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Implementation and Evaluation of Robotics Intravenous Compounding Technology in a Tertiary Hospital Oncology Pharmacy

by

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ABSTRACT

Purpose
The objective of this study was to compare the compounding efficacy, accuracy, and pharmacy technician repetitive strain injury risks between manual pharmacy technician compounding and robotic compounding processes.

Method
This quasi-experimental study at Houston Methodist Hospital Oncology Pharmacy analyzed three weeks of manual compounding data and three weeks of robotic compounding data. The primary endpoint was the medication turnaround time for both manual and robotic methods, calculated from the start to the completion of dose preparation. Secondary endpoints included medication rejection rates, number of doses compounded per technician hours, medication preparation time, and the risk of repetitive injuries for both compounding methods. Statistical analysis used included t-tests, segmented regression, and chi-square tests to evaluate preparation times, failure rates, and ergonomic risks.

Results
A total of 447 medications were prepared manually and 200 doses were prepared via robotic compounding during the study period. The mean turnaround time for manual preparation was 26.6 minutes, compared to 29.0 minutes for robot preparation (95% CI, -5.1-0.1; P=0.053). A total of 2.3% of doses were rejected in manual preparation and 1.5% of doses were rejected in robot preparation (P=0.118). The mean manual preparation time was 15.7 minutes versus the robot's mean preparation time of 6.9 minutes (95% CI, 8.0-9.6; P<0.0001). The compounding efficiency was 0.78 doses per technician hour, indicating a 14% increase in compounding efficiency. Regarding employee safety, for manual compounding, two observations fell in the medium risk range, and two observations were in the high-risk range. For robot compounding, all four observations were in the low-risk range. The Chi-Square Test of Independence was performed to examine the relationship between the method of compounding (robot vs. manual) and the risk of repetitive strain injury (low, medium, high). The result was $X^2=8$ with a significance level of P=0.018.

Conclusion
Robotic compounding shows comparable results in medication turnaround time. It also offers significant advantages in reducing the risk of repetitive strain injuries associated with manual compounding for pharmacy staff. Moreover, robotic compounding has a similar dose rejection rate compared with manual compounding. However, it faces technological limitations and requires future advancements in technology and workflow design to fully optimize automation in oncology pharmacy operations.

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INTRODUCTION

Technology and data science are critical factors in ensuring healthcare efficiency and patient safety. As outlined in the American Society of Health System Pharmacists (ASHP) Practice Advancement Initiative (PAI) 2030, pharmacy departments are encouraged to leverage advanced technologies to ensure the safe compounding of sterile products.[1] Concurrently, the United States Pharmacopeia (USP) <800> emphasizes the importance of safely handling hazardous drugs to promote patient safety, worker safety, and environmental protection.

Numerous studies have demonstrated that intravenous (IV) robotic compounding technology can improve dosing accuracy, ensure compounded product sterility, and reduce hazardous medication contamination.[2,3,4] Two studies comparing dose accuracy for hazardous medication between manual and robotic processes found that robotic compounding had significantly higher accuracy than the manual process, with a failure rate of around 2% when a dose accuracy range was set at 5%.[5] Evidence suggests that chemotherapy compounding robots maintain similar or superior sterility compared to manual compounding.[6] Specifically, one study found that none of the 50 media-filled bags compounded by the IV robot showed turbidity after storage periods of 12 weeks, indicating the absence of microorganisms.[3] A meta-analysis reviewed four studies using the robotic system APOTECAchemo for compounding and found that robotic compounding was associated with significantly lower hazardous contamination rates compared to the manual process.[7] However, studies have shown varied results regarding robot productivity and its impact on operational efficiency. Earlier studies indicated that robotic systems had longer preparation times compared to manual compounding.[2,7] Two studies that used chemotherapy compounding robotic systems KIRO and CytoCare required an additional 4 minutes and 4 seconds, and 3 minutes and 27 seconds, respectively, compared to the manual process.[8,9] Conversely, one study showed decreased medication turnaround time when using the I.V. Station for compounding compared to the manual process.[4] In this context, "turnaround time" was defined as the time between starting medication preparation and the time when a pharmacist completed the final dose verification.[4] One study that utilized the APOTECAchemo robot reported that the preparation time for the robotic compounding process was 5.57 minutes for ready-to-use drugs and 6.11 minutes per preparation for lyophilized drugs, although it did not report the time for manual preparation.[10] No study has directly compared manual and APOTECAchemo robot preparation times. Potential automated solutions to mitigate repetitive strain injuries, commonly linked to manual compounding, have not been explored.[11] While robotic compounding was associated with cost savings due to a closed system, it did not impact Full-time equivalent (FTE) hours.[4,12]

