The influence of education and experience on paediatric emergency drug dosing errors – an interventional questionnaire study using a tabular aid

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Summary

Background: Several interventions including reading drug doses from a table are known to reduce drug dosing errors in paediatric emergencies. The role of education and experience of the operator on the occurrence of these errors with or without supporting aids is unknown.

Methods: Within an interventional questionnaire trial, medical professionals were first asked to indicate their training (nurse [N], medical student [MS], trainee [T] or consultant physician [CP]). They were then requested to calculate the dose of four emergency drugs within 2 minutes time for a child weighing 7 kg, first unaided and then with a tabular aid. Deviations from the recommended dose of 120% (DRD120), 300% (DRD300) and 1000% (DRD1000) with or without the tabular aid were measured.

Results: A total of 186 questionnaires and 1,326 drug prescriptions were available. CP made less unaided emergency drug dosing errors e.g. with epinephrine when compared to T, N and MS (DRD120: CP 18%, T 23%, N 50% and MS 78%, respectively). With the tabular aid, fewer errors were made (DRD120: CP 7% [p=0.031], T 9% [p=0.375], N 11% [p=0.016], MS 0% [p<0.001]). The tabular aid greatly reduced errors in N and MS, eliminating DRD1000 in N and all DRDs in MS. Despite the tabular aid, CP and T continued to make potentially life-threatening errors when prescribing epinephrine.

Conclusions: Although CP and T made fewer unaided emergency drug dosing errors, they failed to gain comparable benefits from a tabular aid. Strict adherence to safety structures and implementation of a safety culture is required to further reduce paediatric emergency drug prescription errors.

Introduction

Medication errors are a major source of morbidity and mortality in patients of all ages [1,2]. Children are at particular risk due to the necessity of individual weight-based drug dose calculations and a lack of familiarity with a "typical" dose [3]. Medication errors occur up to three times more frequently in children than in adult patients, even when routine care is provided by paediatric specialists in specialized paediatric environments [4]. In emergency situations, the error rate increases still further. In a setting involving simulated resuscitations in a paediatric emergency department, one in 32 verbally issued drug prescriptions contained a tenfold error [5]. A dosing error of that magnitude when administering epinephrine during a cardiac arrest is highly unlikely to be compatible with successful resuscitation [6,7].

Out of hospital emergencies occur outside of specialized paediatric environments and are commonly managed by personnel with limited experience of paediatric care [8]. On-scene personnel are often not confident in their ability to administer a correct drug dose for small children [9]. Observed error rates in actual prehospital paediatric emergencies are reported to be more than

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one in three overall and almost 60% of epinephrine administrations [10].

Several interventions to improve the accuracy of drug dosing have been described and shown to have statistically significant effects in clinical trials. However, even though these interventions can reduce the frequency and severity of errors in paediatric emergencies [11] and paediatric anaesthesia [12], they cannot completely eliminate human errors. Even when simple cognitive aids are used – such as reading a drug dose from a clearly structured table – mistakes can be made [13]. The influence of expertise on the safety of drug administration in general is well described [11,14]. However, the influence of training education and experience on the ability of medical professionals to correctly calculate doses of emergency drugs in a questionnaire with or without tabular aids is unknown.

We therefore investigated the abilities of medical and nursing professionals with different levels of training and experience to correctly prescribe paediatric emergency drugs in a structured questionnaire with or without the support of a tabular aid. The aim was to assess the effect of this tabular aid on the correct prescription of common emergency drugs and to determine whether the effect varied according to training and experience.

Methods

No personally identifiable information was collected; participation was voluntary, and consent was inferred by use of the questionnaire. As such, the ethics committee at the University of Witten/Herdecke saw no need for a formal assessment of the study or individual declarations of consent.

We initially designed a questionnaire and piloted this with five members of paediatric anaesthetic staff at a paediatric hospital. This pilot study confirmed that the questionnaire was practicable, and completion was readily achieved within two minutes. The questionnaires were then distributed at symposia for paediatric anaesthesia and emergency medicine, which were attended by participants from across the country. In addition, further copies were offered to physicians and nursing staff affiliated with the departments of anaesthesia at two university hospitals, the paediatric, paediatric surgical and paediatric anaesthetic departments at a children's hospital as well as to medical students in their final year during courses and seminars.

