision support, cost-effectiveness and randomised trial, followed by citation tracking from recent scoping and systematic reviews. Priority was given to randomised and controlled studies, to implementation studies that reported a denominator, to economic evaluations, and to position statements from professional bodies. Oncology-specific somatic testing was excluded. Every numerical statement in the text was checked against the retrieved abstract or full text of the source cited for it.

No quantitative synthesis was attempted. The controlled studies of pharmacist-delivered testing measure different things (hospital readmissions at 60 days, depression scores at six months, patient recall of results, insurance charges over 32 months) in populations that do not belong in one average, and the only systematic review restricted to polypharmacy reached the same decision on the same grounds [6]. Where a figure in this review combines several studies, it displays their reported values side by side and does not average them.

3. How often a genotype would change a prescription

A testing service is only worth building if results are used. On that question the evidence is consistent across three countries and two methods.

The direct method is to genotype a population and count. In the Vanderbilt PREDICT programme, analysis of the first 9,589 preemptively genotyped patients found one or more actionable variants in 91% overall and in 96% of African American patients, on the basis of only five implemented drug-gene interactions; a reactive strategy of ordering each single-gene test as the relevant drug was prescribed would have generated 14,656 separate tests in the same cohort [7]. Among 200 Dutch primary care patients tested by their community pharmacist with an eight-gene panel, 90% carried at least one actionable phenotype [8].

The indirect method combines dispensing records with population phenotype frequencies. Applied to Dutch community pharmacy data for 2016, it estimated that 23.6% of 3,628,597 first prescriptions for 45 drugs involved an actionable gene-drug interaction and that 5.4% required a dose adjustment or a switch to another drug [9]. The same approach applied to a United Kingdom community pharmacy database for 2019 covered 56 drugs and nine genes: of an estimated 27,411,288 first prescriptions a year, 19.1-21.1% carried an actionable interaction and 8.6-9.1% called for an immediate change of dose or drug [10].

Two features of these numbers matter for service design. First, carrying a variant and needing a change are different events: nine in ten people carry something, but only about one new prescription in eleven to nineteen needs altering, so a service is judged on how cheaply it finds that prescription. Second, the value of a panel accrues over time. When the Dutch pilot cohort was followed up after a mean of 2.5 years, 97% of patients had received at least one further prescription for which the stored panel result was relevant, a third had received up to four, and 24.2% of those prescriptions carried an actionable interaction [11]. A single test, properly recorded, kept answering questions.

4. Why the pharmacist

The claim that pharmacists should lead is sometimes made as a matter of professional aspiration. It rests on firmer ground than that.

Pharmacists wrote one of the two guideline systems. The DPWG was established by the Royal Dutch Association for the Advancement of

Pharmacy with the stated objective of producing genotype-based dose recommendations, and by 2011 it had issued them for 53 drugs [3]. The group was formed because existing knowledge was not accessible at the two moments that matter, prescribing and dispensing, and the integration of its guidelines into the working software of Dutch clinicians preceded the community pharmacy studies carried out there [8]. In the United States, the American Society of Health-System Pharmacists has held since 2015, and restated in 2022, that pharmacists are uniquely positioned to lead the clinical application of pharmacogenomics [12,13].

The work also resembles what pharmacists already do. An early and fully described pharmacist-managed service, at St. Jude Children's Research Hospital, was modelled on and integrated with the hospital's existing clinical pharmacokinetics service: pharmacists established competency through accredited seminars, a steering committee decided which tests to adopt, and each result generated a written consult containing an interpretation and a recommendation. In 2009 the service handled 136 clinical pharmacogenetic tests [14]. Adjusting a dose to a CYP2D6 phenotype is conceptually close to adjusting it to a measured drug concentration or a creatinine clearance, and the same reasoning applies.

Position in the medicines pathway is the third argument. The community pharmacist sees every prescription regardless of which prescriber wrote it and is therefore the only clinician with a complete view of the drug list against which a genotype must be read. Prescribers appear to accept this. A structured review of 13 primary care studies describing eight implementation models found strong support among primary care physicians for pharmacist involvement [15], and the 2022 Royal College of Physicians report named general practitioners and pharmacists together as essential members of the multidisciplinary service it proposed [4].

