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Development and Preliminary Validation of a Perioperative Medication Decision Support System (PM-DSS) for Older Patients With Hip Fractures

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Abstract

Purpose

To develop a perioperative medication decision support system (PM-DSS) for older patients with hip fractures to assist in identifying medications requiring preoperative discontinuation and drug-related problems (DRPs), and to preliminarily evaluate its detection performance and workflow efficiency.

Methods

The study comprised a retrospective development phase and a prospective validation phase. During the development phase, clinical data from older patients with hip fractures were used to characterize comorbidities and medication use and to develop the PM-DSS knowledge base. Key recommendations underwent structured expert consultation. During the prospective validation phase, PM-DSS performance was evaluated against an expert-derived reference standard and compared with pharmacist review.

Results

During the development phase, 1,144 patients were included, yielding 88 expert-reviewed recommendations, including 27 on preoperative medication discontinuation and 61 related to DRPs. The validation phase included 182 patients. For identifying medications requiring preoperative discontinuation, the PM-DSS achieved a sensitivity, specificity, and F1 score of 95.00%, 100.00%, and 97.44%, respectively; the corresponding values for identifying DRPs were 64.76%, 99.20%, and 76.82%. PM-DSS processing time was significantly shorter than the time required for manual review.

Conclusion

The PM-DSS effectively supported the identification of medications requiring preoperative discontinuation and DRPs in older patients with hip fractures and significantly reduced pharmacists' review time, suggesting its potential value as a decision-support tool for perioperative medication management.

Key summary points

Aim: To develop and preliminarily validate a perioperative medication decision support system (PM-DSS) for older patients with hip fractures. **Findings:** The PM-DSS showed strong performance in identifying medications requiring preoperative discontinuation, identified drug-related problems with lower sensitivity, and substantially reduced medication review time compared with manual pharmacist review. **Message:** The PM-DSS may support more consistent and efficient perioperative medication

management in older patients with hip fractures, while individualized clinical judgment remains essential.

1 Introduction

Hip fracture is a major health problem among older adults and is associated with substantial disability, mortality, and healthcare burden [1]. With population aging, the incidence of hip fractures continues to rise, and the global number of hip fractures is projected to reach approximately 4.5 million by 2050 [2]. In China, adults aged 60 years or older accounted for 22.0% of the population by the end of 2024, with more than one million new cases of hip fracture occurring annually [3].

Hip arthroplasty is an important treatment option for older patients with hip fractures, facilitating early weight-bearing and mobilization, reducing complications, and improving quality of life and long-term outcomes [4, 5]. Hip fracture surgery is time-sensitive, and current guidelines recommend that surgery be performed within 48 hours of admission whenever possible, after necessary preoperative optimization [6]. However, older patients commonly have multimorbidity and polypharmacy, making drug-related problems (DRPs) and the need for preoperative medication discontinuation common concerns. Failure to promptly identify and address these issues may increase perioperative medication-related risks and delay surgery.

Medication reconciliation facilitates the collection of an accurate medication history and the timely identification of medications requiring discontinuation and DRPs [7]. However, manual medication review is time-consuming, and review outcomes may vary according to pharmacists' expertise. Clinical decision support systems (CDSS) can integrate patient-specific information with evidence-based rules to standardize decision-making and reduce repetitive tasks, thereby supporting perioperative medication management in older patients with hip fractures.

Existing medication-related CDSS have primarily focused on identifying DRPs, whereas tools integrating DRPs identification with preoperative medication discontinuation assessment in older patients undergoing hip fracture surgery remain limited [8, 9].

This study aimed to develop a perioperative medication decision support system (PM-DSS) for older patients with hip fractures to identify medications requiring preoperative discontinuation and DRPs and to conduct a preliminary evaluation of its detection performance and workflow efficiency.

2 Methods

2.1 Study design and PM-DSS development

This study consisted of a retrospective development phase and a prospective validation phase. During the development phase, data were retrospectively collected from patients aged ≥ 60 years with hip fractures who underwent hip arthroplasty at Northern Jiangsu People's Hospital between January 1, 2020, and December 31, 2024. Patients with incomplete or unclear demographic, comorbidity, or medication information were excluded. Common comorbidities and long-term medications were summarized to inform development of the perioperative medication decision support system (PM-DSS).

Medication recommendations were developed based on clinical guidelines, expert consensus statements, prescribing information, relevant literature, and medication-use characteristics in the development cohort. The 2023 AGS Beers Criteria® served as a major reference framework. Recommendations addressed preoperative medication discontinuation, medication use in older adults and specific clinical conditions, drug–drug interactions, and medication use in patients with impaired kidney function.

