Research Paper ■

Medication Administration Errors in Nursing Homes Using an Automated Medication Dispensing System

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A b s t r a c t   **Objective:** To identify the frequency of medication administration errors as well as their potential risk factors in nursing homes using a distribution robot.

Design: The study was a prospective, observational study conducted within three nursing homes in the Netherlands caring for 180 individuals.

Measurements: Medication errors were measured using the disguised observation technique. Types of medication errors were described. The correlation between several potential risk factors and the occurrence of medication errors was studied to identify potential causes for the errors.

Results: In total 2,025 medication administrations to 127 clients were observed. In these administrations 428 errors were observed (21.2%). The most frequently occurring types of errors were use of wrong administration techniques (especially incorrect crushing of medication and not supervising the intake of medication) and wrong time errors (administering the medication at least 1 h early or late).The potential risk factors female gender (odds ratio (OR) 1.39; 95% confidence interval (CI) 1.05–1.83), ATC medication class antibiotics (OR 11.11; 95% CI 2.66–46.50), medication crushed (OR 7.83; 95% CI 5.40–11.36), number of dosages/day/client (OR 1.03; 95% CI 1.01–1.05), nursing home 2 (OR 3.97; 95% CI 2.86–5.50), medication not supplied by distribution robot (OR 2.92; 95% CI 2.04–4.18), time classes "7–10 am" (OR 2.28; 95% CI 1.50–3.47) and "10 am-2 pm" (OR 1.96; 1.18–3.27) and day of the week "Wednesday" (OR 1.46; 95% CI 1.03–2.07) are associated with a higher risk of administration errors.

Conclusions: Medication administration in nursing homes is prone to many errors. This study indicates that the handling of the medication after removing it from the robot packaging may contribute to this high error frequency, which may be reduced by training of nurse attendants, by automated clinical decision support and by measures to reduce workload.

Introduction and Background

In the final decades of the 20th century, automated medication dispensing systems were introduced in hospital pharmacies to minimize medication dispensing errors and to save time and personnel. Several studies showed a moderate decrease in both medication dispensing errors and time.[1–4] In other studies, automated point-of-use distribution systems in hospitals were tested on their effect on medication administration errors.[5,6] In these studies medication administration errors decreased from about 16–10% after introduction of such automated systems.

These results have prompted both community and hospital pharmacies in The Netherlands to using automated dispensing systems for the distribution of medication to nursing homes. These systems are known to reduce dispensing errors,[1–3] but little is known of the occurrence of medication administration errors when using these systems in nursing homes. In fact, literature on medication administration errors in nursing homes (using either automated or non-automated dispensing systems) is scarce. Only a few studies[7,8] looked into this subject using the most accurate study method, namely (disguised) observation.[9,10] In neither of these studies a clear description of the dispensing system is provided. Furthermore, we do not know of any previous studies analyzing potential risk factors for medication administration errors in nursing homes using an automated dispensing system.

Therefore, we conducted a disguised observation study to identify the frequency of medication administration errors as well as the potential risk factors for these errors in nursing homes using an automated dispensing system ("distribution robot").

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Methods

Setting and Study Population

The study was conducted within three nursing homes caring for 180 individuals in two cities in the western part of the Netherlands. One nursing home had three wards, but only two were involved in this study. Each of the other two nursing homes had two wards, all of which were involved in the study. Therefore, six wards were involved in the study. In all nursing homes medication is prescribed by specialized nursing home physicians.

All three nursing homes are supplied with medication by one community pharmacy, using the automated Tosho Topra 4,001 dispensing system. This distribution robot is located in the community pharmacy (which is in a building on a three to five Miles distance from the nursing homes) and is operated by pharmacy technicians under supervision of the community pharmacist. The robot handles solid oral dosage forms (tablets) and packs these dosage forms in plastic bags. One plastic bag is filled with the tablets that have to be administered to a patient, for each round of medication administration. Each plastic bag has a label on which the name and ID number of the patient, the name(s) of the medication(s) and the date and time of administration are printed. The robot thus provides the right medication at the right time and therefore reduces the possibility of these types of errors (errors involved in picking the right medication from a central supply, errors involving administering the drug at the wrong time). Furthermore, as all medication is presented in the robot package, the omission of medication is less likely. By contrast, errors that involve the handling of the medication after removing it from the package are not influenced by the robot (e.g., when a patient needs crushing of his or her medication because of swallowing difficulties, the robot does not provide information on whether crushing of the medication is allowed).