None of this shows that pharmacist-led delivery produces better outcomes than physician-led delivery. No trial has compared the two.

5. Delivery models that have been tested

A 2022 scoping review of non-oncological practice identified 43 studies of pharmacists using pharmacogenomics published between 2007 and 2020. CYP2C19 testing to guide antiplatelet choice was the most studied model, and it appeared in both community and institutional settings [16]. A later scoping review confined to community pharmacy and searched to February 2025 found 17 eligible reports from the Netherlands (six), the United States (five), Canada (four), Spain and Switzerland (one each); three were randomised [17]. The models fall into four groups. Table 1 summarises the studies on which the following sections rely.

Table 1. Controlled and implementation studies of pharmacist-delivered or pharmacist-involved pharmacogenomic testing discussed in this review. Values are as reported by the cited source.

Study, country	Design and setting	Participants	Pharmacist role	Principal finding	Main limitation
Crews 2011, USA [14]	Service description; specialist paediatric hospital	136 tests in 2009	Interpretive consult with recommendation for every result	Service feasible and well received by clinicians	Descriptive; no outcomes
Bank 2019, Netherlands [8]	Prospective pilot; community pharmacies	200	Initiated eight-gene panel at first prescription; advised prescriber	31.0% of incident prescriptions had an actionable interaction; advice accepted for 88.7% of patients	Uncontrolled; 18.0% of eligible patients enrolled
Papastergiou 2017, Canada [18]	Feasibility study; two community pharmacies	100	Offered testing, interpreted report, wrote to physician	Mean 1.3 genotype-related drug therapy problems per patient	Uncontrolled; no clinical endpoint
Elliott 2017, USA [19]	Open-label pilot RCT; home health after hospital discharge	110 (57 tested, 53 untested)	Reviewed drug-drug and drug-gene interactions with decision support; advised clinicians	Readmissions at 60 days: 0.33 vs 0.70 per patient (RR 0.48, 95% CI 0.27-0.82)	Single site; test vendor funded and co-authored the study
Schwartz 2017, USA [20]	Service implementation; primary care practice	50	Medication review with decision support and testing	138 medication-related problems, 24.6% drug-gene; 90.9% of recommendations accepted	Uncontrolled; authors held interests in the decision-support vendor
Bain 2020, USA [21]	Cost analysis; elderly care programme	200 consultations	Genotype-informed consultation to practitioners	70.5% of recommendations accepted; estimated avoidance of $1,983 per participant	Modelled costs; convenience sample
Haga 2021, USA [22]	Cluster RCT; 17 community pharmacies	150	Testing alone vs testing with medication therapy management	High patient satisfaction; drug or dose changed in 8.7%	Compared two pharmacist models; no untested control
Papastergiou 2021, Canada [23]	Single-blind RCT; three community pharmacies	213 (105 guided, 108 standard)	Genotype-guided vs standard pharmacist antidepressant review	PHQ-9 fell by 5.03 vs 2.42 points over six months (interaction p = 0.04)	Prescribers and assessors unblinded
Jarvis 2022, USA [24]	Retrospective difference-in-differences; retirees aged 65 or over	5,288 enrolled vs 22,357 not enrolled	Telepharmacy medication management with decision support	Charges lower by about $218 per member per month; inpatient days down 141 per 1,000	Voluntary enrolment; vendor-employed authors
Swen 2023, seven European countries [25]	Open-label cluster-randomised crossover; 18 hospitals, 9 health centres, 28 community pharmacies	6,944	Pharmacists and physicians received 12-gene result and DPWG advice	Adverse drug reactions 21.0% vs 27.7% in actionable patients (OR 0.70, 95% CI 0.54-0.91)	Open-label, patient-reported outcome

RCT, randomised controlled trial; RR, rate ratio; OR, odds ratio; CI, confidence interval; PHQ-9, Patient Health Questionnaire-9; DPWG, Dutch Pharmacogenetics Working Group.