The oncology pharmacy at Houston Methodist Hospital (HMH) had seen a marked rise in compounding volume in recent years. In 2022, the HMH oncology pharmacy compounded an average of 4,512 IV medication doses per month; this number rose to an average of 4,891

doses per month in 2023. The HMH Oncology pharmacy faced the challenge of optimizing staff resources due to pharmacy technician shortages, USP <800> regulatory compliance requirements, and the growth of volume in outpatient infusion clinics. Bottlenecks in hazardous medication preparation resulting from staffing issues could directly influence nurse clinic workflows, prolong patient clinic time, adversely affect hospital profitability, and ultimately worsen patient outcomes. Moreover, four cases of repetitive strain injury occurred among sterile compounding technicians between 2022 and 2023, requiring time off or restrictions on work duties. The pharmacy leadership team, working with employee health, was actively searching for potential resolutions to minimize the risk of repetitive strain injuries for frontline compounding staff.

This study aimed to fill the gap in the literature by examining the efficiency and safety of chemotherapy robotic compounding systems, and their effect on reducing repetitive strain injury risks among pharmacy technicians. The primary objective was to evaluate medication turnaround time using both manual and robotic compounding techniques. Secondary objectives included the analysis of failure rate, medication preparation time, compounding efficiency, and risks of repetitive injuries during both manual and robotic compounding process.

METHODS

The research study employed a quasi-experimental design to investigate the compounding of the most frequently compounded hazardous medications at HMH Oncology Pharmacy, comparing manual and robotic compounding technologies. HMH is the 1,200-bed flagship tertiary academic medical center. Th oncology pharmacy serves as the primary USP <800> compliant compounding space supporting preparation of hazardous infusions and injections, microbial vector therapies, and intrathecal/intraperitoneal/intravesical therapies for procedural patients. The oncology pharmacy operation serves a 50-bed inpatient cancer center, a 15-bed bone marrow transplantation unit, and a 40-chair outpatient infusion center.

The IV compounding robot APOTECAchemo was received at HMH on November 10th, 2023, and completed installation and testing on January 12th, 2024. The production of patient-specific doses went live on February 18th, 2024. Data on manual preparation was collected from January 29, 2024, to February 19, 2024. The robotic compounding data was collected between February 21, 2024, and March 13, 2024

Compounding Processes

Before IV robotic implementation, HMH Oncology Pharmacy solely utilized a manual hazardous compounding process through the IV workflow management system (DoseEdge, Baxter). The IV workflow management system was equipped with barcode scanning and picture-capturing capabilities and interfaced with the electronic medical record (Epic). Physicians could place orders through computerized prescriber order entry. Then, dual pharmacist verification in the electronic medical record was required before the dose was

ready to be prepared. Technicians manually compounded the dose in the negative pressure IV compounding suite, following step-by-step guidance from the IV workflow management system. An in-process verification, performed by a pharmacist, was done remotely by inspecting pictures before all medications were injected into the final container. The IV workflow management system electronically logged all critical timestamps, including preparation, in-process check, and finishing preparation.

APOTECAchemo robot fully automated solution was equipped with barcode scanning, digital photographic capture, and gravimetric verification technology. The rationale for its adoption was to optimize the preparation of the most frequently used medications by leveraging the robot's capacity for repetitive compounding. The IT team built an interface between the electronic medical records and the robotics system using Health Level Seven standards and designed the dispensing logic for the selected study medications to be compounded through robotics. Verified hazardous medications could be automatically queued into the robot's operating system. Technicians utilized barcode scanning technology to ensure the correct medications were loaded. Technicians also grouped the same medication and dose sizes together to ensure the robot ran at maximum efficiency. Unlike manual compounding, in-process verification was not required for robotic compounding, as the robotic gravimetric technology ensured the correct amount of medication was withdrawn before being added to the final container. After the system finished preparations, the completed products were retrieved from the load zone door and passed on for the pharmacist's final verification.

