PHARMACY

Digital Health and Telepharmacy: Transforming Patient-Centered Pharmacy Services – A Scenario-Based Microsimulation Study

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Abstract

Background: Digital health and telepharmacy may extend pharmacists' capacity to provide medication review, counselling, adherence support and follow-up beyond conventional face-to-face settings. However, the effects of implementation depend on service design, access, digital capability and the clinical context. A transparent scenario-based model can illustrate how plausible changes in service delivery assumptions translate into population-level outcomes, while making clear that model outputs are not observed effects.

Objective: To construct a reproducible microsimulation comparing a hypothetical usual-care pathway with a hypothetical telepharmacy-enabled pathway for adults with long-term conditions, and to quantify the consequences of prespecified assumptions for medication adherence, drug-related problems, missed follow-up and patient satisfaction.

Methods: A two-strategy microsimulation generated 10,000 virtual patient records (5,000 per strategy) using a fixed random seed. The model assigned identical broad population profiles and specified outcome probabilities of 0.60 versus 0.68 for adherence, 0.18 versus 0.14 for at least one drug-related problem, 0.25 versus 0.16 for missed follow-up, and 0.65 versus 0.78 for high satisfaction in usual care and telepharmacy scenarios, respectively. These are analyst-selected illustrative assumptions, not estimates extracted from an empirical cohort. Binary outcomes were sampled from Bernoulli distributions. Absolute risk differences and approximate 95% confidence intervals were calculated; one-way sensitivity analysis varied the assumed adherence uplift from 2 to 12 percentage points.

Results: In this fixed-seed illustrative run, simulated proportions were: medication adherence 60.4% versus 66.9%, drug-related problems 17.4% versus 13.9%, missed follow-up 25.3% versus 16.4%, and high satisfaction 63.6% versus 78.7%, for usual care and telepharmacy scenarios, respectively. Because outcome probabilities were specified by the analyst, these contrasts demonstrate model mechanics and do not estimate causal treatment effects.

Conclusion: The model provides a transparent framework for exploring how assumed telepharmacy service effects could influence care-process outcomes. Its value is methodological and educational; policy or clinical decisions require parameterisation with locally relevant empirical data, validation, uncertainty analysis and prospective evaluation.

Keywords: digital health; telepharmacy; pharmacy practice; microsimulation; medication adherence; patient-centered care; scenario analysis

1 Introduction

Pharmacy practice has progressively expanded from product-focused dispensing towards a broader model of pharmaceutical care in which medication optimisation, patient education, prevention of medication-related harm and continuity of care are central responsibilities. Digital health tools including electronic health records, mobile health applications, video consultations, secure messaging, remote monitoring and clinical decision-support systems offer additional ways to organise and deliver these services. The World Health Organization's updated global strategy emphasises that digital health initiatives require coordinated governance, workforce capability, sustainable investment and interoperable technology rather than isolated deployment of applications [1,2].

Telepharmacy generally describes the delivery of pharmacy services at a distance using information and communication technologies. Depending on the jurisdiction and service model, it may include remote medication review, counselling, medication reconciliation, adherence support, monitoring, professional collaboration and supervision of dispensing-related activities. The scope of practice must remain consistent with local law, professional standards and the pharmacist's competence. Telepharmacy should therefore be understood as a mode of delivering pharmaceutical care, not as a replacement for clinical judgement or for in-person assessment when that is necessary.

A 2025 systematic review of reviews identified a range of telehealth activities in pharmacy practice, including teleconsultation, telemonitoring, telesupport and telecollaboration. The review described potential improvements in access, medication safety, adherence and patient experience, while also noting variation in interventions and outcomes [3]. More recently, a Cochrane review of telepharmacy for people with non-communicable diseases in ambulatory settings found low-certainty evidence suggesting possible improvements in medication adherence and blood pressure, while effects on some other outcomes remained uncertain [4]. These findings support cautious optimism but do not justify assuming that every digital service will produce the same benefit.

In India, national digital-health development and telemedicine policy create an important context for remote care. The national telemedicine guidance issued in 2020 established requirements for telemedicine practice, including professional accountability, consent, records, privacy and security [5]. Pharmacists designing telepharmacy services must distinguish the regulatory provisions applying to registered medical practitioners from those governing pharmacy practice, and should verify current state and national requirements before implementation. The Ayushman Bharat Digital Mission also aims to develop interoperable digital health infrastructure and health-record exchange [6].