5.1 Hospital consult services with in-record alerts

The St. Jude programme moved from reactive consults to preemptive panel testing in 2011 and

is the best-documented example of what a mature pharmacist-run service looks like. Its distinguishing feature is that the pharmacist's interpretation does not stay in a letter. It is encoded as an interruptive alert that fires in the electronic record when a relevant drug is ordered. Over ten years, 4,783 such alerts fired across 12 genes and 60 drugs, and clinicians followed the recommendation in 4,392 of them (92%) [26]. The authors attribute the figure to team-based prescribing and collaborative alert design. It should also be read in context: this is a single specialist paediatric hospital with a decade of clinician education behind its programme, conditions that few general hospitals share.

5.2 Community pharmacy testing at the point of dispensing

In the Dutch Implementation of Pharmacogenetics into Primary Care Project, community pharmacists near Leiden offered an eight-gene, 40-variant panel to patients collecting a first prescription for one of ten drugs, chiefly statins and antidepressants. Between November 2014 and July 2016, 200 patients were enrolled. An actionable interaction was present for 31.0% of the incident prescriptions, most often SLCO1B1 with atorvastatin, and the prescriber accepted the pharmacist's recommendation for 88.7% of patients [8]. The limit of this finding is the denominator: only 18.0% of eligible patients took part.

North American studies used a different trigger. Pharmacists in two Toronto pharmacies offered a commercial multi-gene test to 100 patients as a professional service and identified a mean of 1.3 drug therapy problems per patient that were attributable to the genotype [18]. In North Carolina, a cluster-randomised trial across 17 independent pharmacies compared testing alone with testing embedded in medication therapy management in 150 patients; satisfaction was high in both arms, patients who received the fuller service recalled more of their results, and a drug or dose was changed for 8.7% of participants [22]. Only 11 of the 36 participating pharmacists (31%) had any prior education in the subject [27].

Across the community pharmacy literature the logistics are undemanding. Explaining the test takes 1-10 minutes and collecting saliva about two; laboratory turnaround is 3-14 days when samples are sent singly; 97-100% of patients in the studies that asked were satisfied [17]. The difficulty lies elsewhere, as Section 7 shows.

5.3 Medication review in older adults with polypharmacy

The largest absolute effects have been reported where testing is added to a pharmacist's review of a long drug list. In a pilot trial at one Arkansas home health agency, 110 patients aged 50 or older were randomised after hospital discharge; a study pharmacist reviewed drug-drug, drug-gene and cumulative interactions for the 57 tested patients using a commercial decision-support tool and passed recommendations to clinicians, 77% of which were followed. At 60 days the tested group had 0.33 readmissions per patient against 0.70 (rate ratio 0.48, 95% CI 0.27-0.82; p = 0.007) and 0.39 emergency visits against 0.66 (rate ratio 0.58, 95% CI 0.34-0.99; p = 0.045); the differences at 30 days were not significant [19].

One design detail gives the result more weight than its size suggests. The control group also received pharmacist-guided medication management, using a standard drug information resource, so the comparison isolates the genotype and the decision-support layer from the review itself. Against that, the trial was a single-site pilot without a power calculation or adjustment for multiple comparisons, and the testing company funded it, supplied the software and employed three of the authors.

Uncontrolled and observational work points the same way and carries the same caveat. A primary care practice that added testing to pharmacist medication review found 138 medication-related problems in 50 patients taking a mean of 12.1 drugs; 24.6% were drug-gene interactions and physicians accepted 90.9% of recommendations [20]. In the Program of All-inclusive Care for the Elderly, 158 of 429 drug-gene pairs (36.8%) were clinically actionable and 70.5% of pharmacist recommendations were accepted [21]. A 2022 systematic review of testing in multimorbidity or polypharmacy found 15 eligible studies, 12 of them completed, and noted that most relied on pharmacist-led medication management; it rated the pharmacist-led randomised trial at high risk of bias and every non-comparative study at critical risk [6].

5.4 Antidepressant selection

Psychiatry supplies the only randomised trial in which the community pharmacist was the delivering clinician and the endpoint was a symptom score. In three Ontario pharmacies, 213 outpatients with major depressive or generalised anxiety disorder were assigned to genotype-guided or standard pharmacist review of their antidepressant. Over six months the PHQ-9 fell by 5.03 points with guidance and 2.42 without (time-by-group interaction $p = 0.04$), with parallel differences in anxiety and disability scores and none in treatment satisfaction [23]. Participants were blinded. Prescribers and outcome assessors were not, and prescribers accepted 75.2% of pharmacist recommendations in the guided arm but 52.8% in the standard arm, so the trial cannot separate the pharmacological effect of a better-matched drug from the persuasive effect of a genetic report.

