ELSEVIER

CrossMark

Journal of Clinical Epidemiology 70 (2016) 136–145

Journal of Clinical Epidemiology

Barriers and facilitators perceived by physicians when using prediction models in practice

Teus H. Kappen[a,*], Kim van Loon[a], Martinus A.M. Kappen[a], Leo van Wolfswinkel[a], Yvonne Vergouwe[b,c], Wilton A. van Klei[a], Karel G.M. Moons[a,b], Cor J. Kalkman[a]

[a]*Division of Anesthesiology, Department of Anesthesiology, Intensive Care and Emergency Medicine, University Medical Center Utrecht, P.O. Box 85500, Mail Stop F.06.149, Utrecht 3508 GA, The Netherlands*

[b]*Julius Center for Health Sciences and Primary Care, Department of Epidemiology, University Medical Center Utrecht, P.O. Box 85500, Mail Stop STR.6.131, Utrecht 3508 GA, The Netherlands*

[c]*Department of Public Health, Erasmus Medical Center, P.O. Box 1738, Rotterdam 3000 DR, South Holland, The Netherlands*

Accepted 8 September 2015; Published online 21 September 2015

Abstract

Objectives: Prediction models may facilitate risk-based management of health care conditions. In a large cluster-randomized trial, presenting calculated risks of postoperative nausea and vomiting (PONV) to physicians (assistive approach) increased risk-based management of PONV. This increase did not improve patient outcome—that is, PONV incidence. This prompted us to explore how prediction tools guide the decision-making process of physicians.

Study Design and Setting: Using mixed methods, we interviewed eight physicians to understand how predicted risks were perceived by the physicians and how they influenced decision making. Subsequently, all 57 physicians of the trial were surveyed for how the presented risks influenced their perceptions.

Results: Although the prediction tool made physicians more aware of PONV prevention, the physicians reported three barriers to use predicted risks in their decision making. PONV was not considered an outcome of utmost importance; decision making on PONV prophylaxis was mostly intuitive rather than risk based; prediction models do not weigh benefits and risks of prophylactic drugs.

Conclusion: Combining probabilistic output of the model with their clinical experience may be difficult for physicians, especially when their decision-making process is mostly intuitive. Adding recommendations to predicted risks (directive approach) was considered an important step to facilitate the uptake of a prediction tool.

Keywords: Risk prediction model; Decision support; Mixed methods; Impact study; Decision making; Implementation

1. Introduction

Prediction models are introduced into medical practice to facilitate physician decision making. A good model accurately identifies a patient's likelihood (or probability) of having a current condition (i.e., a diagnostic model) or predict a future health condition (i.e., prognostic model). This information may then be used by health care providers and patients—ideally in shared decision making—to decide on the most appropriate course of action, either treatment, preventive strategies, or a combination of these. It is often recommended that before widespread use in daily practice, the actual impact of diagnostic or prognostic prediction models on clinical decision making and patient outcomes should be formally studied in the so-called "prediction model impact studies." [1–5] We recently performed a large impact study of the implementation of a prediction model. This impact study allowed us to explore how clinicians actually perceive the use of prediction models and use their predicted risks in their decision making.

The impact study was designed as a large cluster-randomized trial on the use of a previously developed, validated,

Funding: This work was supported by The Netherlands Organization for Health Research and Development (ZonMW), The Hague, South Holland, The Netherlands. ZonMW grant numbers: 945.16.202, 912.08.004, and 918.10.615.

Role of the sponsors: The funding agreement ensured the authors' independence in design and conduct of the study; collection, management, analysis, and interpretation of the data; and preparation, review, or approval of the manuscript.

Conflict of interest: None.

* Corresponding author. University Medical Center Utrecht, P.O. Box 85500, Mail Stop Q.04.2.313, Utrecht 3508 GA, The Netherlands. Tel.: +31-88-755-9677; fax: +31-88-756-1160.

E-mail address: teus_kappen@yahoo.com (T.H. Kappen).

http://dx.doi.org/10.1016/j.jclinepi.2015.09.008

What is new?