Not all medication was dispensed using the distribution robot, because certain dosage forms (e.g., suppositories, oral liquid formulations) cannot be dispensed with this system.

After packaging by the robot, the packages are separated per patient by pharmacy assistants. This happens every Tuesday. The following day in the evening the packages are transported to the nursing homes by community pharmacy personnel. Within the nursing homes the packages are received from the pharmacy assistant and are then distributed by nursing home staff to the right wards.

In all nursing homes medication is sometimes administered by qualified nurses, but the majority of medications is administered by nurse attendants, who have in general less specific training in handling of medication than nurses do. However, they are trained in-house to handle medication in general and the robot packages in specific.

For each nursing home a two week study period was used, in which a week was defined as Monday through Friday from 07:00 to 22:00; on Tuesdays no measurements were carried out because of unavailability of the observer. The study was performed from October to Dec 2007.

Study Design

The study was a prospective, observational study of medication administration errors. A medication administration error was defined as any error in the preparation and administration of medication by nurse attendants, i.e., a deviation from written, printed, or verbal medication orders (used by the nurse attendants to administer medication), a deviation from the medication information sheets provided by the manufacturer and/or a deviation from general medication procedures used in the nursing homes. Administration errors were detected using the disguised observation technique.[10] Nurse attendants were unaware of the goal of the study (they were told that the observer came to study the medication distribution system). One observer followed the nurse attendants preparing and administering medication. This observer was a pharmacy technician. In the Netherlands pharmacy technicians are highly educated with a three year full-time schooling program, including on the job training periods in pharmacies (in the second and in the third year of the education).

In order for the pharmacy technician to become familiar with the technique of disguised observation there was a 1 week training period in a nursing home ward not included in the study. For ethical reasons, when the observer expected an administration error to have serious consequences for the patient, he would intervene before the error reached the patient.

All observations (client and medication name, dose, time, etc) were noted on a data collection form designed especially for the study. Afterward, the observations were compared with the written or printed medication orders. Observations were also compared with the medication information sheet to detect errors in the relationship of administration with meals and in the preparation of medication. Finally, for errors concerning the administration of medication with liquid food, a reference guide for hospitals was used to determine whether an error had occurred (consisting of general rules with respect to the administration of medication with liquid food and of a list of medication that should not be crushed), because general medication protocols on this subject were either lacking in the nursing homes or contained insufficient information.

Errors were classified into categories (Table 1).[11] Omission errors consisted of errors regarding not giving the medication to the patient, which can arise by forgetting the administration or by giving the medication to the wrong patient (the patient for which the medication was prescribed is not given the medication in that case). Unordered medication administration consists of virtually the same problems: either picking a medication from the stock that is not meant for the patient (e.g., because it looks like the medication the patient is supposed to have) or giving the medication to the wrong patient (here the wrong patient has an unordered medication administration error). Wrong administration technique errors comprised all errors concerning the administration technique: crushing errors (crushing a tablet that should not be crushed, e.g., because it is enteric coated), unsupervised intake of medication by the patient (in cases the medication intake should be supervised, e.g., because of Alzheimer's disease), wrong technique for administering inhalation preparations (e.g., not shaking the pressurized metered inhaler before use), wrong technique for dissolving effervescent tablets (crushing in stead of dissolving in water and administering after all bubbles have disappeared).

Table 1 ■ Error Categories, Including Examples

Error Category	Examples
Omission (ordered medication not administered)	Tramadol not administered to patient, although order was still active on medication list. Inadvertently not given to client by nurse attendant.
	Paracetamol not administered to patient, although order was still active on medication list. Nurse attendant decided by himself that patient did not need this medication.
Unordered medication administered	Pravastatin was the active medication order on the medication list, but nurse attendant administered simvastatin.
Wrong administration technique	No supervision of metoprolol intake in patient with Alzheimer's disease, although the instruction "supervise medication intake" was clearly printed on the medication list.
	Enteric coated tablet crushed.
Wrong dose	Wrong Number of digoxin tablets given to patient, because of strength mix-up.
Wrong time	Levothyroxine given shortly after meal, in stead of before meal
Seriousness	
Class C (medication administered but no harm)	Wrong Number of eyedrops containing lubricant.
	Medication given too early/late, when intake before or after meal is not important for that specific medication.
Class D (an error has been made which results in an increased frequency of monitoring, but no harm is done)	Ciprofloxacin crushed and mixed with milk product before intake.