The larger physician-led literature urges caution. PRIME Care randomised 1,944 veterans with major depressive disorder across 22 centres. Access to results shifted prescribing sharply away from drugs with predicted interactions (odds ratio 4.32 for receiving a drug with no predicted interaction against one with a moderate or substantial interaction). Remission was more frequent over the 24 weeks as a whole (odds ratio 1.28, 95% CI 1.05-1.57), but by week 24 the groups no longer differed (risk difference 1.5%, 95% CI -2.4% to 5.3%) [28]. Prescribing changed. Durable benefit was not shown.

6. Does the pathway improve outcomes?

6.1 PREPARE

The Ubiquitous Pharmacogenomics consortium's PREPARE study is the reference point for panel testing. Between March 2017 and June 2020 it enrolled 6,944 adults starting one of a defined set of index drugs at 18 hospitals, nine community

health centres and 28 community pharmacies in Austria, Greece, Italy, the Netherlands, Slovenia, Spain and the United Kingdom. Countries were randomised to begin with genotype-guided prescribing or standard care and then crossed over. Participants were genotyped for 50 variants in 12 genes, and those with an actionable result were treated according to DPWG recommendations. Among the 1,558 patients with an actionable result for the index drug, a clinically relevant adverse drug reaction occurred within 12 weeks in 152 of 725 (21.0%) in the study group and 231 of 833 (27.7%) in the control group, an odds ratio of 0.70 (95% CI 0.54-0.91; p = 0.0075) [25]. Community pharmacies made up just over half of the 55 sites, which makes PREPARE the largest test to date of a pathway in which pharmacists received and acted on results.

The interpretation is contested, and the objection is specific. Among all patients, the odds ratio was also 0.70 (628 of 2,923 against 934 of 3,270; 95% CI 0.61-0.79). Subtracting the actionable subgroup leaves the patients whose genotype required no change and whose prescribing was therefore identical in both periods: 476 reactions among 2,198 in the study group and 703 among 2,437 in the control group, an odds ratio of 0.68 (95% CI 0.60-0.78) as calculated in correspondence on the trial [29]. Figure 1 plots the three comparisons. A treatment cannot benefit patients who did not receive it. The outcome was reported by participants who knew their allocation, and the simplest explanation for an identical effect in treated and untreated strata is that knowledge of having been tested altered what was reported. Differential loss to follow-up (11.0% in the study group, 7.9% in the control group) adds to the uncertainty.

PREPARE therefore establishes two things firmly and one thing provisionally. Panel testing with guideline-based advice can be delivered across seven health systems and three care settings, pharmacies included. Actionable results are common enough to matter. Whether acting on them prevents adverse reactions at the reported magnitude remains unproven, because the design cannot distinguish the genotype's effect from the effect of being in the tested group. The population was also narrow in ancestry: 97.7% of participants reported European, Mediterranean or Middle Eastern ethnicity [25].