Despite rapid technology development, service outcomes depend on more than the availability of a video platform. Digital literacy, language, connectivity, disability access, affordability, data governance, workflow integration and escalation pathways may determine whether a service is accessible and safe. A digital-first model that excludes people with limited connectivity or low digital confidence may widen rather than reduce inequity. Accordingly, telepharmacy programmes should provide alternative channels and assess outcomes across population subgroups [7].

The purpose of this paper is not to report a survey or clinical trial. Instead, it develops a scenario-based microsimulation to demonstrate how prespecified assumptions about telepharmacy could be translated into patient-level outcome distributions. Simulation is useful when the data-generating process is explicitly stated, and results are interpreted in relation to the assumptions that produced

them. Good simulation reporting requires clear specification of aims, data-generating mechanisms, estimands, methods and performance measures [8].

2 Aim and objectives

The primary aim was to build a reproducible microsimulation comparing a hypothetical usual-care pathway with a hypothetical telepharmacy-enabled pathway among adults receiving long-term medicines.

- To generate a virtual cohort with defined demographic and clinical descriptors.
- To compare scenario-assigned probabilities for medication adherence, drug-related problems, missed follow-up and high satisfaction.
- To calculate absolute differences and approximate uncertainty intervals for the simulated outcomes.
- To examine how varying the assumed absolute adherence improvement changes expected population-level adherence.
- To identify data requirements and implementation considerations for a future empirical evaluation.

3 Methods

3.1 Study design

This was a deterministic-specification, stochastic-execution microsimulation. Two hypothetical strategies were modelled: (1) usual care, representing conventional in-person or routine pharmacy access without the additional telepharmacy package; and (2) a telepharmacy scenario, representing remote pharmacist consultation, medication review, adherence support and scheduled follow-up. The model is a methodological scenario exercise and not a clinical effectiveness trial.

3.2 Virtual population

The model generated 10,000 virtual records, allocating 5,000 to each strategy. Age was sampled from a normal distribution with a mean of approximately 56 years in usual care and 55 years in the telepharmacy scenario, standard deviation 13 years, and truncation at 18 and 90 years. Sex and condition group were sampled from prespecified categorical distributions. Rural residence was assigned with probability 0.38 in both strategies. These demographic distributions are synthetic design choices and do not represent a national or regional population estimate.

3.3 Model structure and assumptions

Four binary outcomes were generated independently conditional on strategy: adherence at 12 months, at least one drug-related problem, missed follow-up and high satisfaction. The analyst-selected probabilities were 0.60, 0.18, 0.25 and 0.65, respectively, for usual care; and 0.68, 0.14, 0.16 and 0.78 for the telepharmacy scenario. The assumptions were selected to create a plausible illustrative contrast and were not fitted to patient-level source data. They should not be interpreted as expected treatment effects.

3.4 Data generation and reproducibility

A fixed pseudorandom seed (20261106) was used. Each binary outcome was sampled from a Bernoulli distribution with the probability assigned to the corresponding strategy. The full virtual dataset, code-equivalent model specification, summary workbook and figures accompany this manuscript. Re-running the model with the same random-number generator and seed should reproduce the same dataset in a compatible software environment.

3.5 Outcomes and estimands

The estimand for each binary outcome was the difference in simulated proportions between the telepharmacy scenario and usual care. For beneficial outcomes (adherence and high satisfaction), positive differences favour the telepharmacy scenario. For adverse process outcomes (drug-related problems and missed follow-up), negative differences favour the telepharmacy scenario. These are descriptive contrasts between two generated distributions, not causal estimates.

3.6 Statistical analysis

Proportions were calculated as event counts divided by 5,000 within each strategy. Approximate 95% confidence intervals for each proportion were calculated using the normal approximation. The risk difference was calculated as p_telepharmacy minus p_usual care, with a Wald-type 95% confidence interval based on the independent-binomial standard error. These intervals quantify Monte Carlo sampling variation in the generated cohort under the specified probabilities; they do not quantify uncertainty about whether the assumptions are true. One-way sensitivity analysis varied the absolute adherence uplift from 2 to 12 percentage points above a fixed usual-care adherence probability of 60%.

3.7 Ethical considerations

No human participants, identifiable records, clinical records or biological materials were involved. The dataset is entirely synthetic. Accordingly, this computational exercise did not involve participant recruitment or collection of personal health information. Any subsequent empirical study involving patients or pharmacists would require institutional ethics review, informed consent where applicable, data-protection safeguards and prospective registration when required by the study design.