Primary Endpoint

Medication Turnaround Time

The primary endpoint was medication turnaround time for both manual and robotic processes. Medication turnaround time was defined as the time between the initiation of preparation and the final verification of the medication by a pharmacist, at which point it was ready to be delivered. The time of final verification was automatically captured through both the IV workflow management software and the robotic software. The mean medication turnaround time was calculated by dividing the sum of the medication turnaround times by the number of each study medication dispensed. Turnaround time was compared for each medication, as well as the average time for all medications compounded manually or through the robot, respectively.

Secondary Endpoints

Rejected Doses

The number of rejected doses in both the IV workflow system and the robotics system were collected. Manual preparation rejection was determined by the pharmacist who reviewed the pictures captured by the IV workflow management system. If errors were identified by the pharmacists, the IV workflow system documented the reason for rejection and re-queued the dose for technicians to remake. The robot automatically rejected a failed dose if the

medication had a variance limit of more than ±5%. Pharmacists reviewed the doses compounded by the robot, and if an error was found, the pharmacist could reject the dose and requeue the medication in the robot. Both automatic rejections and pharmacist rejections for the robotic system were electronically captured through robotic software. The failure rate for both manual and robotic methods was calculated by dividing the number of rejected doses by the total number of compounded doses for each preparation method, respectively.

Compounding Efficiency

This study utilized the number of doses per technician hour as a surrogate to assess the impact of robotic implementation on technician efficiency in compounding hazardous medication. The doses per technician hour were calculated using the formula: total number of doses prepared / total technician hours scheduled in the hazardous compounding area. Average doses per technician hour during the study period were assessed for both robotic and manual preparation.

Medication Preparation Time

Technician preparation time was defined as the time interval from when a technician begins preparing a dose to when the technician completes dose preparation. Robot preparation time was defined as the period starting from the robot's initiation of dose preparation to its completion. The IV workflow system electronically logged the initiation and completion times for manual preparation. Meanwhile, the robot captured the timestamps for both the beginning and end of robotic preparations. Mean medication preparation times for studied agents were assessed for both manual and robotic compounding. The mean medication preparation time for each medication was calculated by dividing the sum of the studied medication preparation time by the number of doses of the studied medication prepared during the study period.

Repetitive Strain Injury Risk

To evaluate the risk of repetitive strain injury among technicians compounding through manual and robotic methods, the Assessment of Repetitive Tasks (ART) for upper limbs was utilized. The ART tool is an evidence-based method developed by the Health and Safety Executive in the UK, designed to assess risks associated with repetitive tasks involving the upper limbs. The assessment tool's instructions comprehensively consider task frequency, force, posture, and duration to determine a quantitative risk score. Two hospital pharmacy employees served as observers of repetitive strain injury risks for pharmacy technicians and received standardized training by utilizing the ART protocol. The observers conducted non-intrusive observations of randomly selected shifts involving manual and robotic compounding by strictly following the ART observation protocol (Appendix A). All HMH Oncology Pharmacy technicians were notified by the management team that they might be observed as part of ongoing quality improvement efforts. To maintain confidentiality and ensure that the data were used for quality improvement within our organization, all observed data were anonymized. The collected data were used exclusively for internal quality improvement to

assess the impact of robotic implementation on the risk of repetitive strain injury and to develop strategies for optimizing ergonomic safety for Houston Methodist pharmacy technicians. Four observations were conducted on random technicians engaged in manual compounding and on random technicians using robotic compounding, covering six categories: movement frequency, force, posture, breaks, work pace, and work duration. The observers scored each category based on their observation by following the ART tool instruction. The scores were documented via the ART tool flow chart. The task score was calculated by adding together the scores on the score sheet. The exposure score was calculated by multiplying the task score by the duration multipliers. According to the ART protocol, an exposure score between 0-11 is considered low risk for repetitive strain injury. An exposure score between 12-21 is defined as medium risk, and a score equal to or higher than 22 is considered as high risk for repetitive strain injury.[13]

Data Sources

Study medication eligibility requirements included that the medication was among the top 10 most frequently compounded medications, had stability over 4 hours, and could be handled by the robot in its drug form. The frequently compounded hazardous medications were identified by pulling oncology pharmacy outpatient dispensing data from January 1, 2023, to September 1, 2023. The data were retrieved from the electronic medical record's pharmacy dispensing report. Medications were ranked based on the total time allocated for each medication for compounding (calculated by the number of doses compounded times the average time for compounding one dose), from highest to lowest. These medications were targeted upon robotic implementation and were designed to be prioritized for compounding through the robotics system. The eligible medications were compounded solely through the robotic system unless a STAT order was placed, and the robot workflow could not be interrupted. Before the implementation of the robot, the same eligible medications were compounded 100% manually using the DoseEdge system. If a medication was compounded manually post-robotic implementation due to unexpected circumstances, those doses were excluded from the study and analysis. The preparation time for study medication, the number of doses rejected, and the number of doses compounded, and medication turnaround time for both manual and robotic compounding were retrieved from the IV workflow management system software and the robotic operational software, respectively. The technician hours scheduled for hazardous medication compounding, manually or via robot, were retrieved from the technician weekly schedule.

