

Safeguarding the process of drug administration with an emphasis on electronic support tools

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WHAT IS ALREADY KNOWN ABOUT THIS SUBJECT

- Similar to prescription errors also drug administration errors contribute to a large fraction of preventable medication errors and adverse drug events.
- Drug administration can be exceedingly complex with regard to dose form, route of administration, number of co-medications, and setting and accordingly, error rates may vary.

WHAT THIS STUDY ADDS

- The drug-specific drug administration process can be generically structured for distinct dosage forms to allow identification of particularly error prone steps and allocated prevention strategies.
- Potential research gaps in error epidemiology and prevention are highlighted.

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AIMS

The aim of this work is to understand the process of drug administration and identify points in the workflow that resulted in interventions by clinical information systems in order to improve patient safety.

METHODS

To identify a generic way to structure the drug administration process we performed peer-group discussions and supplemented these discussions with a literature search for studies reporting errors in drug administration and strategies for their prevention.

RESULTS

We concluded that the drug administration process might consist of up to 11 sub-steps, which can be grouped into the four sub-processes of preparation, personalization, application and follow-up. Errors in drug handling and administration are diverse and frequent and in many cases not caused by the patient him/herself, but by family members or nurses. Accordingly, different prevention strategies have been set in place with relatively few approaches involving e-health technology.

CONCLUSIONS

A generic structuring of the administration process and particular error-prone sub-steps may facilitate the allocation of prevention strategies and help to identify research gaps.

Introduction

Drug administration as a relevant part of the drug treatment process

In contrast to drug prescription, which mostly lies in the hands of health care personnel, drug administration is everyday practice for almost any human [1]. Hence, in ambulatory care, only a small fraction of drugs are administered by trained personnel such as mobile nursing services, while most drugs are actually administered by patients, family members, or even teachers and school secretaries, all of whom are untrained and have no medical background [2, 3].

Drug administration is an inherent part of everyday life for both adults and children and when asked, every second child (50.8% of 0–17 year olds) [4] and more than two-thirds of adults (71.5% of 18–79 year olds) in Germany stated that they administered drugs during the previous week (data from 2003–2006 [5]). More than 50% of adults administer drugs daily [6]. This fact, however, does not automatically make drug administration a safe and straightforward process and, indeed, drug administration errors are frequent and in the inpatient setting, roughly 30% of errors resulting in adverse drug events (ADE) happen during drug administration [7]. Comparably susceptible to errors is the prescription process [7]. Whereas for the prescribing process electronic prescription platforms with enhanced clinical decision support tools were implemented as promising error prevention strategy [8], similar and theory-driven approaches are only scarcely available for the administration process [9], even though introduction of electronic support in the drug administration process has shown to reduce error rates [10].

Drug treatment is a rather complex and demanding task (Figure 1) and depending on the setting and co-medication a great number of different errors may occur. The aim of this study was to structure the drug administration process (process 5 in Figure 1) in a way that allowed the allocation of current knowledge on frequent sources of errors as well as successful methods to prevent such errors with a particular emphasis on electronic tools. Concurrently, known unexplored sources of errors in the administration process are described to highlight critical, error prone steps and promising measures of error prevention. Therefore this paper should encourage research in the many areas of uncertainty, help generate knowledge of the administration process and ultimately stimulate system changes to eliminate the very numerous errors in this field.

Methods

Description of the drug administration process

To describe the drug administration process, we discussed in peer groups consisting of clinical pharmacists and a clinical pharmacologist drug administration processes for

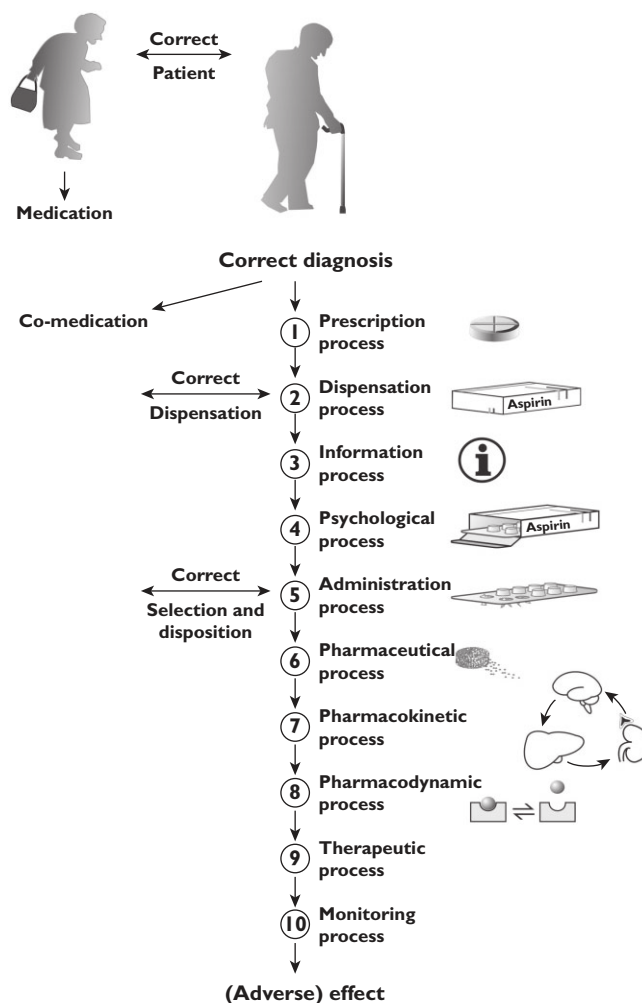


Figure 1

Whenever a drug is prescribed, 10 processes must be carried out in a well-organized sequence to make treatment successful. Each of these processes makes special demands, may be diverse and complex and may be flawed by a range of errors thus requiring rigorous quality management. After selection of an appropriate drug and its prescription (1), the drug has to be dispensed (2) and the patient or health care provider has to be informed about its proper use (3). Then the patient has to be motivated to adhere to this treatment regimen (4) and to ultimately perform a more or less complex sequence of preparation and administration steps (5). In the subsequent pharmaceutical process (6) the drug has to be released from the formulation to get absorbed, distributed and ultimately eliminated (7). Only if the drug reaches the target compartment will it elicit its pharmacodynamic effect (8), which will ultimately produce the intended therapeutic response (or adverse events) (9). Finally, each drug therapy should be monitored appropriately (10) to differentiate between success, excessive exposure and nonresponse

relevant drug forms and routes of administration and described evident sub-steps in detail. Based on this specification we could identify similarities and differences. In order to check whether we missed important steps, we screened the literature on drug administration errors for sub-steps that reportedly trigger administration errors

(Medline search term: ('Drug Administration Routes/instrumentation'[Mesh] OR 'Drug Administration Routes/methods'[Mesh] OR 'medication administration') AND ('Medication Errors'[Mesh] OR 'drug administration error' [all fields])) (last search performed on 6 March 2013).

Within the process of drug administration, we determined that a correct drug administration process would not only require the appropriate preparation of the correct single drug dose, but also the consideration of time, route of administration, administration technique, context factors and appropriate monitoring (Table 1). Even if the distinct application step was performed correctly, drug administration could be erroneous in the context of the individual situation. A typical example is the simultaneous administration of infusions that are pharmaceutically not compatible and will therefore precipitate [11–13]. While we aimed to describe a drug-centred administration process, there are also setting-specific constraints (e.g. dispensing or picking errors in the pharmacy as well as selection of the wrong patient or faulty documentation of the administration process) that may be considered as administration errors and are therefore commonly reported in observational trials. Moreover, we put the main emphasis of this study on regular drug administration and we did not specifically consider particular drugs that require well-defined application techniques and have standardized or particular constraints, such as chemotherapeutics.