4 Results

The model generated 10,000 virtual records, with 5,000 records in each strategy (Table 1). The distribution of outcomes reflects the input probabilities and random sampling variation (Table 2 and Figures 1 and 2). The numerical results below are outputs of this specified simulation run only.

Table 1. Simulated characteristics of the virtual cohort.

Strategy	N	Age, mean ± SD (years)	Female, n (%)	Rural residence, n (%)
Usual care	5,000	55.8 ± 12.9	2598 (52.0%)	1912 (38.2%)
Telepharmacy scenario	5,000	55.0 ± 12.8	2539 (50.8%)	1868 (37.4%)

All records are synthetic; distributions were specified for model illustration.

Table 2. Simulated outcome frequencies by strategy.

Outcome	Usual care, events	Usual care, %	Telepharmacy, events	Telepharmacy, %
Medication adherence	3,021	60.42	3,345	66.90
At least one drug-related problem	870	17.40	694	13.88
Missed follow-up	1,267	25.34	822	16.44
High satisfaction	3,178	63.56	3,935	78.70

Percentages are based on 5,000 virtual records per strategy.

The absolute risk differences and risk ratios are given in Table 3.

Table 3. Simulated absolute risk differences and risk ratios.

Outcome	RD (percentage points)	RD 95% CI, lower	RD 95% CI, upper	Risk ratio
Medication adherence	6.48	4.60	8.36	1.11
At least one drug-related problem	−3.52	−4.94	−2.10	0.80
Missed follow-up	−8.90	−10.48	−7.32	0.65
High satisfaction	15.14	13.39	16.89	1.24

RD, risk difference (telepharmacy scenario minus usual care); CI, confidence interval. Confidence intervals reflect binomial sampling variation under the assumed probabilities only.

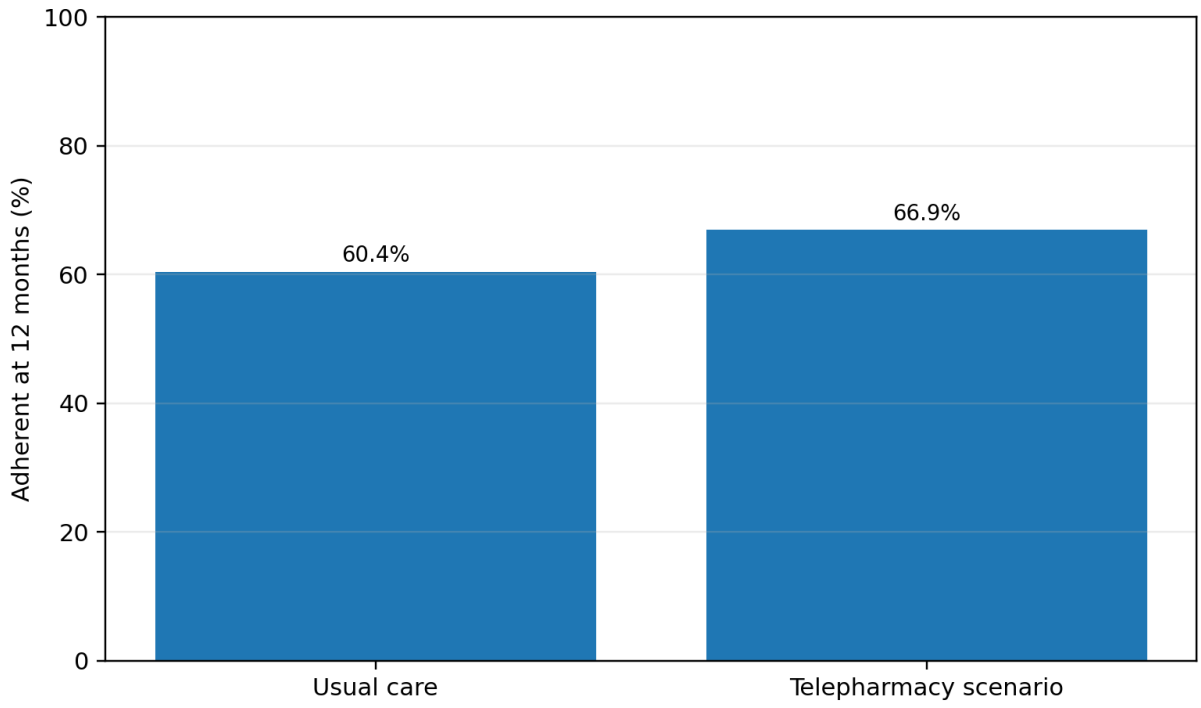


Figure 1. Simulated proportion classified as adherent at 12 months in each strategy.