Statistical Analysis

The two-sample t-test was used to analyze the medication turnaround time and preparation time. The level of statistical significance was set at 0.05 for all endpoints in this study. A predetermined sample size of seven compounds in both manual and robotic compounding would provide 80% study power to detect a preparation time difference of three minutes. The Chi-Square test was used to evaluate the number of rejected doses for both manual and

robotic compounding. Descriptive statistics were applied to doses per technician hour between manual and robotic preparations. The Fisher exact test was employed to analyze the risk of repetitive strain injury between manual and robotic compounding. All statistical analyses were performed using the statistical package Minitab 2.0.

RESULTS

Study Medications

The top 10 medications based on the total hours used for compounding from January 1, 2023, to September 1, 2023, ranked from highest to lowest, were ganciclovir, mycophenolate, fluorouracil, cyclophosphamide, carboplatin, gemcitabine, cytarabine, paclitaxel, doxorubicin, and etoposide. For fluorouracil, only the initial bolus dose was compounded through the robot. Mycophenolate was excluded from robot compounding due to drug form incompatibility, as there were no commercially available dextrose 5% vials for medication reconstitution. Ganciclovir was excluded from the study since the pharmacy was in the process of switching products from powder to ready-to-use solution, and this would mean different ganciclovir products would be studied for manual and robot preparation.

A total of 447 medications were prepared manually between January 29, 2024, and February 19, 2024. This included 79 doses of carboplatin, 66 doses of cyclophosphamide, 55 doses of cytarabine, 7 doses of doxorubicin, 51 doses of etoposide, 39 doses of fluorouracil (bolus infusion), 50 doses of gemcitabine, and 60 doses of paclitaxel. Meanwhile, 200 medications were prepared via robot from February 21, 2024, to March 13, 2024, including 46 doses of carboplatin, 37 doses of cyclophosphamide, 6 doses of cytarabine, 17 doses of doxorubicin, 7 doses of etoposide, 24 doses of fluorouracil (bolus infusion), 24 doses of gemcitabine, and 39 doses of paclitaxel (Figure 1). The results for this study's primary, secondary, and descriptive endpoints were summarized in table 1.

Figure 1: Number of Doses Compounded Manually vs. Robot Per Medication

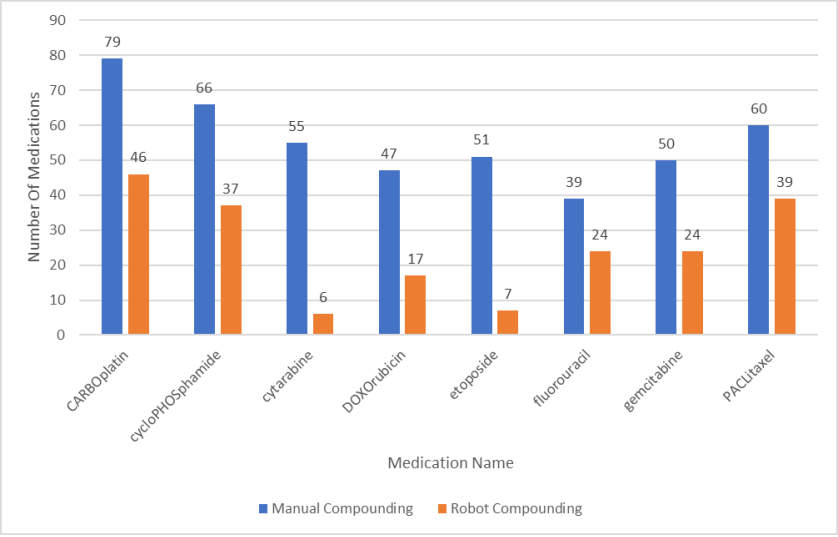

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Table 1: Study Endpoints Summary