Wrong dose errors consisted of administering the wrong strength of the medication or the wrong number of dosage forms. A wrong time error was defined as the administration of medication at least 60 minutes earlier or later than prescribed or as a wrong time in relation to food intake (e.g., for thyroid preparations, which should be taken on an empty stomach).

In addition, administration errors were classified into 9 classes of seriousness from the National Coordinating Council for Medication Error Reporting and Prevention (NCCMERP) taxonomy of medication errors: A—an error has been made but the medication does not reach the client; B—an error has been made and the medication reaches the client, but no harm is done because the medication is not administered; C—medication administered but no harm; D—an error has been made which results in an increased frequency of monitoring, but no harm is done; E—an error has been made resulting in temporary harm necessitating treatment; F—temporary harm resulting in an increased length of hospital stay (or, for this study, in hospitalization of the client); G—permanent damage; H—client nearly dies; I—an error has been made which results in the death of the client.[11]

The error severity was classified independently by one hospital pharmacist and two community pharmacists. For those errors that were classified in different classes of severity, the three pharmacists came together to reach consensus.

All medicines were classified according to the anatomical therapeutic chemical (ATC) code.[12]

The study is in accordance with the principles in the Declaration of Helsinki and Dutch Privacy Regulations. Because the study was entirely observational (non-interventional) and all data were collected anonymously, informed consent and ethical approval from the Medical Ethics Committee were not necessary.

Data Analysis

The observation period of two weeks per nursing home (i.e., in total 6 wks) was primarily chosen to have the possibility to study enough opportunities for medication administration. Assuming an average error frequency of 5%, $\alpha = 0.05$ and power of 80% a sample size of 263 medication administrations was calculated (about 90 per nursing home) to be able to identify odds ratio's for the correlation of various risk factors with administration errors of at least 2.5. Therefore, to be on the safe side, an observation period of two weeks was chosen.

The following variables were registered and entered into a database (MS Access 2003): patient age and gender, nursing home, ward, medicine (name and dosage form) and ATC code, day and time of administration, route of administration, medication crushed (for patients experiencing difficulty swallowing medication), number of medicines and number of dosages administered to a client that day, whether an error has been made or not, error category and error seriousness category, type of nurse attendant (qualified nurse, regular nurse attendant or trainee); number of years of experience of nurse attendant and medication supplied by distribution robot or not (as mentioned before, not all medication can be supplied by the distribution robot).

These data were analyzed using the statistical package for social sciences (SPSS) version 14.0.

The frequency of errors (fe) was calculated by dividing the number of administrations with one or more errors (ne) by the sum of the number of observed medication administrations (whether ordered or not) (nA) and the number of medicines observed to be omitted (no). Thus:

$$Fe = ne/(nA + no).$$

The error frequency was reported as a percentage (fe × 100%).

Table 2 ■ Demographic Variables and Error Frequency per Nursing Home

	1 (N = 36)	2 (N = 50)	3 (N = 41)
Mean age (median; range)	85 (85; 67-102)	85 (84; 74-99)	85 (84; 66-98)
Gender (% female)	67	80	85
Number of medication administrations observed	578	760	687
Error frequency (%)	9.9	27	25

The correlation between potential risk factors (patient age and gender, medication class, dosage form, medication crushed [included as a potential risk factor based on previous research[11]], number of medicines per client, number of dosages per client, day and time of administration, nursing home, ward, supplied by distribution robot or not, type of nurse attendant and experience of nurse attendant) and the occurrence of errors was studied using univariate logistic regression analysis. In this way, for each potential risk factor an odds ratio (OR) was calculated together with a 95% confidence interval (CI). For all potential risk factors identified in the univariate analysis to be statistically significantly associated with the occurrence of errors, a multivariate logistic regression analysis was performed using the enter method. The potential confounders were included in the multivariate model when they changed the beta-coefficient with more than 10%. In this way, for each potential risk factor identified in the univariate model different confounders could be identified, depending on their influence on the beta-coefficient.

Results

Two thousand, two hundred, twenty-five (2,025) medication administrations to 127 clients (28 male, mean age 84.3 yrs range 66–102 yrs) were observed. In these administrations 428 errors were observed (frequency = 428/2,025 (21.2%)).

The error frequencies and the demographic variables of the patient per nursing home can be found in Table 2.

Table 3 shows the errors for the three nursing homes, divided into categories and into classes of seriousness and representative examples for each category and class can be found in Table 1. Administration technique errors were the most frequently occurring category, followed by wrong time errors (which included administration of medication in wrong relation to meal) and omission errors.