Key recommendations underwent structured expert consultation involving six clinical pharmacists, two orthopedic surgeons, and two anesthesiologists, all with ≥ 5 years of clinical experience. Experts assessed clinical relevance, and preoperative discontinuation risk was categorized according to expert agreement as high (≥ 80%), moderate (40%–79%), or low (< 40%). Expert authority was assessed using Cr = (Ca + Cs)/2, where Ca and Cs represented the coefficients for basis of judgment and familiarity, respectively. Inter-expert agreement was assessed using Gwet's AC_1.

Expert-reviewed recommendations were incorporated into the PM-DSS knowledge base. The decision engine was developed using Python and Flask. Patient-specific clinical and medication information was automatically matched against predefined rules to generate medication recommendations and alerts.

2.2 Prospective validation and performance evaluation

During the prospective validation phase, patients with hip fractures scheduled for total hip arthroplasty or hemiarthroplasty between January 1 and September 30, 2025, were screened for eligibility. Inclusion criteria were age ≥ 60 years, at least one comorbidity, long-term use of at least one medication, and complete clinical information available within 24 h of admission. Patients with missing key information, failure to undergo surgery as planned, or direct postoperative transfer to the intensive care unit were excluded.

The same 10-member expert panel established the reference standard. Each case was independently reviewed, and disagreements were resolved through consensus discussion. PM-DSS outputs were compared with the expert-derived reference standard and classified as true positive, false positive, false negative, or true negative. SN, SP, PPV, NPV, accuracy, and F1 score were calculated.

Three pharmacists—an experienced clinical pharmacist, a pharmacist with limited experience in this field, and a non-specialist pharmacist—independently reviewed the same validation cases. Their performance was compared with the same reference standard. Manual review time and PM-DSS processing time were recorded for each case.

2.3 Statistical analysis

Continuous data were summarized as mean ± standard deviation or median (interquartile range), as appropriate. Paired comparisons between PM-DSS and pharmacist review times used the Wilcoxon signed-rank test. Differences among the three pharmacists were assessed using the Friedman test. Time savings across medication-burden groups were compared using the Kruskal–Wallis test followed by Dunn's multiple-comparison test. A two-sided $P < 0.05$ was considered statistically significant.Statistical analyses were performed using SPSS 22.0.

3 Results

3.1 Patient medication characteristics

The development cohort included 1,144 patients, with a mean age of 76.37 ± 8.06 years and a male-to-female ratio of 1:2. A total of 1,755 comorbidities were recorded; cardiovascular diseases were the most common, with essential hypertension accounting for the largest proportion (Fig. 1).

Among the 2,036 medication records, cardiovascular, endocrine, and nervous system medications accounted for 56.75%, 17.85%, and 10.65%, respectively (Fig. 2).

3.2 Development of medication recommendations and expert consultation

Based primarily on the 2023 AGS Beers Criteria® [10] and adapted for perioperative medication management, the recommendations covered four areas: (1) preoperative medication discontinuation and medication use in older adults; (2) medication use in specific diseases or clinical conditions; (3) potentially clinically important drug-drug interactions that should be avoided; and (4) medications that should be avoided or require dose reduction in older adults with impaired kidney function.

The framework covered 150 medications and included 122 perioperative recommendations, 47 recommendations on medication use in older adults, 16 disease-specific recommendations, and 15 recommendations on drug–drug interactions or medication use in patients with impaired kidney function. Medications suitable for continuation were not included in the expert consultation, which instead focused on medications requiring preoperative discontinuation, medications for which discontinuation remained controversial, and clinically relevant DRPs. Of the 88 expert-reviewed recommendations, 27 addressed preoperative medication discontinuation and 61 addressed DRPs.

All 10 questionnaires were returned and deemed valid. Ca, Cs, and Cr were 0.95, 0.90, and 0.93, respectively, with a Cr of 0.93 indicating a high level of expert authority. Gwet's AC_1 was 0.70 ($P < 0.001$), indicating good overall agreement. Expert agreement was ≥ 80% for 72 recommendations, 40%-79% for 15, and < 40% for one.

3.3 Development of the PM-DSS

The PM-DSS knowledge base centered on preoperative medication discontinuation and DRPs, with additional components addressing medication use in specific disease states, drug–drug interactions, and impaired kidney function. The system comprised nine modules: patient information management, disease status management, medication identification and extraction, medication recommendation analysis, alerts for preoperative medication discontinuation and DRPs, drug–drug interaction assessment, medication use in patients with impaired kidney function, medication database management, and report generation. Patient-specific information was automatically matched against knowledge-base rules to generate medication recommendations (Fig. 3a).