	Manual Compounding (n=445 preparations)	Robotic Compounding (n=200 preparations)	P value
Primary Endpoint			
Medication Turnaround Time, Mean (SD), minutes	26.6 (12.1)	29.1 (16.4)	P=0.053
Second Endpoints			
Failure Rate, n (%)	10 (2.24%)	3 (1.50%)	P=0.532
Doses Per Technician Hour (doses/hour)	0.68	0.78	N/A
Medication Preparation Time, Mean (SD), minutes	15.7 (7.2)	6.9 (3.5)	P<0.001
Repetitive Strain Injury Risk, number per category	Low: 0 Medium:2 High:2	Low: 4 Medium:0 High:0	P=0.018

Medication Turnaround Time

The average medication turnaround time for manual preparation of carboplatin, cyclophosphamide, cytarabine, doxorubicin, etoposide, fluorouracil, gemcitabine, and paclitaxel are 27.1 minutes, 26.5 minutes, 25.8 minutes, 25.5 minutes, 26.5 minutes, 25.3 minutes, 25.5 minutes, and 29.5 minutes, respectively. Conversely, the average medication turnaround times for these medications using robot compounding are 28.6 minutes, 33.4 minutes, 26.7 minutes, 28.5 minutes, 23.7 minutes, 28.0 minutes, 25.4 minutes, and 30.4 minutes, respectively. The mean turnaround time for manual preparation was 26.6 minutes, compared to 29.0 minutes for robot preparation (95% CI, -5.1-0.1; P=0.053) (Table 2).

Table 2: Manual Vs. Robotic Medication Turnaround Time Per Medication

Medication Name	Manual Preparation Doses, n	Manual Preparation Time (mins)	Robot Preparation Doses, n	Robot Preparation Time (mins)	P Value
CARBOplatin	79	27.1	46	28.6	P=0.601
cycloPHOSphamide	66	26.5	37	33.4	P=0.182
cytarabine	55	25.8	6	26.7	P=0.796
DOXOrubicin	47	25.5	17	28.5	P=0.397
etoposide	51	26.5	7	23.7	P=0.503
fluorouracil	39	25.3	24	28.0	P=0.359
gemcitabine	50	25.5	24	25.4	P=0.971
PACLitaxel	60	29.5	39	30.4	P=0.782
Total	447	26.6	200	29.0	P=0.053

Rejected Doses

During the manual compounding study period, a total of 10 doses were rejected by pharmacists and required rework out of 445 doses prepared during the study period. The rejected doses included 3 doses of carboplatin, 1 dose of cyclophosphamide, 2 doses of cytarabine, 3 doses of fluorouracil, and 1 dose of gemcitabine. One dose was rejected due to the wrong concentration, 7 doses were rejected due to the wrong amount, 1 dose was rejected due to a missing picture, and 1 dose had missing documentation for the reason for rejection. During the robotic compounding, a total of 3 doses were rejected due to a variance limit of more than 5%, which included 1 dose of paclitaxel and 2 doses of cytarabine. No robotic compounded doses were rejected by pharmacists. Six doses failed due to user error or mechanical failure. Two doses failed because the robot was unable to correctly grasp a component. One dose failed due to the robot arm not being powered, which typically indicates the robot detects interference or unexpected resistance. One dose failed because the wrong solvent bag was loaded into the robot, and the robot identified the user error and requested the correct solvent. Two doses failed because the robot could not identify the medication vials. A total of 2.3% of doses were rejected in manual preparation and 1.5% of doses were rejected in robot preparation (P=0.118).

Medication Preparation Time

The average preparation times for carboplatin, cyclophosphamide, cytarabine, doxorubicin, etoposide, fluorouracil, gemcitabine, and paclitaxel are 17.3 minutes, 15.5 minutes, 13.9 minutes, 14.1 minutes, 14.2 minutes, 14.3 minutes, 15.8 minutes, and 18.7 minutes, respectively. The average robotic preparation times for the same medications were 7.2 minutes, 7.9 minutes, 5.5 minutes, 6.7 minutes, 6.7 minutes, 4.7 minutes, 6.4 minutes, and 7.4 minutes, respectively. The mean manual preparation time was 15.7 minutes versus the robot's mean preparation time of 6.9 minutes (95% CI, 8.0-9.6; P<0.0001) (Table 3).