- Conscious integration of a predicted risk into a physician"s decision-making process may be difficult and require a lot of attention. In a high-workload environment it is important to consider how the prediction model may be accommodated in the workflow of physicians to ease its attentional demands. Adding actionable recommendations to predicted risks and provide the reasoning behind the risk may reduce these demands and improve the uptake of the prediction model.

and recalibrated prediction model for postoperative nausea and vomiting (PONV) [6,7]. PONV is a common problem in the first 24 hours after surgery with general anesthesia, affecting—on average—30% of all surgical patients [6,8,9]. At the start of anesthesia, physicians who were randomized to the intervention group were ''exposed'' to model-based risk estimates of PONV for their individual patients, as calculated by an online prediction model. When compared with the unexposed physicians—that is, the ''care-as-usual'' control group—physicians who were presented the patients' individual PONV risks indeed administered more prophylactic antiemetic drugs to their patients. However, the overall increased administration of antiemetic prophylaxis did not result in a clinically relevant decrease in either the overall or risk-dependent incidence of PONV. This discrepancy was unexpected. From the results of the trial alone, we were unable to discern between possible causes for this discrepancy. One possible cause was that simply presenting risk scores only had a minimal impact on the physicians' behavior. Other possible causes were that the prediction model did not accurately target patients who will respond to the antiemetic effects of the prophylactic drugs or that the actual effectiveness of the prophylactic drugs was not as high as their studied efficacy [10,11].

We hypothesized that physicians with a greater inclination to treat PONV prophylactically would have administered more risk-dependent prophylaxis during the original randomized controlled trial (RCT) and thus their patients may have had a lower incidence of PONV. Hence, we performed an additional mixed methods study using both qualitative and quantitative methods to improve our understanding of how predicted risks are perceived, how they influence physician decision making, and which presentation format is considered most useful. We aimed to gain insight in why clinical implementation of a validated and recalibrated predictive model did not improve patient outcomes in our example cluster RCT. Furthermore, the results of this mixed methods study may help to formulate general recommendations for the design and conduct of impact trials and implementation of prediction models in clinical practice.

2. Method

2.1. Example study

The example study was a cluster-randomized trial on the clinical effects of implementing a prediction model for PONV [6]. This cluster RCT included 57 physicians of the Anesthesiology department at the University Medical Center Utrecht who treated over 11,000 patients between March 16, 2006, and December 21, 2007. After randomization of the physicians, we compared antiemetic prescription and PONV outcomes from the intervention group of physicians who were ''exposed'' to their patients' PONV risks to the care-as-usual group. The model implementation strategy was assistive, that is, the risk estimates were shown during the anesthetic case, but without any patient-specific recommendations on PONV prophylaxis [1,4]. During the cluster RCT, the physicians of the intervention group administered more risk-dependent PONV prophylaxis to their patients than physicians of the care-as-usual group. This increase in risk-dependent PONV prophylaxis in the intervention group did not result in a lower incidence of PONV.

2.2. Design of the present study

The present mixed methods study consisted of a sequential qualitative and quantitative phase, performed at the end of the cluster RCT. We first collected qualitative data on possible facilitators and barriers for the risk-dependent prophylactic treatment of PONV through face-to-face, semistructured interviews with physicians who participated in the cluster RCT (December 2007). The interviews were structured according to an interview guide constructed by the first and third author (T.H.K. and M.A.M.K.) and were conducted by the third author (M.A.M.K.). Interview transcripts were analyzed by the second and first author (K.V.L. and T.H.K.), using a grounded theory approach to identify differences in physicians' conceptions and barriers on prophylactic PONV management. Second, a structured survey was conducted among all physicians who participated in the RCT (January and February 2008). The interviews suggested differences in the conceptions and barriers between physicians of the intervention group and the care-as-usual group. Therefore, the survey among all anesthesiologists participating in the trial aimed to quantify whether exposure to predicted risks as calculated by the prediction model resulted in similar differences. Additional information on the methods can be found online (Appendix A at www.jclinepi.com for the interviews; Appendix B at www.jclinepi.com for the survey).

2.3. Interviews

Physicians were selected for the interviews by stratified random sampling from the pool of enrolled physicians. Stratification allowed for selection of physicians in different career stages (resident or junior attending vs. senior attending) and different randomization statuses within

the RCT (intervention vs. care as usual). Two physicians per stratum were expected to provide sufficient variation in the conceptions and barriers of physicians to administer prophylactic antiemetics to their patients during general anesthesia. In total, eight physicians were interviewed.

A semistructured interview schedule was devised using both open and closed questions. Questions were formulated according to four prespecified topics: (1) perceived patient burden of PONV by the physician; (2) professional risk stratification: how does the physician identify patients at risk for PONV; (3) the decision-making process regarding preventive antiemetic strategies; and (4) attitude toward the use of prediction models and decision support for prophylactic treatment of PONV. The specific phrasing and order of questions were only meant as a guide; interviewer and interviewees were encouraged to explore the different themes during the conversation. The duration of the interviews ranged from 20 to 60 minutes. Data saturation was achieved after eight interviews, and additional interviews were not expected to provide new insights [12–14]. The individual responses to each question were sorted, coded, and then rearranged into themes. Axial coding was used to group the themes into broader thematic topics, using Microsoft Excel (Redmond, Washington, USA). The themes and topics were subsequently integrated into central themes.