Epidemiology of drug administration errors and options for prevention

We employed the above mentioned literature search to identify the frequency and nature of drug administration errors. We aimed to describe the epidemiology of drug administration errors according to the above mentioned scheme of relevant sub-steps in drug administration (without focusing on specific indications but only on specific dosage forms) and allocated prevention strategies where appropriate. Hence, this approach would regroup different types of errors such as wrong dose errors, wrong time errors, omission and commission errors which served in many earlier studies as error categories [14].

To identify solutions based on electronic information and technology systems for prevention of administration errors we performed a specific search ('Drug Administration Routes'[Mesh] OR 'self administration'[Mesh] OR 'medication administration') AND 'Medication Errors'[Mesh] AND 'Decision Support Systems, Clinical'[Mesh]) (last search performed on 6 March 2013).

Results

Description of the drug administration process

We analyzed drug administration processes for frequent (according to [15]) or specific dosage forms, i.e. solid and

liquid oral drugs, inhalers, eye drops, nasal sprays, ointments, transdermal systems, suppositories, infusions and injections. As a result, we concluded that the drug administration process might consist of up to 11 drug-related sub-steps that can be grouped into the four sub-processes of preparation, personalization, application and follow-up and that are framed by three setting-related sub-steps (i.e. delivery of drug, identification of patient (before the drug-related administration process) and documentation (after drug-related administration process) (Figure 2, Table 1)). Hence, this description of the drug administration process complements the error- and process-related description of the administration process with the nine Rs [16].

Epidemiology of drug administration errors and options for prevention

Errors in drug handling and administration are diverse and frequent (Table 1) and in many cases not caused by the patient him/herself, but by family members [17] or the professional provider administering the drug [11–13, 17–19]. Accordingly, different prevention strategies have been set in place (Table 1). A substantial fraction of errors ultimately leading to flaws in the administration process is not linked to different steps of the administration process itself but rather to setting-related constraints such as the identification of the right patient [20, 21] or the documentation of drug administration (responsible for 13% of all errors classified as administration errors in one study [20]), or the administration at the right time. Most of the e-health technologies focus on these setting-related constraints, i.e. barcoding patients, automated dispensing systems and medication administration records.

Error frequency might vary along with the medication error detection method. In the inpatient setting, the most common technique is direct observation, where a third person, openly or disguised, observes the process of drug administration and documents important steps by using checklists [18, 22]. Direct observation can both reduce and increase error rates. On the one hand, observation can lead to increased attention of the person being observed ('Hawthorne' effect) and on the other, it can lead to increased nervousness and insecurity. However, while Hawthorne effects have been described [23], these effects seem to be reducible if the observation spans across a longer period of time [24]. Direct observation can also be employed with patients or family members to detect administration errors when using inhalers [25–28], insulin pens [29], eye drops [30, 31], parenteral drugs [17, 18, 32, 33] or per oral drugs [17], for instance. Such assessments form the basis to describe the epidemiology of administration errors as well as other influencing variables and are essential to describe the benefit of potential error prevention strategies.

Table 1

Process steps in drug administration, sources and frequencies of errors and options for error prevention

Number	Title	Description	Error sources and error frequencies	Prevention strategies	Electronic support
1	Identification and removal from the secondary packaging	Identification of the drug (prevention of sound-alike [62, 63] or look-alike [64] confusion) and opening of the secondary packaging to remove the drug are the first steps in drug administration.	<ul style="list-style-type: none"> • Ambulatory care: 2% of patients claimed to have difficulties in identifying the drug package and 10% in opening the secondary packaging [35]. • Hospital care: picking errors account for 23% of disposition errors and are mostly caused by confusions of the strength and more rarely of names [62]. About 2% of picking processes in the inpatient care setting are erroneous [55]. 	<ul style="list-style-type: none"> • Modification of the labelling (e.g. tall man lettering [65, 66]) or introduction of colour codes [67, 68]. Controversially discussed [69], especially because the introduction of new colour codes has been shown to be associated with higher error-rates during and right after the transition time [70]. 	<ul style="list-style-type: none"> • Hospital care: Automated dispensing cabinets or carousels [71] reduce identification errors with varying impact [72]; unit-based drug-dispensing cabinets reduce the overall medication error rate [73]. Scanning drug packages for identification reduced administration errors [20] and integration of RFID solutions might be future solutions [74].
2	Removal from the immediate packaging	Removal from the immediate packaging before application (e.g. blister, dropping device or ampoule). This is also important if capsules have to be removed from their blister to put them into an inhaler.	<ul style="list-style-type: none"> • 10–25% of elderly patients expressed difficulty removing drugs from blisters [75–78], 14% had difficulties in opening screw-tops [76], 40–62% in opening plaster packaging [77], 12–64% in opening childproofed closures [75, 77, 78] and two thirds of patients with rheumatic arthritis in opening suppository packaging [79] (54% could not remove suppository [80]). 	<ul style="list-style-type: none"> • Before drug selection, the physical capabilities of the person in charge should be checked, e.g. by measuring hand grip strength [81, 82]. • If the person in charge is likely to fail and no alternative is available, medical aids can be added. 	<ul style="list-style-type: none"> • No support options with electronic tools have been reported.
3	Preparation of medical aids and devices	Medical aids can be part of the brand (e.g. insulin pen or inhaler), or may be added to the drug administration process to support the person in charge. They should be selected carefully to match the patient's needs.	<ul style="list-style-type: none"> • 17–29% of patients fail to open medication organizers (Dosett) [75, 78]. • Inappropriate devices to split tablets are frequently applied [83, 84] or proper use of the device is not appropriately trained [49]. • Parenteral administration systems must be prepared before administering the drug [85, 86]. 	<ul style="list-style-type: none"> • For these steps, education programmes and practical training courses for patients, family members and nurses have been developed and tested [13, 17, 48, 87, 88]. Besides verbal counselling, written information without [17, 89] and with pictograms [90, 91], video tapes [92] and practical training under supervision have been employed [17]. Also interactive teaching strategies [88] and implementation of medical aids such as calculators [25, 93] can reduce errors during this step, particularly if the teaching strategy is tailored to the target group [94]. 	<ul style="list-style-type: none"> • Education and training can also be supported with e-learning modules [96, 97].
4	Preparation of drug	Drugs with differing dispensing and administration form need to be prepared in one step (e.g. solving effervescent tablets before use) or several sub-steps (e.g. preparing a powder for IV administration). Drug preparation may impact the stability of the drug and hence its storage conditions, shelf life (subsequent steps must be performed within a certain time frame) or even dosage.	<ul style="list-style-type: none"> • 30% of faulty intravenous administrations resulted from inappropriate solvents or wrong volumes [18, 32, 33, 98]. • In oral administrations, >50% of crushing or splitting processes and >80% of dissolving processes before administration via tube are erroneous [17], and in nursing homes, 10% of patients received oral drugs in an unauthorised modification [99] with crushing tablets and opening capsules being the most frequent administration errors [100]. • When administering inhalative drugs, 13–45% of the patients do not shake the inhaler before use [25–28]. • In 25% of administrations, dropping devices are incorrectly employed [48]. • With eye drops up to 80% higher doses are administered [30], and with nasal drops, up to 86% of patients administered wrong doses [101]. • Inconsistent labelling [102] or inappropriate measuring devices [103] result in wrong dosage of liquid formulations (67% vs. 15% when using an oral syringe vs. a cup). • 1% of tablets prohibited to split are split [104, 105] • Inhaled drugs are overdosed by 3–22% of patients [26, 28]. • Parenteral drug application is particularly error prone (calculation errors) [18, 32, 33, 98]. 	<ul style="list-style-type: none"> • For these steps, education programmes and practical training courses for patients, family members and nurses have been developed and tested [13, 17, 48, 87, 88]. Besides verbal counselling, written information without [17, 89] and with pictograms [90, 91], video tapes [92] and practical training under supervision have been employed [17]. Also interactive teaching strategies [88] and implementation of medical aids such as calculators [25, 93] can reduce errors during this step, particularly if the teaching strategy is tailored to the target group [94]. 	<ul style="list-style-type: none"> • Education and training can also be supported with e-learning modules [96, 97].
5	Dose individualization	Before, during, after, or instead of drug preparation a dose preparation step might be necessary such as splitting a tablet (without preceding preparation), splitting a tablet before crushing it (before preparation) or measuring a syrup with a measuring container (after preparation).	<ul style="list-style-type: none"> • 10–25% of elderly patients expressed difficulty removing drugs from blisters [75–78], 14% had difficulties in opening screw-tops [76], 40–62% in opening plaster packaging [77], 12–64% in opening childproofed closures [75, 77, 78] and two thirds of patients with rheumatic arthritis in opening suppository packaging [79] (54% could not remove suppository [80]). 	<ul style="list-style-type: none"> • Before drug selection, the physical capabilities of the person in charge should be checked, e.g. by measuring hand grip strength [81, 82]. • If the person in charge is likely to fail and no alternative is available, medical aids can be added. 	<ul style="list-style-type: none"> • No support options with electronic tools have been reported.