Figure 2: Manual vs. Robot Medication Preparation Time Per Medication

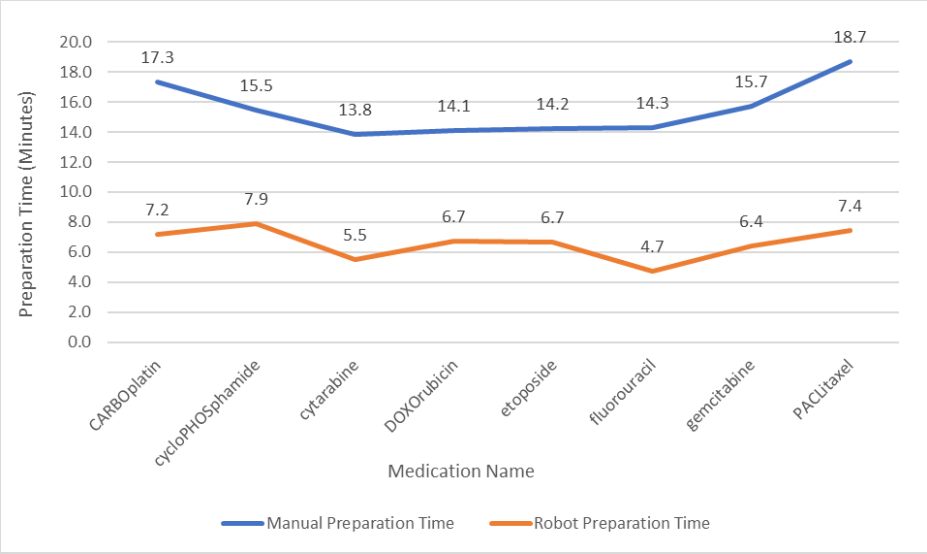

Table 3: Manual vs. Robot Medication Preparation Time Per Medication

Medication Name	Manual Preparation Doses, n	Manual Preparation Time (mins)	Robot Preparation Doses, n	Robot Preparation Time (mins)	P Value
CARBOplatin	79	17.3	46	7.2	P<0.0001
cycloPHOSphamide	66	15.5	37	7.9	P<0.0001
cytarabine	55	13.8	6	5.5	P<0.0001
DOXOrubicin	47	14.1	17	6.7	P<0.0001
etoposide	51	14.2	7	6.7	P=0.024
fluorouracil	39	14.3	24	4.7	P<0.0001
gemcitabine	50	15.7	24	6.4	P<0.0001
PACLitaxel	60	18.7	39	7.4	P<0.0001
Total	447	15.7	200	6.9	P<0.0001

Compounding Efficiency

Between January 29, 2024, and February 19, 2024, 82 shifts (8 hours per shift) and 656 technician hours were scheduled for manual hazardous compounding, during which 447 doses were produced. The compounding efficiency for manual compounding was 0.68 doses per technician hour. Between February 21, 2024, and March 13, 2024, 32 shifts and 256 technician hours were scheduled for robotic compounding, resulting in the production of 200 doses using the robot. The compounding efficiency was 0.78 doses per technician hour, which indicated a 14% increase in compounding efficiency.

Repetitive Strain Injury Risk

Four observations were made using the ART tool, which included two instances of manual compounding and two of robotic compounding. The left-hand task score was 18 with an exposure score of 13.5, while the right-hand task score was 22 with an exposure score of 16.5. During the second observation of manual compounding, both hands recorded a task score of 30 and an exposure score of 30. For the first observation of robotic compounding, both hands received a task score of 2 and an exposure score of 1.5. In the second observation, the task scores for both hands were 8, with the exposure scores matching at 8. For manual compounding, 2 observations fell in the medium risk range, and 2 observations were in the high-risk range. For robot compounding, all 4 observations were in the low-risk range. The Chi-Square Test of Independence was performed to examine the relationship between the method of compounding (robot vs. manual) and the risk of repetitive strain injury (low, medium, high). The result was $X^2=8$ with a significant level of p=0.018 (Table 4).