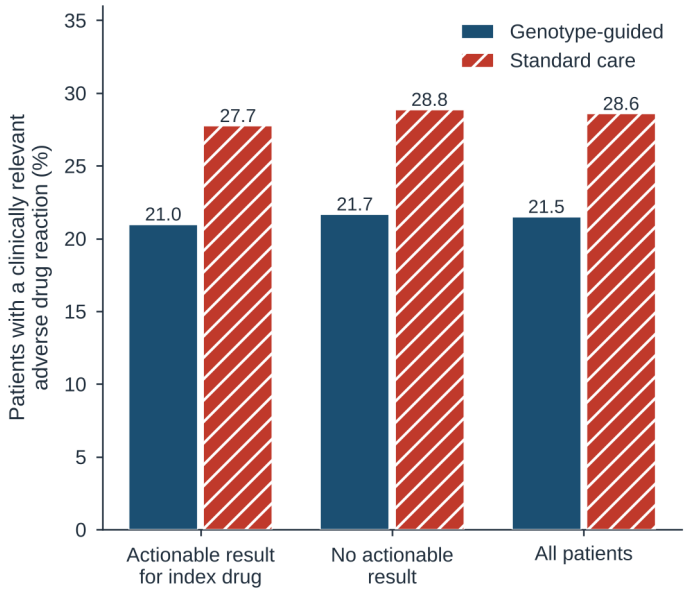


Figure 1. In PREPARE, the reduction in clinically relevant adverse drug reactions was the same whether or not the genotype changed prescribing. Bars show the percentage of patients with a reaction within 12 weeks in the genotype-guided (solid) and standard care (hatched) groups for patients with an actionable result for the index drug (152/725 vs 231/833), patients without one (476/2,198 vs 703/2,437, obtained by subtraction) and all patients (628/2,923 vs 934/3,270). No error bars are drawn because the values are single proportions; odds ratios and confidence intervals are given in the text. Data from Swen et al. [25], with the non-actionable stratum as derived by Rogers et al. [29].

6.2 Trials in which the pharmacist was the intervention

Three randomised trials place a pharmacist at the centre. The home health pilot found fewer readmissions at 60 days [19]. The Ontario trial found a larger fall in depression scores [23]. The North Carolina trial compared two pharmacist-delivered formats and had no untested arm, so it speaks to feasibility and not to effect [22]. Together the first two enrolled 323 patients. Both favoured testing, both had unblinded outcome assessment or commercially involved investigators, and neither followed patients beyond six months.

That is the whole of the randomised evidence for pharmacist-led delivery as such. It is consistent in direction and inadequate in quantity.

7. Where the pathway leaks

Figure 2 sets the six steps of a pharmacist-led pathway against what studies have measured at each. Four steps sit with the pharmacist. Two depend on others, and it is at those two that most of the value is lost.

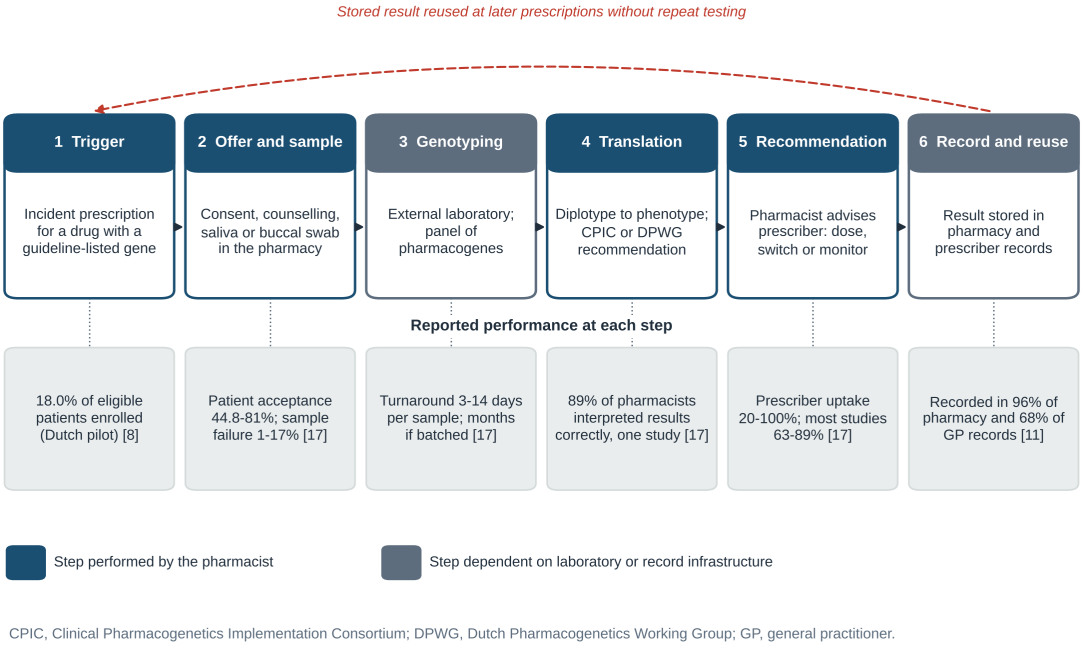


Figure 2. A pharmacist-led pharmacogenomic pathway performs well at the steps the pharmacist controls and loses most at the handoffs. Upper row: the six steps from a triggering prescription to a stored, reusable result; dark blue headers mark steps performed by the pharmacist and grey headers mark steps that depend on laboratory or record infrastructure. Lower row: performance reported for each step in implementation studies, with the source in brackets. The dashed arrow shows reuse of a stored result at later prescriptions. Percentages are ranges across studies or single-study values as labelled and are not pooled. CPIC, Clinical Pharmacogenetics Implementation Consortium; DPWG, Dutch Pharmacogenetics Working Group; GP, general practitioner.