As can be seen from Table 1, administration technique errors mainly concerned the incorrect crushing of tablets for intake with fluids because many clients of nursing homes have difficulty in swallowing solid oral dosage forms. Nurse attendants tend to crush all tablets for such clients, even when this is not allowed because of enteric coating or slow release. Another frequently occurring error in this class concerned the lack of supervision of intake of medication, when such instruction was clearly printed on the medication list.

Wrong time errors consisted mainly of medications not given at the time ordered on the medication lists (within a 60 min margin). But other examples from this category concern wrong time of intake in relation to meals (e.g., for levothyroxine, see Table 1), which is more clinically relevant.

The errors were in general of intermediate seriousness; no interventions by the observer were deemed necessary because of potential life threatening errors that were about to occur.

The correlation between the occurrence of administration errors and several potential risk factors is shown in Table 4, both for the univariate and the multivariate analysis.

In the multivariate analysis, the potential risk factors female gender (OR 1.39), ATC medication class antibiotics (OR 11.1), medication crushed (OR 7.83), number of dosages/day/client (OR 1.03), nursing home 2 (OR 3.97), medication not supplied by distribution robot (OR 2.92), time classes "7–10 am" (OR 2.28) and "10 am-2 PM" (OR 1.96) and day of the week "Wednesday" (OR 1.46) are associated with a higher risk of administration errors. By contrast, the use of medication classes 'cardiovascular' (OR 0.44) and "gynaecological" (OR 0.28) are independently associated with a lower risk of administration errors, compared to the use of gastrointestinal medicines as a reference category.

Table 3 ■ Administration Errors for the Nursing Homes, Divided into Categories and into Classes of Seriousness

Nursing Homes	1 N (%)	2 N (%)	3 N (%)	Total n (%)
Categories				
• omission	6 (11)	9 (4.4)	3 (1.8)	18 (4.2)
• unordered medication	2 (3.5)	1 (0.5)	3 (1.8)	6 (1.4)
• wrong administration technique	34 (60)	152 (75)	126 (75)	312 (73)
• wrong dose	4 (7.0)	4 (2.0)	7 (4.2)	15 (3.5)
• wrong time	11 (19)	37 (18)	29 (17)	77 (18)
Total	57 (100)	203 (100)	168 (100)	428 (100)
Seriousness				
• C[1]	23 (40)	45 (22)	135 (80)	203 (47)
• D[2]	34 (60)	158 (78)	33 (20)	225 (53)

[1]Class C: an error has been made and the medication was administered but no harm is done.
[2]Class D: an error has been made which results in an increased frequency of monitoring, but no harm is done.

Table 4 ■ Correlation of Administration Errors with Potential Risk Factors (Statistically Significant Correlations in Multivariate Analysis in Bold)