6	Disposition	Before the drug is applied, the medication is dispensed and eventually checked by a third party. Disposition can be bundled (for instance in long term care) and can also take place before step 4 and 5.	<ul style="list-style-type: none"> Context factors can facilitate the occurrence of disposition errors [42] and in a nursing home, 7% of drugs dispensed in pill organizers were wrong [105]. 	Disposition of drugs is often linked with handovers and information loss. Disposition errors can be reduced by introduction of unit dose systems [106] or single packaged drugs that allow identification of the single dose.	<ul style="list-style-type: none"> Ward-based automated dispensing cabinets can reduce disposition errors [70]. There are no electronic checks for pre-filled pill organizers.
7	Harmonization with the co-medication and context	Single doses have to be harmonized with the co-medication in order to prevent incompatibilities (e.g. precipitation) and maximize therapeutic efficacy.	<ul style="list-style-type: none"> Intensive care: 6% of infusions were incompatible [11] and >50% of intensive care patients received at least one incompatible combination [13]. Regular care: 3% of infusions were incompatible [98]. Regular care: 2.3% [19] – 13.9% [107] of all administration errors were due to administration of oral drugs with food if fasting state would be recommended. 	Prevention of incompatible drugs can be trained [11] and optimized by information leaflets [11, 13]. If process changes are induced, training effects are sustained [12].	Information on incompatible drugs can be provided in electronic CDS [108].
8	Application/ intake	Depending on the route of application and the technique of intake, drug application consists of one to several more or less complicated sub-steps that determine the complexity of drug administration and, accordingly, potential training needs and odds for failure and success.	<ul style="list-style-type: none"> Intensive care: 0.8 errors per administration for gastric tube applications (compared with 0.6 for parenterals and 0.2 for per orals [18]). Nurses performed 40% of application processes faultily, patients up to 97% of processes [17, 18]. Patients are prone to apply inhaled drugs wrongly (30–60% of patients with critical errors [25–28], followed by injection and oral liquids [109]. >70% of patients apply eye drops faultily [30, 31, 110]. 73.3% of i.v. errors refer to the rate of infusion and 33.3% to the volume [32, 111]. In another study, a too rapid bolus injection was the most frequent i.v. error (49.7%) [112]. 	<ul style="list-style-type: none"> The distinct steps of drug application can be optimized by policies or educational training [11, 17, 26, 28, 30, 31]. Medical aids can reduce error rates (e.g. eye drops dispenser with visual support [47], pre-filled insulin pens instead of using syringes and vials [29] or with specific techniques to reduce required strength [113]). Unique devices (e.g. luer vs. non-luer) may prevent route errors, if tested [114]. 	The electronic device most frequently introduced and analyzed are smart pumps [115]. Benefit and potential risk must be closely monitored [116] and efficient error reduction requires linkage to EHR [117] and/or barcode-assisted administration [118].
9	End of application	Some drug applications require active termination (e.g. infusion pumps, transdermal systems).	<ul style="list-style-type: none"> Case reports describe excessive and potentially fatal doses if continuous application is not actively stopped [38, 39, 119]. 		Smart pumps usually support active termination by alarm signals.
10	Follow-up	Some medical aids need a follow-up (e.g. cleaning of inhalation devices).	<ul style="list-style-type: none"> Healthcare workers are exposed to unintended needlestick injuries (about 16.9 injuries /100.000 devices used [120,121]. 		
11	Monitoring	Specific monitoring for successful administration (e.g. that suppository remains in the rectum [123]).	<ul style="list-style-type: none"> A specific monitoring after inhaled drugs is neglected by up to 50% of patients [26]. 	Introduction of safety needle devices can reduce the error rates [120].	Video surveillance can identify [25] and monitor [122] patients with wrong inhalation technique.

CDS, clinical decision support; EHR, electronic health record; RFID, radio-frequency identification.