7.1 From recommendation to prescription

A pharmacist's recommendation changes nothing until a prescriber acts on it. In community pharmacy studies, the proportion of recommendations adopted by physicians ranged from 20% to 100%, with most studies between 63% and 89%, and physicians reported low engagement with the service [17]. In the polypharmacy literature the range was 30-79% [6]. Figure 3 shows the individual values from the studies reviewed here. The highest belong to settings where the recommendation arrived inside the prescriber's own workflow, as an alert in the hospital record or from a pharmacist working in the practice, and the lowest to settings where it arrived as external correspondence.

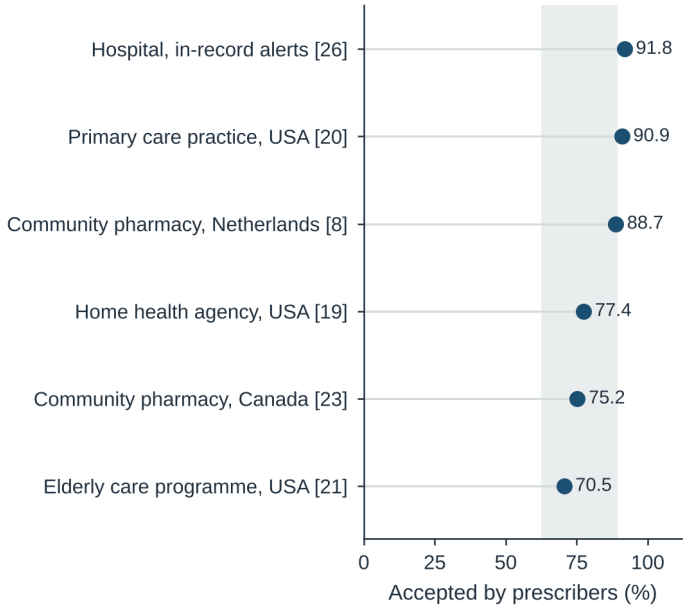


Figure 3. Prescribers accept most pharmacist pharmacogenomic recommendations, and acceptance is highest where advice is delivered inside the prescriber's workflow. Points show the percentage of recommendations accepted in six programmes, as reported by each source (reference numbers in brackets); the hospital value is clinician adherence to in-record alerts authored by the pharmacogenomics service (4,392/4,783) and the home health value is 96/124. The shaded band marks the 63-89% range within which most community pharmacy studies fell in a 2025 scoping review. Values are single proportions from studies of differing design and are not pooled; no error bars are shown.

Time compounds the problem. Obtaining prescriber approval took a mean of about 13 days (range 1-30) in the community studies, and the full cycle from offer to changed prescription ran from about a week to five or six weeks [17]. In the home health trial, therapy was changed on average about three weeks after enrolment, which the investigators offered as a reason for the absent effect at 30 days [19]. For a statin this delay is tolerable. For clopidogrel after a stent or an opioid after surgery, the drug has done its work, or failed to, before the result arrives. Reactive testing at the pharmacy counter suits chronic therapy; acute indications need the result to exist already.

7.2 From result to record

The Dutch follow-up study shows what happens to a result after the consultation ends. A mean of 2.5 years on, the panel result was recorded in 96% of pharmacy records and 68% of general practice records [11]. Nearly a third of prescribers, then, would have started a new drug with no sign that a relevant genotype was on file. Inconsistent documentation in electronic records recurs as a barrier across the community pharmacy literature, as does poor interoperability between records and decision-support tools in primary care [15,17].

The St. Jude experience suggests the remedy. Where the genotype is held as structured data and the pharmacist's interpretation is delivered as an alert at the moment of ordering, adherence

reaches 92% and the result is reused automatically for every later drug [26]. The pharmacist's expert contribution shifts from writing individual letters to authoring and maintaining the rules. Table 2 sets out the barriers by step and the responses for which there is published support.