	Univariate OR (95% CI)	Multivariate OR (95% CI)	Adjusted For
Patient characteristics			
Age (in years)	0.98 (0.96–1.00)	0.99 (0.97–1.01)	gender, ward, day of the week, dosage form, Number of dosages/day/client
Gender			age, nursing home, dosage form, Number of dosages/day/client, supplied by robot
Male	Ref.[3]	Ref.	
Female	1.40 (1.09–1.81)	**1.39 (1.05–1.83)**	
Medication characteristics			
ATC medication class*			ward, dosage form, supplied by robot, medication crushed
Gastro-intestinal	Ref.	Ref.	
Blood	1.45 (1.00–2.11)	1.13 (0.74–1.72)	
Cardiovascular	0.58 (0.42–0.81)	**0.44 (0.30–0.64)**	
Dermatological	0.49 (0.06–4.01)	1.36 (0.13–13.68)	
Gynaecological	0.35 (0.11–1.18)	**0.28 (0.08–0.98)**	
Hormones	0.57 (0.19–1.68)	0.70 (0.23–2.21)	
Antibiotics	7.67 (2.31–25.47)	**11.11 (2.66–46.50)**	
Musculoskeletal	1.71 (0.90–3.24)	1.15 (0.56–2.33)	
Neurological	1.13 (0.84–1.53)	0.76 (0.53–1.08)	
Respiratory	0.39 (0.38–1.11)	0.49 (0.11–2.24)	
Eye	0.68 (0.18–0.84)	0.76 (0.24–2.40)	
Other	0.29 (0.08–5.91)	3.85 (0.40–37.14)	
Dosage form*,†			
Oral powder	Ref.		
Injection	0.20 (0.02–1.72)		
Eyedrop	0.84 (0.27–2.58)		
Solid oral form	2.15 (0.91–5.09)		
Liquid oral form	2.35 (0.92–6.00)		
Cream/ointment	1.05 (0.11–10.06)		
Inhalation form	1.52 (0.56–4.13)		
Medication crushed			nursing home
No	Ref.	Ref.	
Yes	4.00 (3.10–5.17)	**7.83 (5.40–11.36)**	
Number of medicines/day/client[5]	0.98 (0.95–1.01)		
Number of dosages/day/client	1.03 (1.01–1.05)	**1.03 (1.01–1.05)**	no confounders identified
Organization characteristics			
Nursing home			experience nurse attendant, medication crushed
1	Ref.	Ref.	
2	3.33 (2.43–4.57)	**3.90 (2.82–5.41)**	
3	2.96 (2.14–4.09)	1.00 (0.66–1.52)	
Supplied by robot			nursing home, ATC medication class
Yes	Ref.	Ref.	
No	1.82 (1.39–2.37)	**2.92 (2.04–4.18)**	
Time characteristics			nursing home, ATC medication class, day of the week
Time class			
6 PM to 10 PM	Ref.	Ref.	
7 To 10 am	1.58 (1.13–2.20)	**2.28 (1.50–3.47)**	
10 am to 2 PM	1.95 (1.24–3.08)	**1.96 (1.18–3.27)**	
2 PM to 6 PM	1.31 (0.89–1.94)	1.31 (0.87–1.99)	
Day‡			gender, nursing home, experience nurse attendant, time class
Monday	Ref.	Ref.	
Wednesday	1.09 (0.80–1.49)	**1.46 (1.03–2.07)**	
Thursday	0.90 (0.65–1.25)	0.76 (0.53–1.09)	
Friday	1.61 (1.21–2.12)	1.03 (0.74–1.43)	
Nurse attendant characteristics			nursing home, day of the week, training of nurse attendant, medication crushed
Experience (in years)			
0–1	Ref.	Ref.	
1–5	0.45 (0.29–0.70)	0.45 (0.17–1.22)	
> 5	0.48 (0.32–0.72)	0.54 (0.21–1.42)	

Table 4 ■ (continued)

	Univariate OR (95% CI)	Multivariate OR (95% CI)	Adjusted For
Training			nursing home, day of the week, experience nurse attendant, time class, medication crushed
Registered nurse	Ref.	Ref.	
Nurse attendant	0.56 (0.32–0.96)	0.78 (0.42–1.45)	
Trainee nurse attendant	1.14 (0.57–2.27)	0.57 (0.14–2.31)	

OR = odds ratio, CI = confidence interval, Ref. = reference category.

*Classes with one or more empty cells are not shown (e.g., medication class ocular: only three administrations that all contained one or more errors).

†Univariate analysis showed no significant correlations, so multivariate analysis not performed.

‡Tuesday not measured because of unavailability of observer.

Discussion

This is a study within three nursing homes, that uses the disguised observation technique for the assessment of medication administration errors and that also looked into potential risk factors for administration errors. The main findings reflected that administration errors were most likely to occur in the distribution process steps, that are not covered by the robot, i.e., crushing of medication and the administration of medication that cannot be supplied by the robot (e.g., liquid dosage forms, inhalation forms). Other studies using the disguised observation technique to study administration errors in nursing homes (without specification of the use of dispensing robots in the studies), identified error frequencies of 25%[7] and 36%,[8] which are (slightly) higher than our frequency of 21%.

The seriousness class of the errors was intermediate, which means that they were judged by the raters as unlikely to have caused damage to the patients. However, adverse events were not actually studied in the patients, which is a limitation of this study. As even non-serious errors may be indicators of failures in the medication distribution system that potentially lead to more serious errors, they deserve the same attention as serious errors.

The distribution robot was introduced in nursing homes to minimalize medication dispensing and administration errors, which is supported by some studies looking into the effect of point-of-use distribution robots in hospitals.[5,6] Introduction of these robots resulted in lowering of error frequencies in these hospitals. By contrast, Balka et al warn for an over-optimistic view on the effect of automatic drug dispensing systems on patient safety.[13] They suggest two main reasons for a potentially limited effect on patient safety, namely the fact that these automated systems do not prevent all types of errors and the fact that work processes are influenced by the introduction of such systems. This last reason implies that a careful implementation process is necessary to introduce the automated system safely.