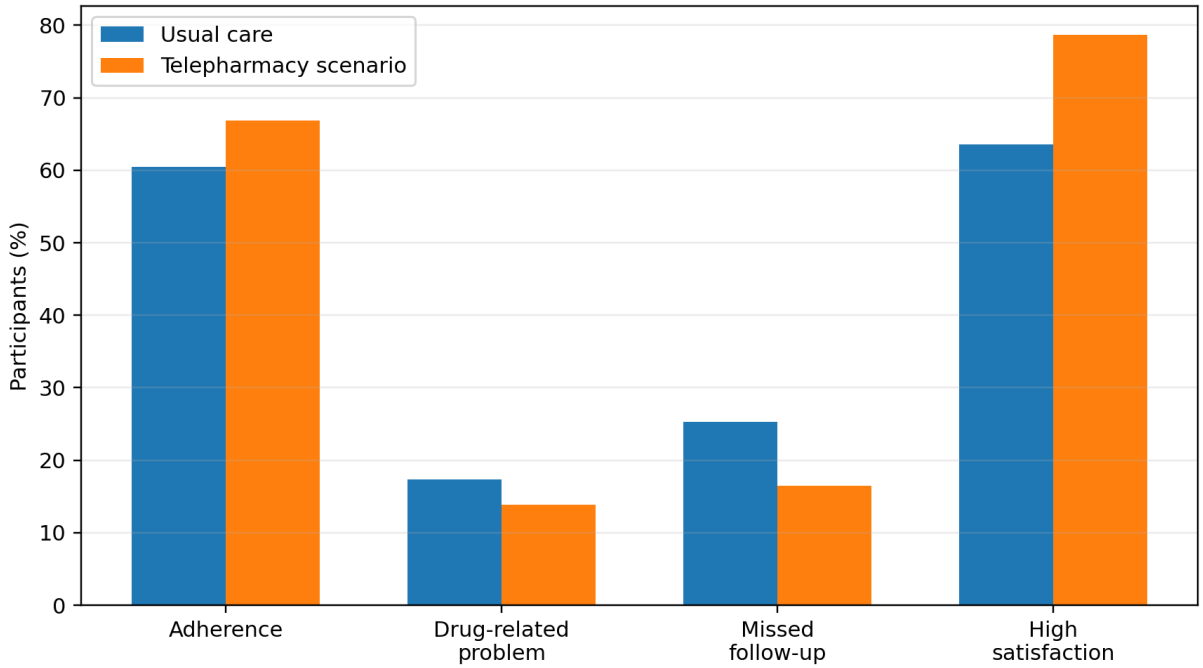


Figure 2. Simulated distribution of four modelled outcomes by strategy.

4.1 Sensitivity analysis

The results of the one-way sensitivity analysis are given in Table 4 and Figure 3.

Table 4. One-way sensitivity analysis for assumed adherence uplift.

Assumed absolute adherence uplift (percentage points)	Usual-care adherence probability	Telepharmacy adherence probability	Expected additional adherent patients per 1,000
2.0	0.60	0.62	20.0
4.0	0.60	0.64	40.0
6.0	0.60	0.66	60.0
8.0	0.60	0.68	80.0
10.0	0.60	0.70	100.0
12.0	0.60	0.72	120.0

Usual-care adherence probability fixed at 60%; telepharmacy probability varied from 62% to 72%. Values are expected proportions, not observed data.