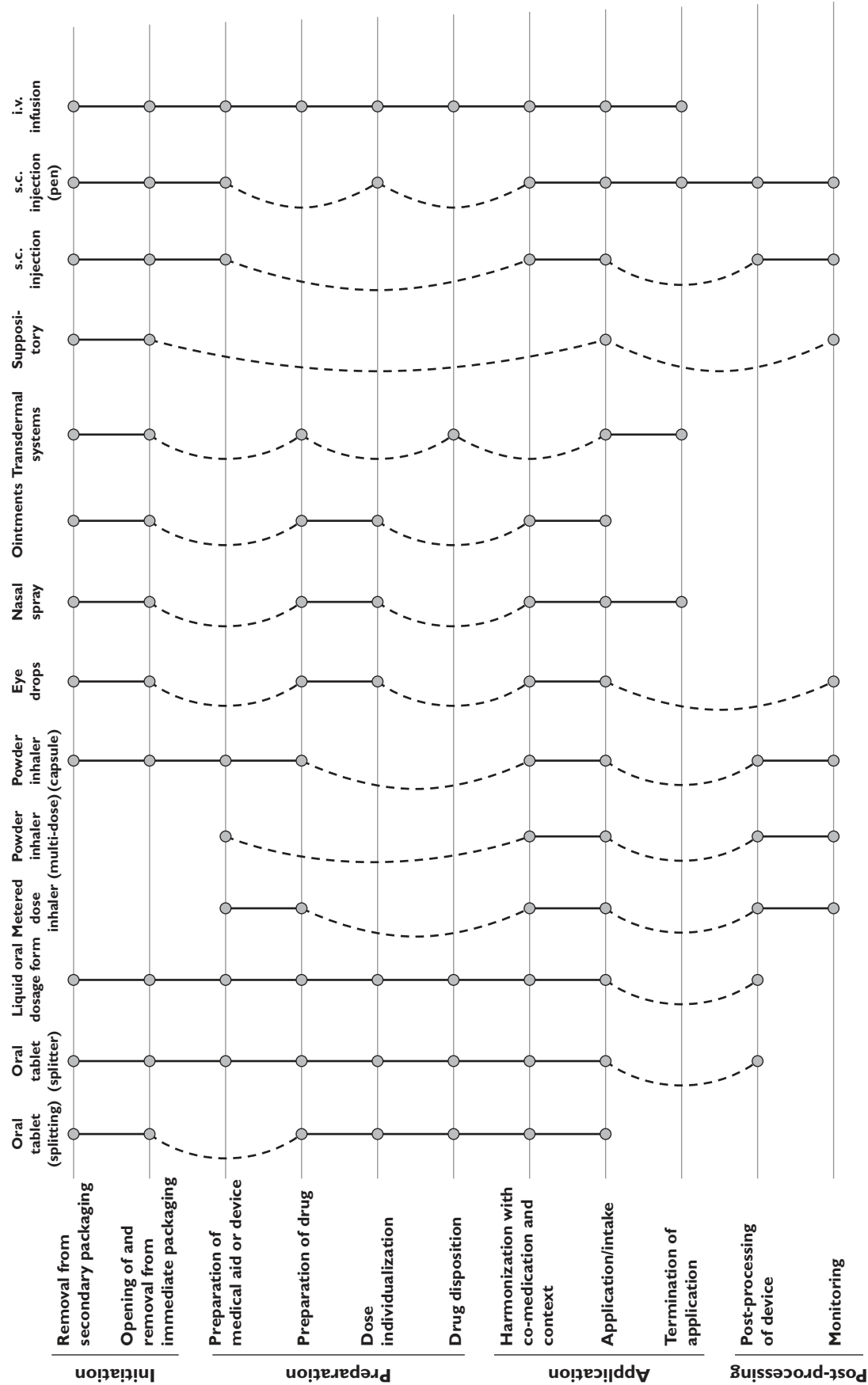


Figure 2

Depiction of different variants of process sequence in the drug administration process. Described are different drug dose forms and aligned medical aids. Dotted lines are sub-steps that are performed automatically or are not required

Discussion

When looking at the entire drug treatment process, early studies suggested that in inpatient care, one in three medication errors was related to the drug administration process [7]. At this time, there are few corresponding studies for the ambulatory sector. However in one paediatric study, 70% of preventable ADEs were related to drug administration by parents [34]. Given the frequency of drug administration, the complexity and multitude of required sub-steps, and the number of involved people some of whom are not trained in drug administration, it seems reasonable to assume that drug administration errors might even be far more prominent in the ambulatory setting than in the hospital setting. Moreover, in contrast to the prescription process, the administration process is the last step before the drug actually reaches the patient. Whereas drug prescription errors can be detected and corrected during the course of the treatment process (near-misses), drug administration errors are costly to detect, difficult to intercept, and may, therefore, have a high risk of reaching the patient and translating into an adverse patient outcome. Indeed, flaws and deficits in each sub-step of drug administration might entail adverse outcomes, while different outcomes are typically linked to distinct sub-steps. For instance, problems in correct identification of drug packages are likely to be associated with decreased adherence [35], as are difficulties in handling drugs during the personalization process (e.g. tablet splitting [36, 37]), whereas errors in drug dosage and drug application are related to non-response [38] or toxicity [39, 40]. Hence, the prevention of drug administration errors appears important, particularly in the ambulatory care setting, where the incidence rate might be higher and subsequent strategies to counteract adverse outcomes following administration errors might be less accessible. To minimize sources of error in drug administration, their identification and specification is crucial. Hence, various efforts were made to render the general classification of 'prescription and administration errors' more precise [14, 41] and develop the basis for a targeted implementation of error prevention strategies. Both explorative and qualitative assessments [42] as well as structured (semi-) theoretical approaches such as failure mode and effects analysis (FMEA) [43] with a specific emphasis on reliability [44] have been employed to describe drug administration processes. The more precisely the administration process is divided into its sub-steps, the easier observation techniques can be employed to assess drug administration [18] and the effect of intervention strategies. This will also form the basis for targeted interventions aimed at improving such deficits. Generally, administration errors can either result from treatment- or process-related faults (e.g. picking the wrong drug or treating the wrong patient) or from drug-specific challenges (e.g. crushing a sustained-release

tablet). Hence, approaches to reduce administration errors may focus on the drug itself, the entire process in a given setting as well as the individual patient or a specific patient population. In either case, the error source (e.g. slips or oversights, gaps in knowledge, violations of established rules, lack of skills or false beliefs) will determine the most appropriate set of prevention strategy.

To date, most interventions have aimed at reducing the overall rate of administration errors without focusing specifically on critical sub-steps. Such global measures were mainly intended to optimize or disentangle the entire process by improving the surrounding conditions (e.g. reducing disturbances) [45], introducing in-process controls [46], or selecting [29] or modifying [47] medical aids and appliances. These should, however, be chosen individually and integrated carefully to reduce errors successfully [26, 27, 48–51]. If the error is not linked to a particular step of the drug-specific administration but rather to the setting-specific treatment process (e.g. selection of the wrong patient), the implementation of barcoding has shown benefits both in reducing dispensing errors [52] as well as administration errors, particularly if the patient was also scanned before drug administration [20, 21]. This benefit is not seen in all studies [53] and is potentially more evident if barcoding is linked to electronic medication administration records [54]. Moreover, a simplification of the entire process by reducing or automating the necessary sub-steps can reduce error rates [55] or avoid errors altogether. For instance, pre-filled multidose inhalers [25] or pre-filled insulin pens [28], which can be more easily administered, show lower error rates than single dose inhalers or refill pens. Moreover, drug adherence is better with insulin pens than with syringes and ampoules [56].

Electronic information and technology systems have only been scarcely evaluated as approaches for error prevention within the distinct drug administration process and focus most often on the administration of intravenous drugs (smart pumps). However, there are a variety of electronic tools that have been assessed as reminder or alert systems before drug administration actually takes place with varying results. In one study, complete oblivion could be decreased by reminders via voice mail [57]. Text messages showed both higher persistence of adherence rates [58] as well as no impact in another patient population where text messages did not improve adherence [59]. Reminding systems might be particularly successful, if they consider context factors and issue dynamic alerts [60]. For ambulatory patients, complete medication management systems that are supposed to provide the patient with the right drug at the right time and remind him/her to take the medicine have been developed but not yet evaluated to measure their potential benefit [61].