Our study seems to confirm these warnings by Balka et al as it shows that even in nursing homes for which medication is dispensed by a distribution robot, the error frequency is still high. This can be explained by the complexity of tasks that have to be performed and that are not supported by the robot (yet). Whether implementation issues may have also played a role in this high error frequency was not specifically studied by us, but merits attention in future studies.

Our study indicates that the observed administration errors rarely occur with respect to the error types that the robot may prevent (i.e., omission errors, unordered medication administered and wrong dose errors), but occur mainly in handling the medication after removing it from the distribution robot package, i.e., the administration technique errors. For example, our study indicates that crushing of medication is a potential risk factor for administration errors. In nursing homes many clients have difficulty in swallowing medication, so nurse attendants often crush their medication and mix the crushed medication through their food. This results in many errors, which is confirmed by two earlier studies identifying crushing of medication for administration through the enteral feeding tube as a potential risk factor for administration errors.[11,14]

Another frequently occurring error was lack of supervision of medication intake by the nurse attendant, although this was clearly mentioned on the medication administration list of the client. In nursing home inhabitants suffering from dementia, supervision is necessary to ensure the medication is actually taken and to prevent demented clients from taking the wrong medication. We feel this error may be caused by understaffing, which is a problem in Dutch nursing homes. Although we have not actually measured workload, potential risk factors that are an indication for workload (number of dosages per day per client, time classes in the morning hours when clients need assistance to get of out bed and to get washed and dressed) show a positive correlation with the occurrence of administration errors, thus strengthening this hypothesis. Pharmacists may help in reducing this workload by considering which medications can be administered in the afternoon or evening instead of in the morning hours.

Understaffing may also explain the correlations found for nursing home 2 and Wednesday, but these potential risk factors are less clearly associated with workload and we have not explored this in more detail.

For the potential risk factor medication class, the correlation of antibiotics with administration errors is most pronounced. This can be explained by the fact that antibiotics are given in short courses and thus are not part of the long-term medication of the patient. The nurse attendant builds up routine with long-term medication but is more likely to make administration errors with medication that is given for short-term courses. The negative correlations of

cardiovascular and gynaecological medication with errors may be explained by the reverse phenomenon: these classes contain much chronic medication.

Finally, female gender of the patient was identified as a potential risk factor for administration errors. No explanation can be given for this correlation as it seems unlikely that patient gender influences the risk of administration errors. Probably other unknown confounders have influenced this correlation. Future studies should therefore look into other potential risk factors to determine additional potential risk factors for administration errors.

Also, future controlled studies should be designed to look more closely at medication administration errors and their causes, especially in relation to further developments in robots and in automated clinical decision support for more complex tasks. This clinical decision support should not only warn for potential errors (e.g., "this medication is not allowed to be crushed"), but should also provide alternatives for the specific patient category (e.g., "use the liquid form of this medicine in case the patient cannot swallow"). In that way the prescribing physician can already make the right choice in stead of placing such decisions with nurse attendants.

A limitation of our study is the short study period and the fact that the observations were carried out during the daytime on four days of the week only. Therefore, the conclusions on time class and day of the week as potential risk factors have to be drawn with caution. Another limitation is the fact that we were not able to study more direct indicators of workload. Such indicators, including for example the number of nurse attendants per 100 clients and the complexity of care (using disease severity indexes as measures) should be the subject of future studies.

Finally, the study was performed in three nursing homes only, which may limit the generalizability.

Because of these limitations and the fact that we have not conducted a controlled but a mere observational study, the findings need to be interpreted as preliminary findings that require confirmation in controlled studies. Nevertheless, the information provided by this study indicates the type of errors and potential risk factors for these errors in nursing homes using distribution robots for dispensing medication. The study indicates that the use of a distribution robot results in relatively low frequencies of errors that the robot is able to prevent technically (e.g., omission errors, wrong dose errors), but also that a distribution robot (in its present form) has no influence on errors in handling the medication after removing it from the robot package.

Conclusions

Medication administration errors are common in the nursing homes studied, even though they are already using a distribution robot with the purpose to diminish these errors. This can be explained by the complexity of tasks that cannot be supported by the robots. The potential risk factors with a statistically significant correlation with errors (such as "crushing of medication") support the conclusion that especially complex tasks lead to errors in nursing homes with distribution robots.

After additional studies have confirmed our preliminary findings, the identified potential risk factors and causes may be the focus for future improvements to reduce this error frequency. Especially, training in appropriate medication crushing, automated clinical decision support for information on crushing and for performing other complex tasks, and reduction of workload to optimize medication intake supervision may result in fewer medication errors. Controlled studies should confirm the effects of such measures.

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