Recommendations for preoperative medication discontinuation were color-coded by expert consensus-based risk category: red for high risk, orange for moderate risk, and green for low risk (Fig. 3b). Alerts related to DRPs were primarily presented as text-based prompts to minimize unnecessary interruptions and alert fatigue. The database management module enabled ongoing refinement of the knowledge base in response to updated guidelines and clinical feedback (Fig. 3c).

3.4 Validation of the PM-DSS

The validation cohort included 182 patients. At admission, 91 patients were receiving 100 medications requiring preoperative discontinuation, accounting for 17.01% of all medications evaluated. DRPs were identified in 74 patients and involved 105 medications, accounting for 17.41% of all medications evaluated. These findings suggest that both preoperative medication discontinuation and DRPs were common in this population.

The PM-DSS demonstrated strong performance in identifying medications requiring preoperative discontinuation, with an SN of 95.00%, SP of 100.00%, PPV of 100.00%, and NPV of 98.99%; no false-positive alerts occurred. The F1 score was 97.44%. Detailed results are presented in Tables 1 and Supplementary Table 1.

Table 1
Confusion matrices for preoperative medication discontinuation and DRPs

Panel A. Preoperative medication discontinuation				
		Reference standard: positive	**Reference standard: negative**	
PM-DSS	Discontinuation alert triggered (positive)	95(TP)	0(FP)	95
	Discontinuation alert not triggered (negative)	5(FN)	488(TN)	493
Total		100	488	588
Panel B. DRPs				
		Reference standard: DRPs present	Reference standard: no DRPs	Total
		DRPs present (positive)	No DRPs (negative)	
PM-DSS	DRPs alert triggered (positive)	68(TP)	4(FP)	72
	DRPs alert not triggered (negative)	37(FN)	494(TN)	531
Total		105	498	603

Note: DRPs, drug-related problems; PM-DSS, perioperative medication decision support system; TP, true positive; FP, false positive; FN, false negative; TN, true negative.

Performance in identifying DRPs was lower than that for identifying medications requiring preoperative discontinuation, with an F1 score of 76.82%. High SP and PPV indicated few false-positive alerts, whereas the relatively low SN indicated that some DRPs were missed. Detailed results are presented in Tables 1 and Supplementary Table 1.

Pharmacists 1, 2, and 3 represented an experienced clinical pharmacist, a pharmacist with limited experience in this field, and a non-specialist pharmacist, respectively. For preoperative medication discontinuation, the PM-DSS demonstrated high SN and SP and performed favorably compared with the three pharmacists. For identifying DRPs, the SN of the PM-DSS was comparable to that of the experienced clinical pharmacist and higher than that of either of the other two pharmacists (Table 2).

Table 2
Performance evaluation of the PM-DSS and clinical pharmacists in identifying preoperative medication discontinuation and DRPs

Review task	Evaluator	SN,% (95% CI)	SP,% (95% CI)	PPV,% (95% CI)	NPV,% (95% CI)
Preoperative medication discontinuation identification (n = 588)	PM-DSS	95.00 (90.7–99.3)	100.00 (99.4–100.0)	100.00 (96.2–100.0)	98.99 (97.9–100.0)
	Pharmacist 1	78.23 (69.8–86.6)	100.00 (99.4–100.0)	100.00 (95.5–100.0)	95.67 (93.7–97.7)
	Pharmacist 2	99.01 (97.1–100.0)	71.87 (67.8–76.0)	42.19 (36.0-48.4)	99.72 (99.2–100.0)
	Pharmacist 3	96.04 (92.5–99.6)	86.65 (83.4–89.9)	59.88 (52.2–67.5)	99.06 (98.0-100.0)
DRPs identification (n = 603)	PM-DSS	64.76 (55.4–74.1)	99.20 (98.4–100.0)	94.44 (88.7–100.0)	93.03 (90.8–95.3)
	Pharmacist 1	68.18 (59.3–77.0)	97.97 (96.7–99.2)	88.24 (81.0-95.5)	93.24 (91.0-95.4)
	Pharmacist 2	47.57 (37.8–57.4)	99.00 (98.1–99.9)	90.74 (82.5–99.0)	90.16 (87.6–92.7)
	Pharmacist 3	46.73 (37.0-56.5)	95.59 (93.7–97.4)	69.44 (58.5–80.4)	89.27 (86.6–92.0)

Note: CI, confidence interval; DRPs, drug-related problems; NPV, negative predictive value; PM-DSS, perioperative medication decision support system; PPV, positive predictive value; SN, sensitivity; SP, specificity.