In all the aforementioned cases, the questionnaire was handed out after a brief verbal introduction had been provided to all the participants of the event or the members of staff of the respective departments. The questionnaire contained three distinct parts on three separate sheets stapled together in such a way that only the current page was

Figure 1

Weight 7.1–9.5 kg

	Drug	Dosage	Dose	Concentration	Single bolus in ml	
Anaesthesia	Thiopentone	(5 mg/kg)	35.5–47.5 mg	25 mg/ml	1.4–1.9 ml	neat
Anaesthesia	Propofol 1%	(3 mg/kg)	21.3–28.5 mg	10 mg/ml	2.1–2.9 ml	neat
Anaesthesia	Etomidate	(0.2 mg/kg)	1.4–1.9 mg	2 mg/ml	0.7–1.0 ml	neat
Anaesthesia	Midazolam	(0.2 mg/kg)	1.4–1.9 mg	1 mg/ml	1.4–1.9 ml	of a 1:5 or 3:15 solution
Anaesthesia	S-Ketamine	(1 mg/kg)	7.1–9.5 mg	5 mg/ml	1.4–1.9 ml	if 5 mg/ml !!
Analgesia	Fentanyl	(2 µg/kg)	14.2–19.0 µg	50 µg/ml	0.3–0.4 ml	neat
Analgesia	Sufentanil	(0.2 µg/kg)	1.4–1.9 µg	5 µg/ml	0.3–0.4 ml	neat
Analgesia	Alfentanil	(20 µg/kg)	142.0–190.0 µg	500 µg/ml	0.3–0.4 ml	neat
Analgesia	Piritramide/Dipidolor®	(0.05 mg/kg)	0.4–0.5 mg	1 mg/ml	0.4–0.5 ml	of a 2:15 solution
Analgesia	Morphine	(0.1 mg/kg)	0.7–1.0 mg	1 mg/ml	0.7–1.0 ml	of a 1:10 solution
Neuromuscular block	Vecuronium or cisatracurium	(0.1 mg/kg)	0.7–1.0 mg	1 mg/ml	0.7–1.0 ml	neat
Neuromuscular block	Mivacurium or atracurium	(0.2 mg/kg)	1.4–1.9 mg	1 mg/ml	1.4–1.9 ml	neat
Neuromuscular block	Succinylcholine 2%	(2 mg/kg)	14.2–19.0 mg	20 mg/ml	0.7–1.0 ml	neat
Neuromuscular block	Rocuronium	(0.6 mg/kg)	4.3–5.7 mg	10 mg/ml	0.4–0.6 ml	neat

	Drug	Dosage	Dose	Concentration	Single bolus in ml	
Resuscitation	Fluid bolus (see normal values for maintenance requirements)	(10 ml/kg)	Balanced electrolyte solution		71–95 ml	neat
Resuscitation	**Adrenaline during resuscitation**	(10 µg/kg)	71–95 µg	100 µg/ml	0.7–1.0 ml	of a 1:10 solution

Tabular aid provided for calculating drug doses for children; excerpt from the Paediatric Emergency Ruler ("Pädiatrisches Notfalllineal – PädNFL") [15]. What is meant by „neat" in the respective medication is described in more detail in the instructions for use of the emergency ruler.

visible. The first page inquired about the vocation and level of training (nurse, medical student, trainee or consultant) of the participant. All participating nurses were from paediatric anaesthesia or paediatric intensive care services. Medical students were in their final year. On the second page, the participants were asked to complete a written prescription for an infant weighing 7 kg for four drugs commonly used in paediatric emergencies (fentanyl, propofol, rocuronium for inducing anaesthesia and epinephrine for resuscitation) without any additional aids. The participants were requested to provide a distinct dose (not a range). The final part of the questionnaire requested a prescription for the same child and the same indications with the participants explicitly asked to use a tabular aid printed at the top of the page (Fig. 1). This table was taken from the Paediatric Emergency Ruler (PädNFL; www.notfalllineal.de), a length-based dosing recommendation tool which has been previously described [15]. This device is placed next to a child lying fully stretched out in a supine position and aligned with the heel of the child. Dosing recommendations can be read from the segment of the device which comes to be aligned with the head. The effectiveness of the PädNFL has been demonstrated in a prospective nationwide trial in prehospital paediatric emergencies, preventing 9 out of 10 severe drug dosing errors [15]. Approximately 35,000 of these devices are used across German-speaking countries. Therefore, we choose an excerpt from tables used on this established device as an example for an evaluated tabular dosing aid. When using a tabular aid, there is a high probability that the actual weight of the child will not be listed exactly in the table. As this may cause irritation and distraction we chose – without further comment – to use a weight in our scenario which was not listed exactly in the table (7.0 rather than 7.1 kg). The participants had a maximum of two minutes to fill in the questionnaire, after which the sheets were collected.