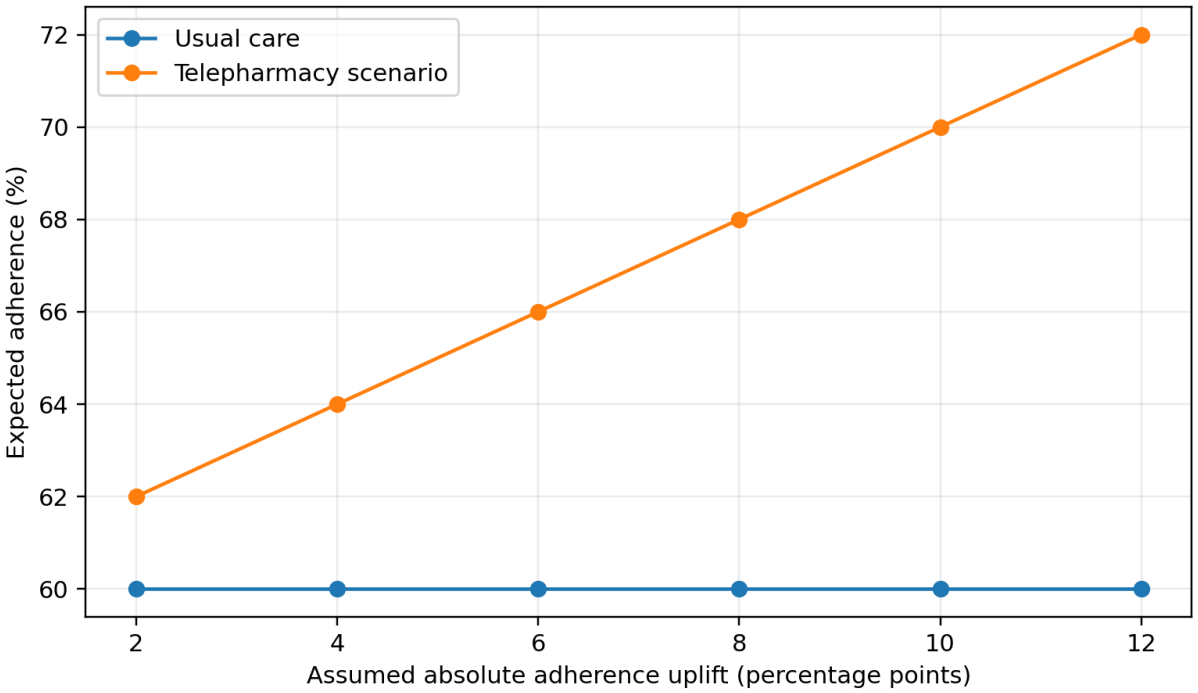


Figure 3. Sensitivity of expected adherence to the assumed absolute telepharmacy uplift.

4.2 Proposed service workflow

The proposed workflow (Figure 4) begins with identifying patients who may benefit from remote pharmaceutical care, followed by identity verification and consent, remote consultation, medication reconciliation, review of adherence and medicine-related concerns, and documentation. Pharmacists should use predefined escalation criteria for red-flag symptoms, suspected serious adverse reactions, complex clinical deterioration or needs that cannot be safely addressed remotely. The patient should be directed to an appropriate prescriber or urgent service when indicated.

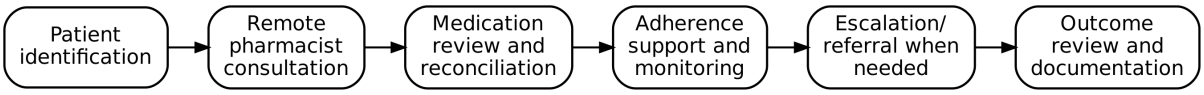


Figure 4. Proposed patient-centred telepharmacy workflow; this is a conceptual service model, not a tested intervention.

5 Discussion

This microsimulation illustrates how explicit assumptions about telepharmacy can be translated into a virtual cohort and a set of interpretable process outcomes. Under the selected scenario inputs, the telepharmacy pathway produced a higher simulated adherence proportion and a higher satisfaction proportion, and lower simulated proportions of drug-related problems and missed follow-up. These outputs are expected consequences of the probabilities assigned to the telepharmacy arm. They should not be described as evidence that telepharmacy actually causes these improvements.

The model is consistent in direction with the possibility of benefit described in recent evidence syntheses, but the distinction between consistency and validation is essential. The 2025 systematic review of reviews found that pharmacy telehealth interventions include a wide range of consultation, monitoring, support and collaboration activities, making it difficult to treat telepharmacy as a single uniform intervention [9]. The 2026 Cochrane review reported low-certainty evidence for improved

medication adherence and possible blood-pressure benefits in ambulatory patients with non-communicable diseases, while noting uncertainty for several other outcomes [10]. The probabilities used in this simulation were not estimated from those reviews and must not be presented as their findings.

A key implication is that implementation should be service-specific. A medication adherence programme for a patient with hypertension may require different workflows from a high-risk anticoagulation review, insulin education or medication reconciliation after hospital discharge. The telepharmacy service should define eligible patients, scope of pharmacist activity, documentation standards, referral thresholds, communication channels, response times and arrangements for continuity when the digital service is unavailable.

Patient-centred design is equally important. Video consultations may support visual interaction, while telephone calls may be more accessible where bandwidth is limited. Secure messaging can support reminders and asynchronous questions, but it requires clear expectations about response times and urgent symptoms. Digital services should use accessible language, support local languages where feasible, consider hearing or visual impairment, and offer a non-digital alternative. Digital exclusion can occur through lack of smartphones, data costs, low literacy, poor connectivity or limited confidence in online services.