The median manual review times for the three pharmacists ranged from 1 to 2 min per patient, compared with 0.24 min for the PM-DSS ($P < 0.05$). Use of the PM-DSS corresponded to an 80% reduction in manual review time, indicating a substantial improvement in medication review efficiency (Fig. 4a).

Time savings with the PM-DSS increased with medication burden, and this time-saving benefit was particularly evident in patients with polypharmacy (Fig. 4b)

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**For panels b1–b3, comparisons among medication-burden groups were performed using the Kruskal–Wallis test followed by Dunn's multiple-comparison test. ****$p < 0.0001$, **$p < 0.01$, *$p < 0.05$, ns not significant.

4 Discussion

The knowledge base was built on 5 years of real-world data from 1,144 older patients with hip fractures, covering both comorbidities and medication use, and was supplemented by clinical guidelines, consensus statements, prescribing information, and expert opinion. This framework was designed to support evidence-based, locally tailored perioperative medication management. Cardiovascular diseases and related medications predominated, with hypertension being the most frequent comorbidity. For antihypertensive agents such as ACEIs and ARBs, discontinuation decisions require consideration of guideline recommendations alongside blood pressure control, anesthetic risk, and surgical timing. Expert consensus was therefore used to refine the recommendations and stratify them by discontinuation risk, highlighting medications requiring greater clinical attention while supporting, rather than replacing, individualized clinical decision-making.

A distinctive feature of the PM-DSS is the integration of preoperative medication discontinuation assessment and the identification of DRPs within a single workflow. Previous systems, including PharmaCheck, EQs, and QMR, have focused primarily on identifying DRPs, whereas dedicated tools for preoperative medication discontinuation in hip fracture surgery have rarely been reported [8, 9, 11–15]. In this time-sensitive population, integrating these tasks may reduce information fragmentation and duplicate review, representing a clinically relevant application of perioperative decision support.

Preliminary validation showed that the PM-DSS achieved a high F1 score and PPV in identifying medications requiring preoperative discontinuation, indicating strong detection performance with few false-positive alerts. The lower SN of the experienced clinical pharmacist compared with the other two pharmacists may reflect greater reliance on individualized judgment incorporating blood pressure control, surgical timing, and prior medication response. In contrast, the less-experienced and non-specialist pharmacists had higher SN but lower PPV, suggesting that strict application of guideline criteria may lead to over-recommendation of medication discontinuation. By combining evidence-based rules with expert consensus, the PM-DSS may help balance SN, specificity, and alert burden. Nevertheless, final discontinuation decisions should remain individualized according to each patient's clinical circumstances.

Identifying DRPs is more complex than identifying medications requiring preoperative discontinuation because it requires integration of multiple clinical factors, including comorbidities, medications, doses, dosing frequency, therapeutic duplication, drug–drug interactions, and hepatic and renal function. The SN of the PM-DSS for identifying DRPs was comparable to that of the experienced clinical pharmacist and higher than that of either of the other two pharmacists, supporting its potential value as a decision-support tool, although some DRPs were missed. Expanding rule coverage may improve SN but may also

increase non-actionable alerts and alert fatigue. Future refinement should therefore prioritize high-risk, actionable DRPs and incorporate ongoing clinical feedback.

Previous work reported that clinical pharmacists spent an average of 43 min on admission medication review, 26 min on discharge review, and 16 min on prescription review for older patients with hip fractures [9]. In the present study, the PM-DSS substantially reduced medication review time. Because manual review becomes increasingly time-consuming with greater medication burden, whereas computerized rule matching requires relatively little additional time, the efficiency advantage of the PM-DSS was more pronounced in patients with polypharmacy.

This study has several limitations. First, Chinese patent medicines were not incorporated into the knowledge base because of their complex compositions and the lack of clear, standardized evidence regarding perioperative discontinuation; these medications therefore still require manual assessment. Second, the current rules for identifying DRPs do not fully account for individualized factors such as dose, dosing frequency, and complex drug–drug interactions, which may partly explain the lower SN for identifying DRPs than for identifying medications requiring preoperative discontinuation. Third, as a single-center system, the PM-DSS primarily reflects local patterns of comorbidities and medication use, and its applicability to other institutions and surgical populations requires external validation. Future studies should expand medication coverage, refine the rule base, and use multicenter prospective designs to evaluate effects on clinical outcomes and the quality of pharmaceutical care.