All data were entered into an Excel spreadsheet (Microsoft Corp., Redmond, WA, USA) and independently verified by a second person. If a dose-range was submitted within a questionnaire (despite the instruction not to do so), the mean of the stated range was used. The recommended dose for fentanyl was defined as 2 µg/kg body weight, for propofol as 3 mg/kg, for rocuronium as 0.6 mg/kg and for epinephrine as 10 µg/kg. Dosing errors were classified into three categories defined by relative deviations from the recommended dose larger than 120% (i.e. deviations by a factor of 1.2, outside the range of 83% to 120%, 'DRD120'), 300% (i.e. deviations by a factor of 3, outside 33% to 300%, 'DRD300') or 1,000% (i.e. deviations by a factor of 10, outside 10% to 1,000%, 'DRD1000'), respectively. Differences (unaided vs. aided by the table) in the frequency of dosing errors within groups were compared using McNemar's test. Only paired prescriptions, i.e. those where participants had provided unambiguous prescriptions both without aids and with the table, were used for McNemar's testing. All calculations were performed using Excel, SPSS Statistics 24 (IBM Corp., Armonk, NY, USA) and R 3.2.2 (R Foundation for Statistical Computing, Vienna, Austria; package exact2x2, function Mcnemar.exact).

Table 1

Analysis of drug prescription errors by all participants. The dosing errors were divided into three categories defined by relative deviations from the recommended dose: larger than 120% = DRD120, 300% = DRD300, or 1,000% = DRD1000. For paired data, differences (unaided vs. aided) in the frequency of dosing errors were tested using the exact McNemar's test. Data was considered paired when both components (unaided and aided) of a prescription could be evaluated.

	Fentanyl	Propofol	Rocuronium	Epinephrine	All drugs
Total number of possible prescriptions	186	186	186	186	744
Omitted data (unaided)	26 (14.0%)	28 (15.1%)	37 (19.9%)	22 (11.8%)	113 (15.2%)
Omitted data (aided)	11 (5.9%)	12 (6.5%)	14 (7.5%)	12 (6.5%)	49 (6.6%)
Number of paired datasets	151 (81.2%)	148 (79.6%)	140 (75.3%)	154 (82.8%)	593 (79.7%)
unaided					
DRD120	103 (68.2%)	108 (73.0%)	75 (53.6%)	45 (29.2%)	331 (55.8%)
DRD300	33 (21.9%)	19 (12.8%)	19 (13.6%)	24 (15.6%)	95 (16.0%)
DRD1000	5 (3.3%)	4 (2.7%)	6 (4.3%)	6 (3.9%)	21 (3.5%)
aided					
DRD120	11 (7.3%)	16 (10.8%)	10 (7.1%)	11 (7.1%)	48 (8.1%)
DRD300	4 (2.6%)	4 (2.7%)	4 (2.9%)	8 (5.2%)	20 (3.4%)
DRD1000	0 (0.0%)	0 (0.0%)	0 (0.0%)	2 (1.3%)	2 (0.3%)
McNemar´s test					
DRD120	p<0.001	p<0.001	p<0.001	p<0.001	p<0.001
DRD300	p<0.001	p<0.001	p=0.001	p=0.002	p<0.001
DRD1000	p=0.063	p=0.125	p=0.031	p=0.289	p=0.004

Results

In total, 190 completed questionnaires were collected from 230 questionnaires handed out (82,6%). Four questionnaires were excluded from further analysis as no information concerning training was available. Although the participants were requested to complete all drug prescriptions, 162 out of a possible 1,488 drug prescriptions were missing or illegible.

The use of the tabular aid resulted in an overall reduction of drug prescription errors for DRD120 and DRD300 for all drugs and for DRD1000 for rocuronium (Table 1). When the tabular aid was available, participants omitted drug prescriptions less than half as often as when it was not. CP were the exception to this finding, omitting prescriptions for epinephrine more frequently when the table was available than when it was not (10.1% vs. 3.7%).