2.4. Structured survey

To quantify possible differences between study groups observed during the interviews, all physicians participating in the RCT received a Web-based survey. The survey addressed the same four topics used in the interviews. For each topic, a specific set of questions was formulated, and a summary score was used to rank the physicians according to their attitude toward that particular topic. For each question, the physicians were ranked according to their numerical answers. The median of all rankings for a single physician was then used as a summary ranking score for that particular topic (see Appendix at www.jclinepi.com). For each allocation group, the medians and interquartile ranges (IQRs) of the summary ranking scores per topic were calculated. Multiple testing was avoided by using the median of all four summary ranking scores for each physician as an overall rank score, which was tested using a Wilcoxon rank test. A two-sided alpha of <0.05 was considered statistically significant.

During the interview analysis, the question arose whether physicians from the intervention group preferred an actionable recommendation instead of simply being presented a predicted PONV risk, and—in contrast—care-as-usual physicians would have preferred the prediction model over the recommendation. This question was addressed in the survey using a post hoc analysis on a selection of questions from "Attitudes toward prediction models and decision support." The questions which addressed either the predicted risk, a recommendation, or both were pooled and analyzed using a Wilcoxon rank test (see Appendix B at www.jclinepi.com).

2.5. Adjusting the cluster-randomized trial analysis

The original RCT studied the PONV incidence (primary outcome) and the number of prophylactic antiemetics administered per patient (secondary outcome) for risk-dependent differences between allocation groups using mixed effects regression analyses [6]. We hypothesized that physicians with a greater inclination to treat PONV prophylactically would have administered more risk-dependent prophylaxis during the original RCT and thus their patients may have had a lower incidence of PONV. As the overall rank score from the Web-based survey was expected to reflect this inclination of physicians to treat PONV prophylactically, we adjusted the original RCT analysis of both outcomes for the overall rank score (see Appendix B at www.jclinepi.com).

3. Results

3.1. Interviews

The results of the eight interviews were rearranged into 17 themes according to prespecified topics of the interview model (Tables 1–4 and Appendix A at www.jclinepi.com). Four overarching categories—or central themes—emerged from the 17 themes, which are described in the following sections.

3.2. PONV is not a main area of attention

Awareness of PONV as a clinical problem and perceived patient burden appeared to be low. The interviewees of both groups reported that they considered PONV to be a side effect of general anesthesia (theme 1D, Table 1 and Appendix A at www.jclinepi.com) and that it should not be "excessively" treated because of a low burden relative to more serious complications (themes 3B and 3C, Table 3). Knowledge of the different elements of a PONV prevention strategy appeared to be quite fragmented. There was a large variation in reported PONV risk factors among all interviewees (themes 2A and 2B, Table 2), and several interviewees from both groups were reluctant to administer either dexamethasone, droperidol, or both without being able to explain their reluctance (theme 3A, Table 3). Additionally, it was reported not to be a regular topic of discussions among the medical staff of the anesthesia department (theme 1D, quote 14).

3.2.1. Intervention group: limited effect of the implementation strategy

The strategy for implementation of the prediction model seemed to have resulted in a limited increase in knowledge and awareness regarding all the aspects of PONV

Table 1. Quotes from the interview analysis on topic 1: perceived severity of PONV