Table 4: Manual and Robot Compounding Observation ART Score

Observation	Observation One	Observation One	Observation Two	Observation Two	Observation One	Observation One	Observation Two	Observation Two
Compound Method	Manual	Manul	Manual	Manual	Robot	Robot	Robot	Robot
Hand	Left	Right	Left	Right	Left	Right	Left	Right
Frequency Score	6	6	9	9	0	0	0	0
Force Score	4	8	8	8	0	0	0	0
Posture Score	6	6	4	4	2	2	2	2
Breaks/ work pace	2	2	9	9	0	0	6	6
Task Score	18	22	30	30	2	2	8	8
Duration	X0.75	X0.75	X1	X1	X0.75	X0.75	X1	X1
Exposure Score	13.5	16.5	30	30	1.5	1.5	8	8
Risk Category	Medium	Medium	High	High	Low	Low	Low	Low

DISCUSSION

This research study compared the impact of manual and robotic compounding on various operational metrics within a tertiary hospital oncology pharmacy, focusing on medication turnaround time, medication preparation time, dose rejection rate, compounding efficiency, and repetitive strain injury risks. There was no difference in medication turnaround time between manual and robotic compounding (26.6 minutes vs 29.0 minutes), suggesting that while robotic compounding significantly reduced preparation time, other factors within the pharmacy operation may mitigate this efficiency. One factor to consider was that the data collection period was immediately after the robot operation went live, and pharmacists were still undergoing training and familiarizing themselves with the robot-compounded medication verification process, which could potentially artificially increase the medication turnaround time.

The findings from this research demonstrated a statistically significant longer preparation time for manual preparation of 15.7 minutes compared to the robot's mean preparation time

of 6.9 minutes. The robotic average medication preparation time was aligned with the study performed by Iwamoto et al. at a Japanese hospital, which reported a robotic compounding time of 6.1 minutes. Iwamoto did not report the manual compounding time for the same medication, making this study the first research comparing manual and robotic medication preparation times. Also note, the preparation time for robotic compounding did not include the time the technician spent loading the robot and unloading the medication from the robot to attach lines. Therefore, the overall preparation time for each dose via robot compounding was anticipated to be longer than the reported time. The robotic compounding also demonstrated higher doses per hour ratio when compared to the manual compounding process (0.78 doses/hour vs. 0.68 doses/hour), indicating that fewer technician hours were needed for compounding the same number of doses for the studied medication during the study period.

The chi-square test revealed no statistically significant association between robot and manual compounding methods and the rate of dose rejection. However, all manually compounded rejected doses were due to wrong doses or wrong concentrations, identified by pharmacists. In contrast, during robot compounding, all failures and rejections were conducted by the robot through self-checks. The majority of robot compounding failures were due to mechanical errors and user errors, which was unique to the study period right after the go-live phase. During this time, engineers continued performing minor calibrations on the robot, and technicians were still undergoing hands-on training while operating the robot. In the study conducted by Nurgat et al. on the CytoCare compounding robot, with a given error range of 5%, there were 812 failures in 4846 doses, indicating a failure rate of 16%.[14] The ApotecaChemo robot had a lower failure rate at 4.5% compared to the CytoCare robot.

This study found that robot compounding demonstrated a significantly lower risk for repetitive strain injury compared to manual compounding. This result presented compelling evidence for the ergonomic benefits of utilizing robot compounding. This was the first study to evaluate the repetitive strain injury risk associated with staff performing sterile compounding. With all observations for robot compounding indicating a low risk for repetitive strain injury, and all manual compounding indicating either medium or high risk, this study suggested that robot adoption should be considered for long-term health and safety implications for pharmacy staff.

This study has some limitations. The data collected for robotic compounding were conducted during the first three weeks of robot go-live. Pharmacy employees involved in robot compounding were still adapting to the new operational workflow. The use of only the most frequently used medication may have limited the generalizability of the research findings. Another limitation was that for robot preparation time, the time spent loading the robot for preparation and unloading medication for attaching lines was not captured through the robot software timestamp. This omission made the overall medication preparation time less

reflective of an accurate efficiency comparison between robot and manual compounding. Further research involving more study medications, along with an implementation of a washout period, could be beneficial for evaluating the impact of robotic compounding on operational efficiency and employee safety.

CONCLUSION

Robotic compounding shows comparable results in medication turnaround time. It also offers significant advantages in reducing the risk of repetitive strain injuries associated with manual compounding for pharmacy staff. Moreover, robotic compounding has a similar dose rejection rate compared with manual compounding, but significantly reduces medication preparation time. There are technological limitations to robot compounding, including compatibility issues with certain medication forms and a limited impact on overall medication turnaround time. Future advancement in robotic technology and operational workflow design optimization are essential to leverage the full potential of automation in oncology pharmacy operations.

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