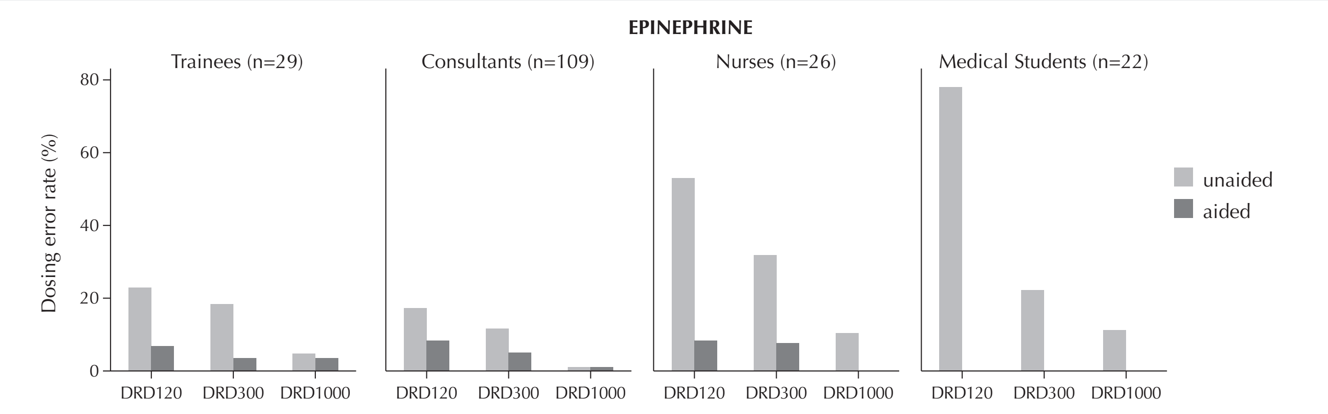
Table 2 describes the effect of the tabular aid on the rate of occurrence of prescription errors made by nurses [N], medical students [MS], trainees [T] and consultants [CP]. The use of the tabular aid reduced drug prescription errors for epinephrine for DRD120 errors for consultants, nurses and medical students across all professional groups and levels of experience. Although when unaided, rates of drug prescription errors made by nurses and students were higher for all DRDs when compared with trainees or consultants, they were similar or lower when using the tabular aid (Fig. 2). Only medical students completely eliminated drug prescription errors for epinephrine and propofol using the tabular aid. Despite the help of the table, consultant physicians still made errors at all three levels of intensity (DRDs).

Table 2

Analysis of drug prescription errors for epinephrine according to vocation and training. The dosing errors were divided into three categories defined by relative deviations from the recommended dose: larger than 120% = DRD120. 300% = DRD300. or 1.000% = DRD1000. For paired data. differences (unaided vs. aided) in the frequency of dosing errors were tested using the exact McNemar's test. Data was considered paired when both components (unaided and aided) of a prescription could be evaluated.

	Trainees	Consultants	Nurses	Medical Students
Actual respondents	29	109	26	22
Omitted data unaided	7 (24.1%)	4 (3.7%)	7 (26.9%)	4 (18.2%)
Omitted data aided	0 (0.0%)	11 (10.1%)	1 (3.8%)	1 (4.5%)
EPINEPHRINE – Number of paired datasets	22 (75.9%)	96 (88.1%)	18 (69.2%)	18 (81.8%)
unaided				
DRD120	5 (22.7%)	17 (17.7%)	9 (50.0%)	14(77.8%)
DRD300	4 (18.2%)	11 (11.5%)	5 (27.8%)	4 (22.2%)
DRD1000	1 (4.5%)	1 (1.0%)	2 (11.1%)	2 (11.1%)
aided				
DRD120	2 (9.1%)	7 (7.3%)	2 (11.1%)	0 (0.0%)
DRD300	1 (4.5%)	5 (5.2%)	2 (11.1%)	0 (0.0%)
DRD1000	1 (4.5%)	1 (1.0%)	0 (0.0%)	0 (0.0%)
McNemar´s test				
DRD120	p=0.375	p=0.031	p=0.016	p<0.001
DRD300	p=0.375	p=0.146	p=0.25	p=0.125
DRD1000	p=1.000	p=1.000	p=0.500	p=0.500

Figure 2



Deviation from the recommended dose (DRD) for epinephrine: 120% (DRD120), 300% (DRD300) or 1,000% (DRD1000) for prescriptions issued by junior doctors, consultants, nurses and medical students, unaided or supported by a tabular aid respectively.