5 Conclusion

The PM-DSS supported accurate identification of medications requiring preoperative discontinuation and generated alerts for DRPs in older patients with hip fractures while substantially reducing pharmacists' review time. Further work should refine the knowledge base and decision rules, integrate the system with hospital information systems, and validate its generalizability and clinical value in multicenter studies.

Declarations

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Competing Interests The authors have no relevant financial or non-financial interests to disclose.

Ethics approval

This study was approved by the Ethics Committee of Northern Jiangsu People's Hospital (approval Nos. 2023ky199 and 2025ky061) and was conducted in accordance with the Declaration of Helsinki and its later amendments.

Consent to participate.

The requirement for informed consent was waived by the Ethics Committee for the retrospective development phase because of the retrospective nature of the study. Written or verbal informed consent to participate was obtained from all participants enrolled in the prospective validation phase.

Data availability

The datasets generated and/or analysed during the current study are not publicly available because of patient privacy and institutional restrictions but may be available from the corresponding author on reasonable request and with appropriate institutional approval.

Author Contributions Xiang Gao and Xinyuan Ban have contributed equally to this work and should be considered co-first authors. Xuan Zhang and Hua Zhu have contributed equally to this work and should be considered co-corresponding authors.Xiang Gao and Xinyuan Ban contributed to the conceptualization and design of the study, data collection, data curation, formal analysis, validation, and preparation of the original manuscript. Yibing Shi and Chunqing Liu contributed to data collection, clinical evaluation, and interpretation of the results. Xuan Zhang and Hua Zhu contributed to study conceptualization, methodology, supervision, and critical revision of the manuscript. All authors reviewed and approved the final manuscript.