Interoperability is another major determinant of quality. Pharmacists need access, where lawfully authorised, to sufficiently complete medication lists, allergy information, diagnoses, laboratory results and relevant discharge summaries. Fragmented records can increase reconciliation errors and duplicate therapy. India's digital-health ecosystem provides an opportunity to improve continuity, but practical benefits depend on adoption, consent architecture, data quality, technical interoperability and the availability of trained personnel [11].

Privacy and cybersecurity must be designed into the service rather than added after implementation. Telepharmacy platforms should apply role-based access, authentication, encryption, secure storage, audit trails, data minimisation and documented retention policies. Patients should understand what information is collected, why it is needed, who may access it and how it may be shared. The Indian telemedicine guidance highlights the importance of consent, records, privacy and security for telemedicine practice [12]; pharmacy service operators should also assess the current data-protection and professional requirements applicable to their activities.

The proposed workflow places medication review and escalation at the centre of the service. Remote access must not encourage pharmacists to work beyond their scope or delay referral. A safe service needs clear pathways for suspected adverse drug reactions, medication errors, therapeutic failure, acute deterioration and situations requiring physical examination. It should also define how prescriptions are authenticated and how dispensing and delivery arrangements comply with applicable law.

From a research perspective, the model demonstrates the importance of separating parameter uncertainty from Monte Carlo variation. Increasing the number of virtual patients would narrow sampling intervals around the specified probabilities, but it would not make the assumptions more credible. The main uncertainty is whether the assumed probabilities are appropriate for the intended population and service. A robust next-stage model should estimate parameters from local observational data or trials, incorporate correlations among outcomes, include patient heterogeneity, and conduct probabilistic sensitivity analysis.

6 Strengths and limitations

Strengths include a transparent data-generating process, a fixed random seed, a complete synthetic dataset, prespecified outcomes, clearly labelled figures and an explicit distinction between model outputs and empirical evidence. The approach is suitable for teaching, protocol development, software testing and planning future data collection.

Several limitations are substantial. First, all outcome probabilities were analyst-selected illustrative assumptions rather than estimates derived from a representative empirical dataset. Second, outcomes were generated independently, although adherence, drug-related problems, follow-up and satisfaction may be correlated in real settings. Third, the model did not include costs, health-related quality of life, hospitalisation, disease-specific biomarkers, adverse-event severity or long-term clinical endpoints. Fourth, the population profile was synthetic and not calibrated to a defined Indian state, health system or disease cohort. Fifth, the model did not account for digital access, health literacy, language, disability, platform reliability or provider workload as individual-level determinants. Finally, the approximate confidence intervals reflect random sampling within the model and must not be interpreted as confidence intervals for real-world treatment effects.

7 Future research directions

Future work should begin with a clearly defined service and target population, such as adults with hypertension receiving pharmacist-led medication review in community settings. A prospective implementation study could measure recruitment, reach, retention, consultation completion, medication discrepancies, validated adherence, blood pressure, patient-reported experience, equity outcomes and cost. A pragmatic controlled design may be appropriate after feasibility and acceptability have been established. Mixed-methods interviews could explain why patients and pharmacists adopt or discontinue the service.

A calibrated simulation could then be developed using the empirical study estimates. It should include uncertainty distributions for all key parameters, correlation structures where evidence supports them, subgroup analyses, and scenario testing for connectivity, staffing, consultation duration and service intensity. Model verification, external validation and transparent publication of code and assumptions would improve credibility [13,14].

8 Conclusion

Digital health and telepharmacy offer promising ways to extend patient-centred pharmaceutical care, particularly through remote consultation, medication review, adherence support and continuity of follow-up. This scenario-based microsimulation demonstrates a reproducible method for exploring the implications of explicitly stated assumptions. The generated results are hypothetical and do not establish clinical effectiveness. Real-world adoption should be guided by local empirical evidence, regulatory compliance, equitable access, privacy protection, professional accountability, and prospective evaluation.

Declarations

Funding: No external funding was received for this computational demonstration.

Data availability: The complete synthetic virtual dataset and analysis workbook are supplied as supplementary files. They contain no real patient or pharmacist data.

Ethics approval: Not applicable to this synthetic-data simulation because no human participants or identifiable personal data were involved. Any empirical follow-up study requires prior ethics review.

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