Discussion

This current study confirms the beneficial effect of cognitive aids to reduce drug dosing errors. It also demonstrates that education and experience result in fewer unaided errors. The significant improvement in the rate of prescription errors at DRD120 and DRD300 levels across all participants underlines the effectiveness of simple tabular aids. The limited occurrence of DRD1000 errors in this study makes it impossible to determine statistical significance for the effect of preventing such errors. Despite this, the tabular aid prevented one in three DRD1000 errors when prescribing epinephrine, achieving clinical relevance despite lacking statistical significance. Every single such error most likely precludes survival of a child under resuscitation [6,7].

Studies reporting on dosing errors most commonly define an error as a 20% deviation (DRD120) [10,16–18] although such errors are most likely to be clinically insignificant. Anaesthetic drugs, for example, are frequently administered across a dosing range (e.g. propofol within 3–5 mg/kg [19]) with adjustment often required based on clinical effect. As such, a large dose variation within individual requirements is to be expected. Furthermore, there are no universally accepted thresholds for incorrect dosage in general or for individual drugs. As such, for most medications it is unclear exactly which magnitude of over- or underdose may cause harm to the patient.

Nevertheless, for epinephrine the correct dose (of 10 µg/kg) is clearly defined and a DRD300 is clearly beyond the recommendations for patients of any age, with international guidelines specifically warning of higher doses; a DRD1000 is most likely to be fatal [8,20,21]. Thus, there are clear dosing recommendations for epinephrine, clear definitions of wrong doses and recognized clinical relevance for overdoses, making it an ideal drug for investigating dosage errors. Due to the absence of a clearly defined correct dose of drugs for emergency anaesthesia (propofol, fentanyl and rocuronium), these were excluded from the evaluation of dosing accuracy differentiated by occupational group and experience. Instead, only summarized error rates and the number of omissions were described. We nevertheless chose to present a questionnaire which did not solely ask respondents to prescribe epinephrine but was instead based on real life situations in which health-care providers must also prescribe multiple drugs and are at the same time confronted with additional demands.

It has previously been shown numerous times that training and individual experience result in improved drug safety [11,14]. In addition, several cognitive aids have been shown to lead to a further reduction in drug prescription error rates [11,12]. It is, therefore, astounding that a combination of experience and the availability of a cognitive aid to enhance drug safety did not lead to a cumulative reduction of drug dosing errors. The lack of a comparable benefit of the tabular aid on the dosing precision of consultant staff was in stark contrast to the improved prescription performance seen in medical students, who showed the highest unaided error rates but when prescribing epinephrine using the table made zero errors in all categories of DRD120, 300 and 1000. Consultants still made erroneous prescriptions at all three levels (including DRD1000). A previous study which also used a tabular aid assumed that drug dosing errors were not being eliminated because misreading was occurring [13]. Misreading, however, would be expected to occur independently of training and experience and as such cannot explain the observations made in our study.

Clearly, experience and qualification can improve performance but may also adversely affect the acceptance and use of cognitive aids or supporting tools. Consultants omitted more drug prescriptions aided than unaided, which was in contrast to all other groups. This study did not query attitudes toward or acceptance or rejection of cognitive aids or safety structures. It can, therefore, only be speculated that our findings indicate a greater reluctance amongst consultants to embrace the tabular aid. This hypothesis requires further investigations to focus on attitudes of different professional groups towards safety structures.