No.	Quote	Interviewee
Theme 1A: knowledge of the frequency of PONV		
1	I do not know the percentages…A number of patients, but not that many…Actually, I do not see it [author's note: PONV] that often. No, I do not see many patients who get nauseous…The percentage [author's note: percentage of PONV] is not that high, so might I say 1 in 10? Well, no, I don't know.	Senior attending, care-as-usual group
Theme 1B: perception of the frequency of PONV among their patients		
2	It occurs in more than 1 out of 3 patients. And yes, I do believe that is a lot.	Resident, intervention group
3	You see, that is my experience of late, as I now mostly provide anesthesia for neurosurgical procedures. They do become nauseous, but because of the type of procedure, in fact, I don't see it that often.	Senior attending, care-as-usual group
4	The risk of PONV, because of the things we do, is quite large.	Senior attending, care-as-usual group
Theme 1C: feedback on PONV occurrence in their patients increases awareness		
5	Well, I received those numbers from the researchers, and they were shockingly higher than I expected.	Senior attending, intervention group
6	…I am more aware of PONV, I administered more prophylaxis and it did not change a thing. So I thought to myself, this is not getting us anywhere.	Senior attending, intervention group
7	I try to pay attention that I administer — to my opinion — adequate prophylaxis and adjust my anesthetic technique to lower the occurrence of PONV.	Resident, intervention group
8	About 40 to 50% of my patients suffer from PONV. I know that from the feedback reports, otherwise I would not have known.	Senior attending, intervention group
9	Of course I see my patients at the postanesthesia care unit, but I rarely hear back from the nursing ward when my patients get nauseous.	Senior attending, care-as-usual group
Theme 1D: PONV is a side effect of general anesthesia		
10	As an anesthesiologist you know that, because of the things you do, you structurally increase the patient's risk of PONV.	Senior attending, care-as-usual group
11	It is inherent to our procedures, I mean, when you are on the bus for a holiday, and you get nauseous because it is a bumpy ride, do you consider that a complication or is it just a part of the bus trip because you are sensitive to motion sickness?	Senior attending, care-as-usual group
12	It is different when the vomiting is that severe that it damages the esophagus, or something like that. Then it could turn into a complication.	Senior attending, care-as-usual group
13	PONV is a side effect of anesthesia and surgery, but if it is too easily overlooked and its prevention is insufficiently being addressed, then one might call it a medical error and consider it a complication.	Junior attending, intervention group
14	Because of the study it [author's note: awareness of PONV] has increased a little bit. However, it is still not a problem which is regularly brought up during case discussions… Perhaps it is just something that slips your mind quite easily.	Resident, intervention group

Abbreviation: PONV, postoperative nausea and vomiting.

prevention (themes 1A, 2A, 2B, and 3A). On the one hand, the interviewees from the intervention group seemed to be more aware of the frequency of PONV, as compared with the interviewees from the care-as-usual group (themes 1A and 1B). On the other hand, interviewees from the intervention group seemed only a little more aware of the efficacy of prophylactic antiemetics (theme 3A), whereas knowledge of other aspects of PONV prevention was similar in both study groups (themes 2A and 2B).

3.3. Unconscious process of decision making

For most physicians, the process of deciding on PONV prophylaxis is implicit. Physicians usually weighed several factors in their decision to administer prophylactic antiemetics: they made a risk assessment based on patient and procedure characteristics (themes 2A and 2B, Table 2 and Appendix A at www.jclinepi.com) and subsequently weigh the risk against benefits, harms, and contraindications of antiemetics (themes 3A and 3C, Table 3). The physicians did not report a well-defined process of assessing and weighing all these factors (themes 2C and 3B), so the process predominantly takes place "unconsciously"—or intuitively.

3.4. Presenting predicted PONV risks may not be sufficient to change professional decisions

Although interviewees from the intervention group reported to use the predicted risks in their decisions on PONV prophylaxis, they were unable to explicate how they used the predicted risk in their decisions on PONV prophylaxis (theme 4B, Table 4 and Appendix A at www.jclinepi.com). The interviewees from the intervention group expected that when a recommendation on PONV prophylaxis would be added to the predicted PONV risk, they would usually follow the advice (theme 4G, quotes 42 and 43). In contrast, the interviewees from the care-as-usual group reported that they would consider the presented risk of PONV mainly as a reminder (theme 4C) and that a recommendation on PONV prophylaxis would not have much added value (theme 4G, quotes 39–41).

Table 2. Quotes from the interview analysis on topic 2: professional risk stratification: how does a physician identify patients at risk for PONV?

No.	Quote	Interviewee
Theme 2A: variation in the use of risk factors		
15	When you see a very stressed and anxious young woman who is scheduled for a laparoscopy, then you immediately think: this will probably be Bingo.	Senior attending, intervention group
16	Yes, people with a history of PONV. People that claim: 'I am always terribly nauseous'. It almost seems like a self-fulfilling prophecy.	Senior attending, intervention group
Theme 2B: risk factors may be experience based or evidence based		
17	Yes, my assessment is based on literature…Relying on your own experience can be quite treacherous, because most patients get nauseous at the nursing ward, not at the postanesthesia care unit, and I do not regularly visit all my patients at the nursing ward.	Resident, care-as-usual group
18	So these are risk factors known from literature, but I do not take them into account to decide on who will become nauseous…For example smoking, if it has any consequences for my anesthetic case, I prefer to consider its pulmonary effects.	Senior attending, care-as-usual group
Theme 2C: weighing different risk factors: no clear-cut risk appraisal		
19	No, it is not a conscious process. It is more that you roughly know the risk factors, you have an overall view of the patient, and then you start thinking: Does this patient has a high risk or not? But in my mind, I am not actually calculating the risk.	Resident, intervention group
20	Just an intuitive feeling: this person will probably suffer from PONV.	Senior attending, care-as-usual group

Abbreviation: PONV, postoperative nausea and vomiting.