Table 2 offers an overview of potentially risky sub-steps and currently available data on error frequencies and options for preventions. Hence, this table might guide both future research activities in order to close the gaps and

Table 2

Alignment of potentially error prone sub-steps of drug administration with reported errors and published evidence on error prevention

	Oral tablet (splitting)	Oral tablet (splitter)	Liquid oral dose form	Metered dose inhaler	Powder inhaler (multi-dose)	Powder inhaler (capsule)	Eye drops	Nasal spray	Ointments	Trans-dermal systems	Suppository	s.c. injections	s.c. injections (pen)	i.v. infusions
	E	P	E	P	E	P	E	P	E	P	E	P	E	P
Removal from secondary packaging	ER		ER		ER		ER		ER		ER		ER	
Opening and removal from immediate packaging	ER		ER		ER		ER		ER		ER		ER	
Preparation of medical aid of device	ER	PR	ER	PR	ER	PR	ER	PR	ER	PR	ER	PR	ER	PR
Preparation of the drug	ER	PR	ER	PR	ER	PR	ER	PR	ER	PR	ER	PR	ER	PR
Dose individualization	ER	PR	ER	PR	ER	PR	ER	PR	ER	PR	ER	PR	ER	PR
Drug disposition	ER	PR	ER	PR	ER	PR	ER	PR	ER	PR	ER	PR	ER	PR
Harmonization with co-medication	ER	PR	ER	PR	ER	PR	ER	PR	ER	PR	ER	PR	ER	PR
Application/intake	ER	PR	ER	PR	ER	PR	ER	PR	ER	PR	ER	PR	ER	PR
Termination of application	ER	PR	ER	PR	ER	PR	ER	PR	ER	PR	ER	PR	ER	PR
Post-processing of device	ER	PR	ER	PR	ER	PR	ER	PR	ER	PR	ER	PR	ER	PR
Monitoring	ER	PR	ER	PR	ER	PR	ER	PR	ER	PR	ER	PR	ER	PR

empty cell = no information available; grey-shaded cell = sub-step is not necessary. ER, errors reported; PR, prevention reported.

serve as checklist to identify potentially error prone processes in an individual setting.

Competing Interests

All authors have completed the Unified Competing Interest form at http://www.icmje.org/coi_disclosure.pdf (available on request from the corresponding author) and declare no support from any organization for the submitted work, no financial relationships with any organizations that might have an interest in the submitted work in the previous 3 years and no other relationships or activities that could appear to have influenced the submitted work.

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REFERENCES

- 1 Haefeli WE. Verabreichungsfehler: welche Informationen braucht ein Patient um seine Arzneimittel-Therapie sicher durchzuführen? *Ther Umsch* 2006; 63: 363–5.
- 2 Price JH, Dake JA, Murnan J, Telljohann SK. Elementary school secretaries' experiences and perceptions of administering prescription medication. *J Sch Health* 2003; 73: 373–9.
- 3 Torre CT, Crowley AA. The diffusion of innovation in nursing regulatory policy: removing a barrier to medication administration training for child care providers. *Policy Polit Nurs Pract* 2011; 12: 141–9.
- 4 Knopf H. Arzneimittelanwendung bei Kindern und Jugendlichen. Erfassung und erste Ergebnisse beim Kinder- und Jugendgesundheitsurvey (KiGGS). Ergebnisse des Kinder- und Jugendgesundheitsurveys (KiGGS). *Bundesgesundheitsblatt Gesundheitsforschung Gesundheitsschutz* 2007; 50: 863–70.
- 5 Knopf H, Melchert HU. Bundes-Gesundheitssurvey: Arzneimittelgebrauch. 2003.
- 6 Knopf H, Melchert HU. Subjektive Angaben zur täglichen Anwendung ausgewählter Arzneimittelgruppen – Erste Ergebnisse des Bundes-Gesundheitssurveys 1998. *Gesundheitswesen* 1999; 61: (Sonderheft 2): S151–S157.
- 7 Bates DW, Cullen DJ, Laird N, Petersen LA, Small SD, Servi D, Laffel G, Sweitzer BJ, Shea BF, Hallisey R, Vander Vliet M, Nemeskal R, Leape LL. Incidence of adverse drug events and potential adverse drug events. Implications for prevention. ADE Prevention Study Group. *JAMA* 1995; 274: 29–34.
- 8 Bates DW, Leape LL, Cullen DJ, Laird N, Petersen LA, Teich JM, Burdick E, Hickey M, Kleefield S, Shea B, Vander Vliet M, Seger DL. Effect of computerized physician order entry and

- a team intervention on prevention of serious medication errors. *JAMA* 1998; 280: 1311–6.
- 9 Wulff K, Cummings GG, Marck P, Yurtseven O. Medication administration technologies and patient safety: a mixed-method systematic review. *J Adv Nurs* 2011; 67: 2080–95.
 - 10 Franklin BD, O'Grady K, Donyai P, Jacklin A, Barber N. The impact of a closed-loop electronic prescribing and administration system on prescribing errors, administration errors and staff time: a before-and-after study. *Qual Saf Health Care* 2007; 16: 279–84.
 - 11 Bertsche T, Mayer Y, Stahl R, Hoppe-Tichy T, Encke J, Haefeli WE. Prevention of intravenous drug incompatibilities in an intensive care unit. *Am J Health Syst Pharm* 2008; 65: 1834–40.
 - 12 Bertsche T, Münk L, Mayer Y, Stahl R, Hoppe-Tichy T, Encke J, Haefeli WE. Sustained effect of implementation of a standard operation procedure to prevent intravenous drug incompatibilities in an intensive care unit after one year. *Am J Health Syst Pharm* 2009; 66: 1250, 1253.
 - 13 Bertsche T, Veith C, Stahl A, Hoppe-Tichy T, Meyer FJ, Katus HA, Haefeli WE. A purging procedure for pantoprazole and 4-lumen catheters to prevent i.v. drug incompatibilities. *Pharm World Sci* 2010; 32: 663–9.
 - 14 American Society of Hospital Pharmacists. ASHP guidelines on preventing medication errors in hospitals. *Am J Hosp Pharm* 1993; 50: 305–14.
 - 15 Witticke D, Seidling HM, Klimm HD, Haefeli WE. Do we prescribe what patients prefer? Pilot study to assess patient preferences for medication regimen characteristics. *Patient Prefer Adherence* 2012; 6: 679–84.
 - 16 Elliott M, Liu Y. The nine rights of medication administration: an overview. *Br J Nurs* 2010; 19: 300–5.
 - 17 Bertsche T, Bertsche A, Krieg E-M, Kunz N, Bergmann K, Hanke G, Hoppe-Tichy T, Ebinger F, Haefeli WE. Prospective pilot intervention study to prevent medication errors in drugs administered to children by mouth or gastric tube: a program for nurses, physicians and parents. *Qual Saf Health Care* 2010; 19: e26.
 - 18 Bertsche T, Niemann D, Mayer Y, Ingram K, Hoppe-Tichy T, Haefeli WE. Prioritising the prevention of medication handling errors. *Pharm World Sci* 2008; 30: 907–15.
 - 19 Berdot S, Sabatier B, Gillaizeau F, Caruba T, Prognon P, Durieux P. Evaluation of drug administration errors in a teaching hospital. *BMC Health Serv Res* 2012; 12: 60.
 - 20 DeYoung JL, Vanderkooi ME, Barletta JF. Effect of bar-code-assisted medication administration on medication error rates in an adult medical intensive care unit. *Am J Health Syst Pharm* 2009; 66: 1110–5.
 - 21 Morriss FH Jr, Abramowitz PW, Nelson SP, Milavetz G, Michael SL, Gordon SN, Pendergast JF, Cook EF. Effectiveness of a barcode medication administration system in reducing preventable adverse drug events in a neonatal intensive care unit: a prospective cohort study. *J Pediatr* 2009; 154: 363–8, 368.e1.
 - 22 Barker KN, Flynn EA, Pepper GA. Observation method of detecting medication errors. *Am J Health Syst Pharm* 2002; 59: 2314–6.
 - 23 Campino A, Lopez-Herrera MC, Lopez-de-Heredia I, Valls-I-Soler A. Medication errors in a neonatal intensive care unit. Influence of observation on the error rate. *Acta Paediatr* 2008; 97: 1591–4.
 - 24 Dean B, Barber N. Validity and reliability of observational methods for studying medication administration errors. *Am J Health Syst Pharm* 2001; 58: 54–9.
 - 25 Rootmensen GN, van Keimpema AR, Jansen HM, de Haan RJ. Predictors of incorrect inhalation technique in patients with asthma or COPD: a study using a validated videotaped scoring method. *J Aerosol Med Pulm Drug Deliv* 2010; 23: 323–8.
 - 26 Melani AS, Canessa P, Coloretto I, DeAngelis G, DeTullio R, Del Donno M, Giacobbe R, Scarlato I, Serafini A, Barbato N, Vaghi A, Sestini P, Educational Study Group of the Italian Association of Hospital Pulmonologists (AIPO). Inhaler mishandling is very common in patients with chronic airflow obstruction and long-term home nebuliser use. *Respir Med* 2012; 106: 668–76.
 - 27 Song WS, Mullon J, Regan NA, Roth BJ. Instruction of hospitalized patients by respiratory therapists on metered-dose inhaler use leads to decrease in patient errors. *Respir Care* 2005; 50: 1040–5.
 - 28 Rau JL. Practical problems with aerosol therapy in COPD. *Respir Care* 2006; 51: 158–72.
 - 29 Reimer T, Hohberg C, Pfützner AH, Jørgensen C, Jensen KH, Pfützner A. Intuitiveness, instruction time, and patient acceptance of a prefilled insulin delivery device and a reusable insulin delivery device in a randomized, open-label, crossover handling study in patients with type 2 diabetes. *Clin Ther* 2008; 30: 2252–62.
 - 30 Gupta R, Patil B, Shah BM, Bali SJ, Mishra SK, Dada T. Evaluating eye drop instillation technique in glaucoma patients. *J Glaucoma* 2012; 21: 189–92.
 - 31 Stone JL, Robin AL, Novack GD, Covert DW, Cagle GD. An objective evaluation of eyedrop instillation in patients with glaucoma. *Arch Ophthalmol* 2009; 127: 732–6.
 - 32 Westbrook JI, Rob MI, Woods A, Parry D. Errors in the administration of intravenous medications in hospital and the role of correct procedures and nurse experience. *BMJ Qual Saf* 2011; 20: 1027–34.
 - 33 Parshuram CS, To T, Seto W, Trope A, Koren G, Laupacis A. Systematic evaluation of errors occurring during the preparation of intravenous medication. *CMAJ* 2008; 178: 42–8.
 - 34 Kaushal R, Goldmann DA, Keohane CA, Christino M, Honour M, Hale AS, Zigmont K, Lehmann LS, Perrin J, Bates DW. Adverse drug events in pediatric outpatients. *Ambul Pediatr* 2007; 7: 383–9.
 - 35 Wilke T, Müller S, Morisky DE. Toward identifying the causes and combinations of causes increasing the risks of nonadherence to medical regimens: combined results of two German self-report surveys. *Value Health* 2011; 14: 1092–100.