It is recognised that the acceptance of safety structures can be deficient in areas involving complex operational procedures. In addition, awareness of personal fallibility and adherence to safety structures is subject to individual variance [22]. Even people who self-report supporting existing safety guidelines do not always reliably adhere to them in everyday life [23]. As an example, although most participating staff at an emergency department demonstrated a positive attitude toward drug safety structures in a questionnaire, none of the different safety structures offered were used in daily routine [24]. The reported reasons were limited feasibility of the suggested measures, which were deemed incompatible with the workflow. But even measures and support tools which have been well-integrated into daily clinical routine are often spurned by clinicians [25]. One component of this rejection is the inability to unlearn previous habits when staff are used to working without the additional safety structures [26]. As such, this phenomenon does not affect individuals who are at the beginning of their career and have not yet acquired such habits (e.g. medical students) and who are ostensibly seeking out support to accomplish their clinical responsibilities [27]. In addition, younger members of staff are in a competitive stage of their career, during which their efforts are routinely subject to appraisement through colleagues and superiors. The importance of these factors decreases with experience, especially when staff enter more senior positions. Decisions made by superiors are less likely to be questioned and are more likely to be based on first impressions and intuition [28]. Furthermore, perception of risk and of own fallibility declines with age [29,30]. For instance, a declining acceptance of safety procedures has been described amongst senior surgeons [31]. In that investigation the forceful statement “Where I am, there is quality” implies the weight afforded to experience and hierarchy over existing safety structures. This attitude was further highlighted in a survey of over 1,000 health care professionals which demonstrated a decreased awareness of personal susceptibility for errors in senior staff [32]. An experienced emergency physician participating in this current study commented that he was loath to use the tabular aid in his daily work, assuming it would appear incompetent should he be seen doing so. Improvements to the culture of error in medicine are to some extent obviously possible and necessary [22].

General assessments of hierarchies or occupational groups should not and must not be derived from the above considerations – these merely represent an attempt to describe possible causes for the observations made. Nevertheless, it is essential to recognise and take into account the mechanisms mentioned when implementing safety structures in all areas of care. This study did not examine the attitudes of employees of different occupational groups and levels of experience towards security structures. Future work is therefore necessary in order to better illustrate these mechanisms with their characteristics and effects.

This current study has several limitations. Firstly, the questionnaire requested an emergency drug prescription outside of a real clinical scenario. The inevitable stress in paediatric emergencies may well lead to higher error rates. The overall DRD300 of 16% in the current study is less than that seen in real-life preclinical scenarios of, for example, 22% [15]. Secondly, it remains unclear whether the acceptance of the use of the tabular aid might have been higher in real-life scenarios, possibly leading to more apparent effects. Thirdly, for reasons unknown, some of the participants omitted prescriptions. This, however, is not an option during real emergency care and might have contributed to an underestimation of the effects observed in this study. In real scenarios, on the other hand, additional safety mechanisms might have been applied. As an example, closed-loop communication – as is recommended by guidelines – could have confirmed that the right drug at the right dose was about to be administered [11,12,33]. Our study did not include any form of closed-loop confirmation, which may have resulted in an overestimation of drug error rates.

Conclusions

This study reports improved performance when using a tabular aid to prescribe commonly used drugs in paediatric emergencies within a questionnaire. Although experienced physicians make fewer unaided emergency drug prescription errors, they fail to gain similar benefits from the tabular aid as compared to those seen in undergraduates. Despite the table, experienced physicians continued to make serious mistakes (errors of up to one order of magnitude) when prescribing epinephrine, while medical students dosed completely error-free. Reasons for this observation remain unclear and need to be examined in future investigations. These should look into attitudes, behaviour and a possible lack of awareness of individual susceptibility to errors. Hierarchical structures and the loss of competition for supervisors may further exacerbate this situation and should be addressed when implementing future safety structures. Every medical professional should be aware of and accept existing safety structures and aids without discrimination.

Declarations

Ethical considerations

No personally identifiable information was collected, and an ethics waiver was granted by the local Ethics Committee (Ethics Committee of the University of Witten/Herdecke, Germany, Prof. Dr. P.W. Gaidzik). Written consent was considered to be unnecessary, and consent was instead inferred by voluntary participation.

Availability of data and materials

The datasets used and/or analysed for the current study are available from the corresponding author upon request.

Competing interests

Dr. Kaufmann holds a Europe-wide registered patent for the Paediatric Emergency Ruler (“Pädiatrisches Notfalllineal – PädNFL”) (OHIM No 002909382-001). He currently has no licensing arrangements and receives no royalties from this patent. All other authors declare that they have no conflicts of interest. The authors alone were responsible for composing the article and for its content.

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Authors’ contributions

All authors participated in planning the study, providing and collecting the questionnaires in their departments or during seminars, analysing and interpreting the data, writing and approval of the manuscript. Iris Steinwegs entered the data into a spreadsheet, Jost Kaufmann verified all data entries and Martin Hellmich performed the statistical analysis.

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