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Figures

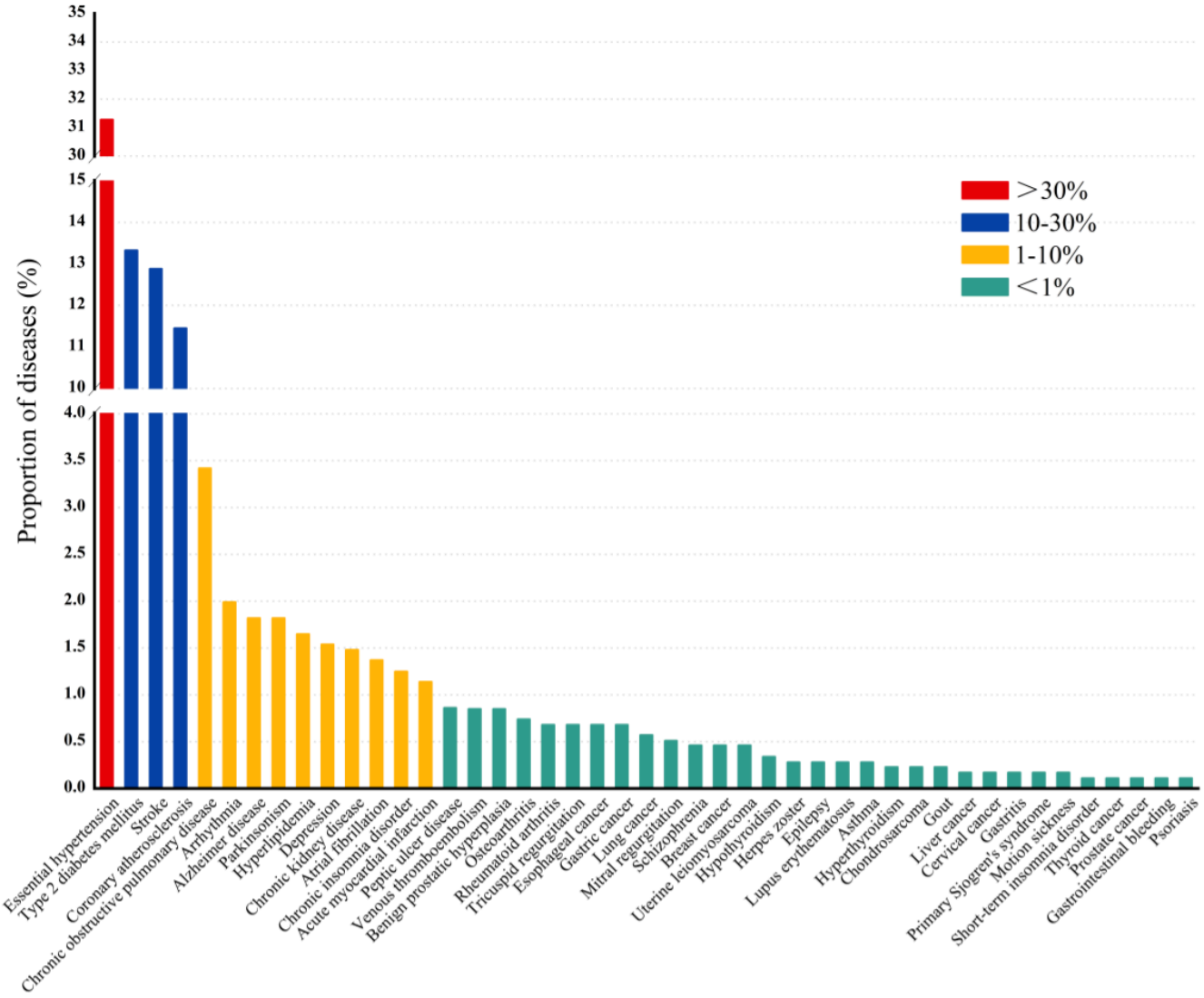

Figure 1

Patient disease characteristics

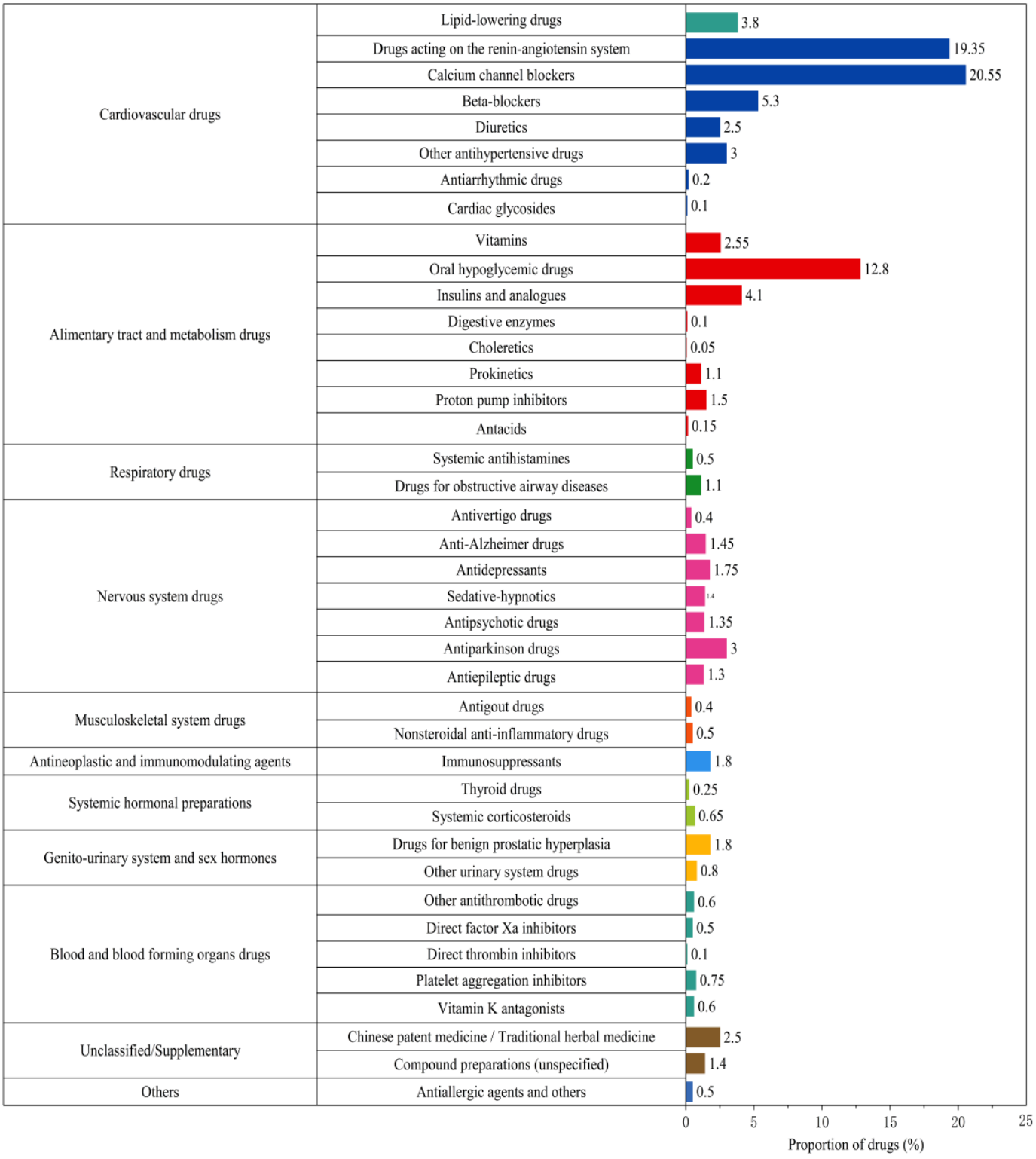

Figure 2

Patient medication details

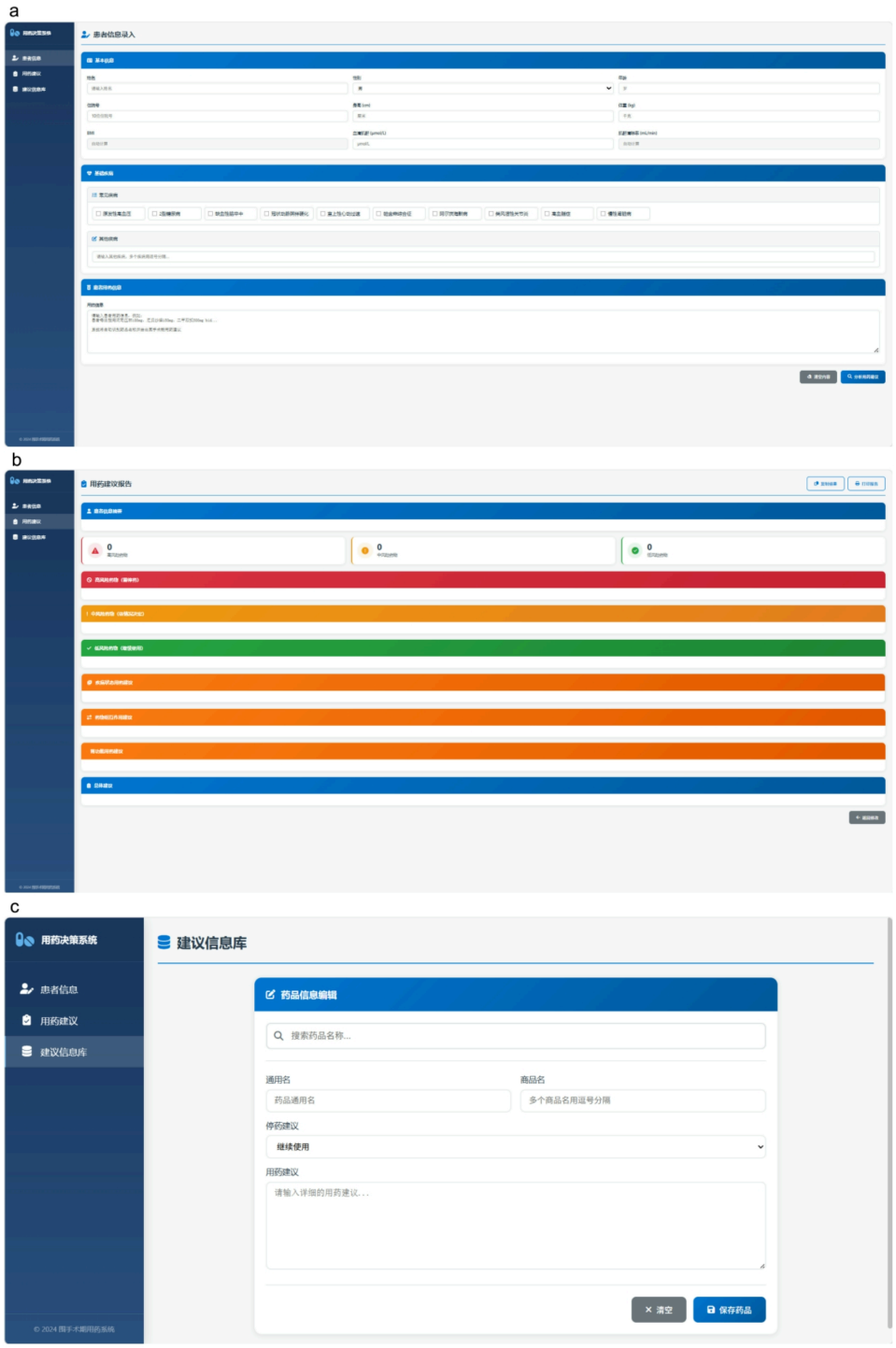

Figure 3

Main interfaces of the perioperative medication decision support system (PM-DSS). **a** Patient information entry interface. **b** Medication recommendation report interface. **c** Recommendation knowledge base interface