- 36 Hixson-Wallace JA, Dotson JB, Blakey SA. Effect of regimen complexity on patient satisfaction and compliance with warfarin therapy. *Clin Appl Thromb Hemost* 2001; 7: 33–7.
- 37 Lam PW, Lum CM, Leung MF. Drug non-adherence and associated risk factors among Chinese geriatric patients in Hong Kong. *Hong Kong Med J* 2007; 13: 284–92.
- 38 Klemsdal TO, Gjesdal K. Intermittent or continuous transdermal nitroglycerin: still an issue, or is the case closed? *Cardiovasc Drugs Ther* 1996; 10: 5–10.
- 39 Lovborg H, Jönsson AK, Hagg S. A fatal outcome after unintentional overdosing of rivastigmine patches. *Curr Drug Saf* 2012; 7: 30–2.
- 40 Tsai MY, Tsai MH, Yang SC, Tseng YL, Chuang YC. Transient global amnesia-like episode due to mistaken intake of zolpidem: drug safety concern in the elderly. *J Patient Saf* 2009; 5: 32–4.
- 41 Barker KN, Flynn EA, Pepper GA, Bates DW, Mikeal RL. Medication errors observed in 36 healthcare facilities. *Arch Intern Med* 2002; 162: 1897–903.
- 42 Gadri A, Pichon R, Zelger GL. A qualitative systemic analysis of drug dispensing in Swiss hospital wards. *Pharm World Sci* 2008; 30: 343–52.
- 43 Moss J. Reducing errors during patient-controlled analgesia therapy through failure mode and effects analysis. *Jt Comm J Qual Patient Saf* 2010; 36: 359–64.
- 44 Shebl NA, Franklin BD, Barber NJ. Is failure mode and effect analysis reliable? *Patient Saf* 2009; 5: 86–94.
- 45 Relihan E, O'Brien V, O'Hara S, Silke B. The impact of a set of interventions to reduce interruptions and distractions to nurses during medication administration. *Qual Saf Health Care* 2010; 19: e52.
- 46 McDowell SE, Mt-Isa S, Ashby D, Ferner RE. Where errors occur in the preparation and administration of intravenous medicines: a systematic review and Bayesian analysis. *Qual Saf Health Care* 2010; 19: 341–5.
- 47 Stack RR, McKellar MJ. Black eye drop bottle tips improve compliance. *Clin Experiment Ophthalmol* 2004; 32: 39–41.
- 48 Peacock G, Parnapy S, Raynor S, Wetmore S. Accuracy and precision of manufacturer-supplied liquid medication administration devices before and after patient education. *J Am Pharm Assoc* (2003) 2010; 50: 84–6.
- 49 Peek BT, Al-Achi A, Coombs SJ. Accuracy of tablet splitting by elderly patients. *JAMA* 2002; 288: 451–2.
- 50 Yin HS, Mendelsohn AL, Wolf MS, Parker RM, Fierman A, van Schaick L, Bazan IS, Kline MD, Dreyer BP. Parents' medication administration errors: role of dosing instruments and health literacy. *Arch Pediatr Adolesc Med* 2010; 164: 181–6.
- 51 McMahon SR, Rimsza ME, Bay RC. Parents can dose liquid medication accurately. *Pediatrics* 1997; 100: 330–3.
- 52 Poon EG, Cina JL, Churchill W, Patel N, Featherstone E, Rothschild JM, Keohane CA, Whittemore AD, Bates DW, Gandhi TK. Medication dispensing errors and potential adverse drug events before and after implementing bar code technology in the pharmacy. *Ann Intern Med* 2006; 145: 426–34.
- 53 Helmons PJ, Wargel LN, Daniels CE. Effect of bar-code-assisted medication administration on medication administration errors and accuracy in multiple patient care areas. *Am J Health Syst Pharm* 2009; 66: 1202–10.
- 54 Poon EG, Keohane CA, Yoon CS, Dittmore M, Bane A, Levitzion-Korach O, Moniz T, Rothschild JM, Kachalia AB, Hayes J, Churchill WW, Lipsitz S, Whittemore AD, Bates DW, Gandhi TK. Effect of bar-code technology on the safety of medication administration. *N Engl J Med* 2010; 362: 1698–707.
- 55 Chapuis C, Roustit M, Bal G, Schwebel C, Pansu P, David-Tchouda S, Foroni L, Calop J, Timsit JF, Allenet B, Bosson JL, Bedouch P. Automated drug dispensing system reduces medication errors in an intensive care setting. *Crit Care Med* 2010; 38: 2275–81.
- 56 Buysman E, Conner C, Aagren M, Bouchard J, Liu F. Adherence and persistence to a regimen of basal insulin in a pre-filled pen compared to vial/syringe in insulin-naïve patients with type 2 diabetes. *Curr Med Res Opin* 2011; 27: 1709–17.
- 57 Leirer O, Morrow DG, Decker Tanke E, Pariente GM. Elders' nonadherence: its assessment and medication reminding by voice mail. *Gerontologist* 1991; 31: 514–20.
- 58 Foreman KF, Stockl KM, Le LB, Fisk E, Shah SM, Lew HC, Solow BK, Curtis BS. Impact of a text messaging pilot program on patient medication adherence. *Clin Ther* 2012; 34: 1084–91.
- 59 Boker A, Feetham HJ, Armstrong A, Purcell P, Jacobe H. Do automated text messages increase adherence to acne therapy? Results of a randomized, controlled trial. *J Am Acad Dermatol* 2012; 67: 1136–42.
- 60 Hayes TL, Cobbinah K, Dishongh T, Kaye JA, Kimel J, Labhard M, Leen T, Lundell J, Ozertem U, Pavel M, Philipose M, Rhodes K, Vurgun S. A study of medication-taking and unobtrusive, intelligent reminding. *Telemed J E Health* 2009; 15: 770–6.
- 61 McCall C, Maynes B, Zou CC, Zhang NJ. An automatic medication self-management and monitoring system for independently living patients. *Med Eng Phys* 2013; 35: 505–14.
- 62 Anto B, Barlow D, Osborne CA, Whittlesea C. Incorrect drug selection at the point of dispensing: a study of potential predisposing factors. *Int J Pharm Pract* 2011; 19: 51–60.
- 63 Aronson JK. Medication errors resulting from the confusion of drug names. *Expert Opin Drug Saf* 2004; 3: 167–72.
- 64 Emmerton LM, Rizk MF. Look-alike and sound-alike medicines: risks and 'solutions'. *Int J Clin Pharm* 2012; 34: 4–8.
- 65 Berman A. Reducing medication errors through naming, labelling, and packaging. *J Med Syst* 2004; 28: 9–29.
- 66 Filik R, Purdy K, Gale A, Gerrett D. Drug name confusion: evaluating the effectiveness of capital ('tall man') letters using eye movement data. *Soc Sci Med* 2004; 59: 2597–601.