Table 2. Barriers at each step of the pharmacist-led pathway and the responses supported by the studies reviewed.

Step	Barrier reported	Response with published support
Trigger and offer	Low enrolment of eligible patients (18.0%) [8]; no agreed eligibility criteria [15]	Embed the offer in an existing service such as medication review [20,22]
Sampling and laboratory	Sample failure 1-17%; turnaround of days to months [17]	Single-sample dispatch in place of batching [17]; preemptive panel so that results precede need [7]
Translation	Limited prior training: 31% of participating pharmacists [27]; low confidence in interpretation [30]	Competency-based training and accredited seminars [14,31]; decision support [19]
Recommendation to prescriber	Acceptance from 20% to 100%; weak prescriber engagement [17]	Pharmacist located in the practice [20]; alerts in the prescriber's record [26]
Record and reuse	Result missing from 32% of general practice records [11]; poor interoperability [15]	Structured storage with point-of-order alerts [26]
Whole pathway	No reimbursement for testing or consultation [13,17,32]	Central commissioning recommended [4]; payer-funded programmes [24]

8. Economics and reimbursement

The most complete economic synthesis covers drugs with CPIC guidelines and searched to June 2021. Of 108 evaluations spanning 39 drugs, 77 (71%) found testing cost-effective (48) or cost-saving (29), 21 (20%) found it not cost-effective and 10 (9%) were uncertain; clopidogrel was the most studied drug, with 22 of 23 analyses favourable [5]. This is strong support for particular single drug-gene tests. It is weaker support for the service under discussion here, because the evaluations largely model one test for one drug and do not cost a pharmacist's consultation, a multi-gene panel or the reuse of results over years.

Evidence specific to pharmacist-delivered panels comes from two analyses with evident limitations. In the Program of All-inclusive Care for the Elderly, modelled cost avoidance from 200 consultations was $233,945 if every recommendation was counted and $162,031 after adjustment for acceptance, a mean of $1,983 per participant [21]. In the Kentucky retirees' programme, claims data showed charges about $218 per member per month lower among 5,288 voluntary enrollees than among 22,357 non-enrollees over 32 months, reported by the authors as roughly $7,000 per patient, with 141 fewer inpatient days per 1,000 members and no significant change in emergency visits [24]. The enrollees had chosen to take part, started with higher costs and more medicines than the comparison group, and were analysed by employees of the company that supplied the decision-support system. The direction of effect is plausible. The size is not established.

Payment is the barrier named most consistently. Lack of reimbursement for the test and for the interpretive consultation appears in the community pharmacy scoping review, in the primary care review and in commentary from the United States, where payment for medication therapy management does not cover the additional time that counselling and interpretation require [13,15,17]. English pharmacists, prescribers and patients interviewed before any service existed there were receptive in principle but identified a lack of implementation resources and expected private funding to precede public commissioning [32]. Sixty-two per cent of patients were reported as willing to pay for testing themselves [17], which describes a market and not a health service.

9. Workforce readiness

A systematic review of 52 studies from 26 countries, representing 12,430 pharmacists and pharmacy students, found the same pattern almost everywhere: attitudes strongly positive, knowledge inadequate, confidence in using or interpreting results low, and a strong wish for more education [30]. The profession wants the role and does not yet feel equipped for it.

Three observations temper the pessimism. Performance in service is better than self-rated confidence would predict; in one community study 89% of pharmacists interpreted results correctly [17]. Training works when it is structured, as the St. Jude competency programme showed at the outset [14]. And a competency framework exists: the core pharmacist competencies in genomics were updated in 2021 by the pharmacogenomics special interest group of the American Association of Colleges of Pharmacy to reflect pharmacist-led clinical services [31]. What the literature does not contain is evidence on how much training is enough, or on whether decision support can substitute for it. The home health trial, in which one study pharmacist working with software was associated with a halving of readmissions, hints that the software carries much of the load [19].

10. Who has been studied

Nearly all of the evidence reviewed here comes from the Netherlands, the United States, Canada and the United Kingdom, and PREPARE drew 97.7% of its participants from a narrow range of ancestries [25]. Allele frequencies differ between populations; the Vanderbilt data showed a higher actionable fraction in African American patients than in the cohort overall on the same five gene-drug pairs [7]. Panels and guidelines validated in European populations may miss variants that matter elsewhere.