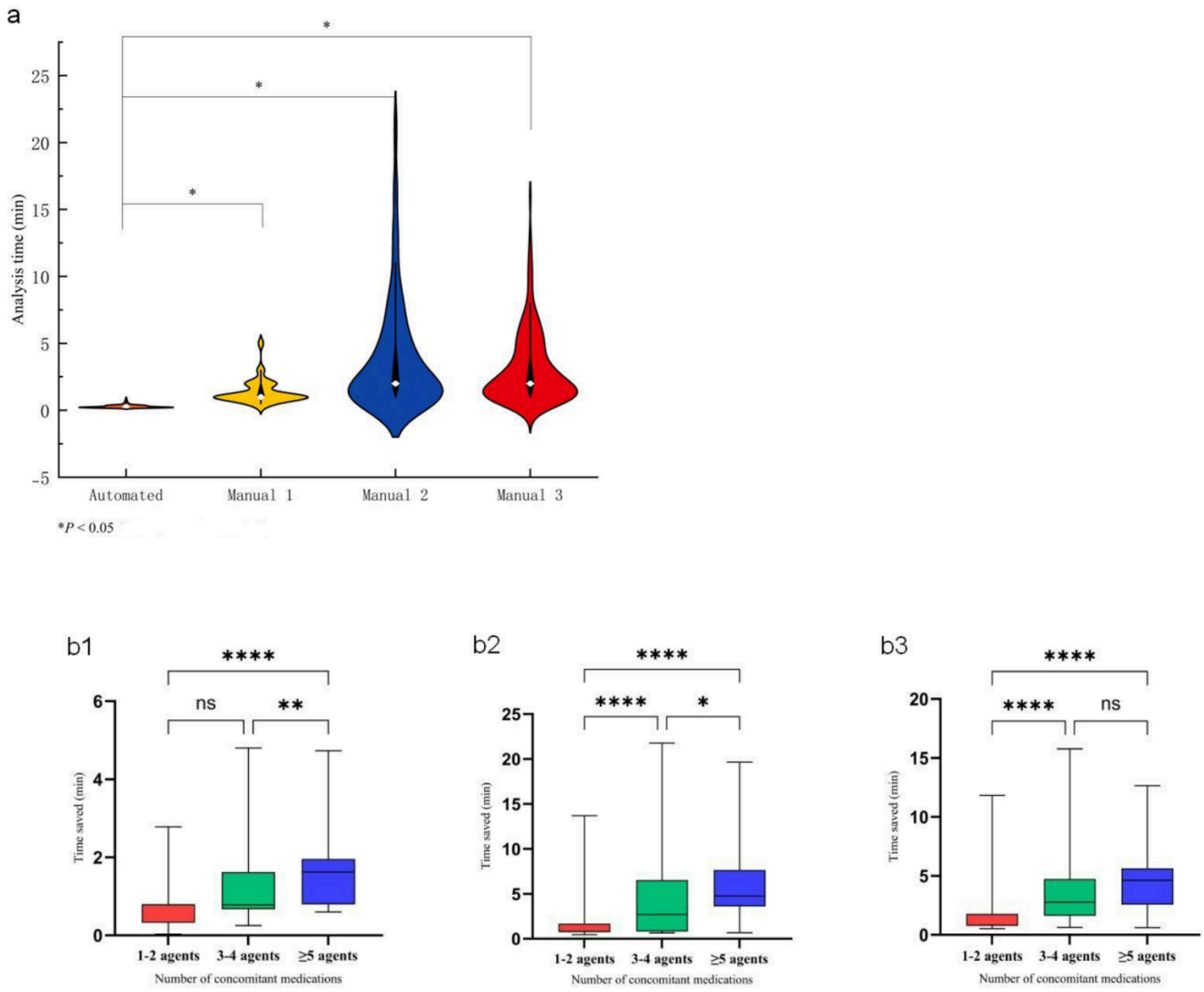

Figure 4

Medication review efficiency of the PM-DSS. **a** Comparison of review time between the PM-DSS and manual review. **b1-b3** time savings with the PM-DSS versus manual review stratified by the number of concomitant medications

**For panels b1–b3, comparisons among medication-burden groups were performed using the Kruskal–Wallis test followed by Dunn's multiple-comparison test. ****$p < 0.0001$, **$p < 0.01$, *$p < 0.05$, ns not significant.

Supplementary Files

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