- 67 Porat N, Bitan Y, Shefi D, Donchin Y, Rozenbaum H. Use of colour-coded labels for intravenous high-risk medications and lines to improve patient safety. *Qual Saf Health Care* 2009; 18: 505–9.
- 68 Lefkowitz M. Do different body colors and labels of insulin pens enhance a patient's ability to correctly identify pens for injecting long-acting versus short-acting insulins? *J Diabetes Sci Technol* 2011; 5: 136–49.
- 69 Filiatrault P, Hyland S. Does colour-coded labelling reduce the risk of medication errors? *Can J Hosp Pharm* 2009; 62: 154–56.
- 70 Haslam GM, Sims C, McIndoe AK, Saunders J, Lovell AT. High latent drug administration error rates associated with the introduction of the international colour coding syringe labelling system. *Eur J Anaesthesiol* 2006; 23: 165–8.
- 71 Temple J, Ludwig B. Implementation and evaluation of carousel dispensing technology in a university medical center pharmacy. *Am J Health Syst Pharm* 2010; 67: 821–9.
- 72 Oswald S, Caldwell R. Dispensing error rate after implementation of an automated pharmacy carousel system. *Am J Health Syst Pharm* 2007; 64: 1427–31.
- 73 Borel JM, Rascati KL. Effect of an automated, nursing unit-based drug-dispensing device on medication errors. *Am J Health Syst Pharm* 1995; 52: 1875–9.
- 74 Peris-Lopez P, Orfila A, Mitrokovska A, van der Lubbe JC. A comprehensive RFID solution to enhance inpatient medication safety. *Int J Med Inform* 2011; 80: 13–24.
- 75 Atkin PA, Finnegan TP, Ogle SJ, Shenfield GM. Functional ability of patients to manage medication packaging: a survey of geriatric inpatients. *Age Ageing* 1994; 23: 113–6.
- 76 Beckman A, Bernstein C, Parker MG, Thorslund M, Fastbom J. The difficulty of opening medicine containers in old age: a population-based study. *Pharm World Sci* 2005; 27: 393–8.
- 77 Keram S, Williams ME. Quantifying the ease or difficulty older persons experience in opening medication containers. *J Am Geriatr Soc* 1988; 36: 198–201.
- 78 Nikolaus T, Kruse W, Bach M, Specht-Leible N, Oster P, Schlierf G. Elderly patients' problems with medication. An in-hospital and follow-up study. *Eur J Clin Pharmacol* 1996; 49: 255–9.
- 79 Verheggen-Laming BN, Phiferons H, Mulder EF, van der Meij NT, van Harten RP, Dijkmans BA. Comparison of packages for suppositories by patients with rheumatoid arthritis. *Scand J Rheumatol* 1988; 17: 161–5.
- 80 Lisberg RB, Higham C, Jayson MI. Problems for rheumatic patients in opening dispensed drug containers. *Br J Rheumatol* 1983; 22: 95–8.
- 81 Kircher W, ed. *Arzneiformen richtig anwenden*, 3rd edn. Stuttgart: Deutscher Apotheker Verlag, 2007.
- 82 Connor AJ, Severn PS. Force requirements in topical medicine use – the squeezability factor. *Eye* 2011; 25: 466–9.
- 83 Cook TJ, Edwards S, Gyemah C, Shah M, Shah I, Fox T. Variability in tablet fragment weights when splitting unscored cyclobenzaprine 10 mg tablets. *J Am Pharm Assoc* 2004; 44: 583–6.
- 84 Verrue C, Mehuy E, Boussery K, Remon JP, Petrovic M. Tablet-splitting: a common yet not so innocent practice. *J Adv Nurs* 2011; 67: 26–32.
- 85 Dalton C, Keenan E, Stevenson V. A novel cause of intrathecal baclofen overdosage: lessons to be learnt. *Clin Rehabil* 2008; 22: 188–90.
- 86 Lovich MA, Peterfreund GL, Sims NM, Peterfreund RA. Central venous catheter infusions: a laboratory model shows large differences in drug delivery dynamics related to catheter dead volume. *Crit Care Med* 2007; 35: 2792–8.
- 87 Yetzer EA, Goetsch N, St Paul M. Teaching adults SAFE medication management. *Rehabil Nurs* 2011; 36: 255–60.
- 88 Sullivan MM, O'Brien CR, Gitelman SE, Shapiro SE, Rushakoff RJ. Impact of an interactive online nursing educational module on insulin errors in hospitalized pediatric patients. *Diabetes Care* 2010; 33: 1744–6.
- 89 Mager DR. Medication errors and the home care patient. *Home Healthc Nurse* 2007; 25: 151–5.
- 90 Dowse R, Ehlers M. Medicine labels incorporating pictograms: do they influence understanding and adherence? *Patient Educ Couns* 2005; 58: 63–70.
- 91 Katz MG, Kripalani S, Weiss BD. Use of pictorial aids in medication instructions: a review of the literature. *Am J Health Syst Pharm* 2006; 63: 2391–7.
- 92 Wilson EA, Park DC, Curtis LM, Cameron KA, Clayman ML, Makoul G, Vom Eigen K, Wolf MS. Media and memory: the efficacy of video and print materials for promoting patient education about asthma. *Patient Educ Couns* 2010; 80: 393–8.
- 93 White RE, Trbovich PL, Easty AC, Savage P, Trip K, Hyland S. Checking it twice: an evaluation of checklists for detecting medication errors at the bedside using a chemotherapy model. *Qual Saf Health Care* 2010; 19: 562–7.
- 94 Morrow DG, Weiner M, Young J, Steinley D, Deer M, Murray MD. Improving medication knowledge among older adults with heart failure: a patient-centered approach to instruction design. *Gerontologist* 2005; 45: 545–52.
- 95 Burruss RA, Carroll NV, Schraa C, Burton B. Outsourcing inpatient i.v. compounding: expense and medication error implications. *Pharm Pract Manag Q* 1996; 16: 52–9.
- 96 Hare C, Davies C, Shepherd M. Safer medicine administration through the use of e-learning. *Nurs Times* 2006; 102: 25–7.
- 97 Franklin BD, O'Grady K, Parr J, Walton I. Using the internet to deliver education on drug safety. *Qual Saf Health Care* 2006; 15: 329–33.
- 98 Taxis K, Barber N. Ethnographic study of incidence and severity of intravenous drug errors. *BMJ* 2003; 326: 684.
- 99 Kirkevold O, Engedal K. What is the matter with crushing pills and opening capsules? *Int J Nurs Pract* 2010; 16: 81–5.
- 100 Haw C, Stubbs J, Dickens G. An observational study of medication administration errors in old-age psychiatric inpatients. *Int J Qual Health Care* 2007; 19: 210–6.