India illustrates the consequence. A 2025 scoping review that set out to catalogue actionable variants for Indian practice identified 24 genes relevant to the outcomes of 57 drugs and named three obstacles to adoption: lack of population-specific data, lack of evidence-based guidelines, and difficulty in interpreting genomic reports [33]. The third is the pharmacist's task in any system. The first two must be solved before a pharmacist-led model built in Leiden or Memphis can be transplanted, and no

implementation study from a low- or middle-income setting was found in the searches for this review.

11. Critical appraisal

The weight of evidence supports four statements.

Actionable drug-gene interactions are frequent in ordinary prescribing, at roughly one in five first prescriptions for the drugs concerned, with a change of drug or dose indicated in 5-9% [9,10]. Pharmacists can deliver every technical step of testing in hospital, community and primary care settings to the satisfaction of patients [16,17]. Prescribers accept the majority of pharmacist recommendations, and accept more of them when advice is integrated into their own records [20,26]. Stored panel results are reused [11].

The evidence does not yet support a fifth statement, that pharmacist-led testing improves patient outcomes. The single large trial has an internal inconsistency that an open-label design cannot resolve [25,29]. The pharmacist-specific trials are small, short and exposed to bias [19,23]. The economic case for the service, as distinct from the test, depends on modelled or self-selected data [21,24].

Several weaknesses run through the literature as a whole. Commercial involvement is common: test or software vendors funded, supplied or co-authored at least three of the studies in Table 1. Denominators are often missing, so adoption is overstated; where one was reported, fewer than one in five eligible patients enrolled [8]. Endpoints are process measures far more often than clinical ones. And publication bias is probable in a field where feasibility pilots with disappointing uptake have little route to print.

This review has limits of its own. It is narrative, the search was not exhaustive and was conducted by web-based querying without a registered protocol, and several sources were read at abstract level only. Studies were not pooled, for the reasons given in Section 2. The conclusions should be read as an argued interpretation of the principal studies and not as an estimate of effect.

12. What should happen next

The decisive study is a trial that removes the ambiguity PREPARE left. It should randomise individuals, test everyone at baseline, and withhold the result from patient and clinician in the control arm so that both groups know they have been genotyped and neither knows which arm they are in until follow-up ends. The intervention should be the full pharmacist-led pathway with advice delivered into the prescriber's record. The primary outcome should be ascertained from records or by blinded assessors, and analysis should prespecify the comparison between actionable and non-actionable strata, since an effect confined to the former is the signature of a true pharmacogenetic benefit. Twelve weeks is too short for a panel whose value accrues with each later prescription; follow-up of at least a year, with reuse of results as a secondary outcome, would match the mechanism.

Two questions can be answered sooner and more cheaply. A head-to-head comparison of delivery routes for the same recommendation (letter,

pharmacist in practice, in-record alert) would show how much of the acceptance gap in Figure 3 is caused by the route and not the setting. And an economic evaluation that costs the pharmacist's time, the panel and multi-year reuse from a payer's perspective would replace the modelled figures on which commissioning arguments now rest.

Outside Europe and North America, the prior need is population data and locally validated guidance, as the Indian review makes plain [33]. Pharmacist training in interpretation can proceed in parallel, because that competency does not depend on which variants a panel includes.

13. Conclusion

Pharmacists helped write the guidelines, built the first clinical services, and have shown in at least five countries that they can offer, interpret and communicate pharmacogenomic tests. Feasibility is not the open question. The pathway underperforms where the pharmacist's advice has to cross into someone else's workflow and where the result has to survive in someone else's record, and both failures have a demonstrated technical remedy in structured storage and point-of-order alerts. Proof that the pharmacist-led pathway improves outcomes, and at what cost, awaits a blinded trial. Until it reports, the defensible position is that pharmacist-led pharmacogenomics is ready to be commissioned as an evaluated service and not yet ready to be assumed as a proven one.

Declarations

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Abbreviations. CPIC, Clinical Pharmacogenetics Implementation Consortium; DPWG, Dutch Pharmacogenetics Working Group; PHQ-9, Patient Health Questionnaire-9; RCT, randomised controlled trial.

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