- 101** Patel RS, McGarry GW. Most patients overdose on topical nasal corticosteroid drops: an accurate delivery device is required. *J Laryngol Otol* 2001; 115: 633–5.
- 102** Yin HS, Wolf MS, Dreyer BP, Sanders LM, Parker RM. Evaluation of consistency in dosing directions and measuring devices for pediatric nonprescription liquid medications. *JAMA* 2010; 304: 2595–602.
- 103** Sobhani P, Christopherson J, Ambrose PJ, Corelli RL. Accuracy of oral liquid measuring devices: comparison of dosing cup and oral dosing syringe. *Ann Pharmacother* 2008; 42: 46–52.
- 104** Quinzler R, Gasse C, Schneider A, Kaufmann-Kolle P, Szecsenyi J, Haefeli WE. The frequency of inappropriate tablet splitting in primary care. *Eur J Clin Pharmacol* 2006; 62: 1065–73.
- 105** Gerber A, Kohaupt I, Lauterbach KW, Buescher G, Stock S, Lungen M. Quantification and classification of errors associated with hand-repackaging of medications in long-term care facilities in Germany. *Am J Geriatr Pharmacother* 2008; 6: 212–9.
- 106** Taxis K, Dean B, Barber N. Hospital drug distribution systems in the UK and Germany – a study of medication errors. *Pharm World Sci* 1999; 21: 25–31.
- 107** Rodriguez-Gonzalez CG, Herranz-Alonso A, Martin-Barbero ML, Duran-Garcia E, Durango-Limarquez MI, Hernández-Sampelayo P, Sanjurjo-Saez M. Prevalence of medication administration errors in two medical units with automated prescription and dispensing. *J Am Med Inform Assoc* 2012; 19: 72–8.
- 108** De Giorgi I, Guignard B, Fonzo-Christe C, Bonnabry P. Evaluation of tools to prevent drug incompatibilities in paediatric and neonatal intensive care units. *Pharm World Sci* 2010; 32: 520–9.
- 109** Alldred DP, Standage C, Fletcher O, Savage I, Carpenter J, Barber N, Raynor DK. The influence of formulation and medicine delivery system on medication administration errors in care homes for older people. *BMJ Qual Saf* 2011; 20: 397–401.
- 110** Winfield AJ, Jessiman D, Williams A, Esakowitz L. A study of the causes of non-compliance by patients prescribed eyedrops. *Br J Ophthalmol* 1990; 74: 477–80.
- 111** Benkirane RR, Abouqal R, Haimeur CC, Ech Cherif S, El Kettani SS, Azzouzi AA, Mdaghri Alaoui AA, Thimou AA, Nejmi MM, Maazouzi WW, Madani NN, R-Edwards I, Soulaymani RR. Incidence of adverse drug events and medication errors in intensive care units: a prospective multicenter study. *J Patient Saf* 2009; 5: 16–22.
- 112** Fahimi F, Ariapanah P, Faizi M, Shafaghi B, Namdar R, Ardakani MT. Errors in preparation and administration of intravenous medications in the intensive care unit of a teaching hospital: an observational study. *Aust Crit Care* 2008; 21: 110–6.
- 113** Wielandt JO, Niemeyer M, Hansen MR, Bucher D, Thomsen NB. An assessment of dose accuracy and injection force of a novel prefilled insulin pen: comparison with a widely used prefilled insulin pen. *Expert Opin Drug Deliv* 2011; 8: 1271–6.
- 114** Cook TM, Payne S, Skryabina E, Hurford D, Clow E, Georgiou A. A simulation-based evaluation of two proposed alternatives to Luer devices for use in neuraxial anaesthesia. *Anaesthesia* 2010; 65: 1069–79.
- 115** Schein JR, Hicks RW, Nelson WW, Sikirica V, Doyle DJ. Patient-controlled analgesia-related medication errors in the postoperative period: causes and prevention. *Drug Saf* 2009; 32: 549–59.
- 116** Rothschild JM, Keohane CA, Cook EF, Orav EJ, Burdick E, Thompson S, Hayes J, Bates DW. A controlled trial of smart infusion pumps to improve medication safety in critically ill patients. *Crit Care Med* 2005; 33: 533–40.
- 117** Evans RS, Carlson R, Johnson KV, Palmer BK, Lloyd JF. Enhanced notification of infusion pump programming errors. *Stud Health Technol Inform* 2010; 160: (Pt 1): 734–8.
- 118** Prusch AE, Suess TM, Paoletti RD, Olin ST, Watts SD. Integrating technology to improve medication administration. *Am J Health Syst Pharm* 2011; 68: 835–42.
- 119** Biedrzycki OJ, Bevan D, Lucas S. Fatal overdose due to prescription fentanyl patches in a patient with sickle cell/ β -thalassemia and acute chest syndrome. *Am J Forensic Med Pathol* 2009; 30: 188–90.
- 120** Adams D, Elliott TSJ. Impact of safety needle devices on occupationally acquired needlestick injuries: a four-year prospective study. *J Hosp Infect* 2006; 64: 50–5.
- 121** Costigliola V, Frid A, Letondeur C, Strauss K. Needlestick injuries in European nurses in diabetes. *Diabetes Metab* 2013; 38: (Suppl 1): S9–14.
- 122** Kamin WES, Genz T, Roeder S, Scheuch G, Cloes R, Juenemann R, Trammer T. The inhalation manager: a new computer-based technique and drug delivery to the patient. *J Aerosol Med* 2003; 16: 21–9.
- 123** Abd-el-Maeboud KH, el-Naggar T, el-Hawi EM, Mahmoud SA, Abd-el-Hay S. Rectal suppository: commonsense and mode of insertion. *Lancet* 1991; 338: 798–800.