The intuitive use of the predicted PONV risk and a stated preference for an actionable recommendation by intervention group interviewees suggested that being presented only with a predicted risk may be difficult to use in a clinical decision. Adding a risk-corresponding treatment recommendation may assist physicians in interpreting the predicted risk for a decision on PONV prophylaxis (theme 4G, quote 43).

3.5. Multifaceted and individualized decision making

The physicians of both groups reported one distinct barrier for using a prediction model: they felt that a prediction model does not take into account all aspects of a specific patient. The prediction model only predicted the risk for a specific outcome and did not weigh the benefit of treatment against the expected harms and contraindications for a particular patient with specific characteristics and comorbidity (theme 4E, Table 4 and Appendix A at www.jclinepi.com). Furthermore, the physicians indicated that even a patient-specific risk prediction is not truly patient specific. The predicted PONV risk is an overall risk and does not reflect the specific pathway for becoming nauseous (theme 4F). The physicians felt that decision support should not be implemented at the cost of their authority to make case-by-case decisions. It is a physician's responsibility to make an individualized decision whether treatment of a specific condition is warranted for his or her patient—even when they decide against the recommendation (theme 4D).

Table 3. Quotes from the interview analysis on topic 3: making decisions on prophylactic antiemetic strategies

No.	Quote	Interviewee
Theme 3A: perceived benefits and harms of prophylactic antiemetic strategies		
21	The only drug that I actually administer as prophylaxis and for which I don't feel any reluctance is ondansetron.	Junior attending, care-as-usual group
22	Well, when your risk is 60% at first and afterward a risk of 40%, then it is about 20% effective.	Resident, intervention group
23	Dexamethasone? Definitely not as prophylaxis. That stuff has too many side effects. And I do not believe that it actually works that well.	Senior attending, care-as-usual group
24	Patients who always become nauseous after surgery, I always just give them dexamethasone, and it works, yes it works really well….No, I don't see many side effects of that.	Senior attending, intervention group
25	There are people who say that a single dose of dexamethasone is not so bad, whereas other people claim that even a single dose may cause serious side effects.	Junior attending, intervention group
26	There is definitely added value for droperidol, I think that is a good drug….I rarely administer droperidol intraoperatively…It provides some drowsiness, but in the low dose that we give, it is hardly a problem.	Senior attending, intervention group
Theme 3B: decisions on PONV prophylaxis are made implicitly		
27	You see, you can prevent nausea for a number of people, but when opposed by one person suffering from a surgical site infection [author's note: a perceived risk of dexamethasone PONV prophylaxis], your net benefit is lost.	Junior attending, care-as-usual group
Theme 3C: PONV prophylaxis: only when indicated		
28	Let's put it this way: to systematically provide PONV prophylaxis to all patients is impossible, because of the side effects. Although, when indicated for a specific patient, I believe you can accept the side effects.	Senior attending, care-as-usual group

Abbreviation: PONV, postoperative nausea and vomiting.

Table 4. Quotes from the interview analysis on topic 4: attitude toward the use of prediction models and decision support

No.	Quote	Interviewee
Theme 4A: intervention group: the predicted PONV risk is higher than their own risk assessment		
29	And I believe the predicted risks were higher because the prediction model actually calculates the risk from all factors associated with PONV, whereas we anesthesiologists lean toward particular touchstone factors such as history of PONV and type of surgery.	Junior attending, intervention group
Theme 4B: intervention group: no conscious roadmap for using the predicted risk		
30	When you open the anesthesia information management system, you immediately see it. Well, it is not that I immediately am consciously aware of it, sometimes I am, but not always. It occasionally happens that at the end of the procedure you think: 'O yes, the risk was high, shall I…	Senior attending, intervention group
31	Yes, well, when I entered the study and I received these predicted risks, I did use them for a while…I used the numbers to decide whether or not I would administer prophylaxis. Lately, I obviously eased on doing that, and I cannot clearly explain why that happened.	Junior attending, intervention group
Theme 4C: care-as-usual group: the predicted risk is mainly a reminder		
32	You know, it is foremost a reminder…Something in your screen that says: 'Remember!'…You are supposed to think of everything, sometimes you just fall short. So when it is on by default…	Senior attending, care-as-usual group
33	You do not benefit that much from a predicted risk. It is more a way to direct your attention to PONV, because to actually solve the problem itself you need more details than just a predicted risk.	Senior attending, care-as-usual group
Theme 4D: authority in making decisions is more important than decision support		
34	There is nothing wrong with a recommendation, as long as it does not become compulsory.	Junior attending, care-as-usual group
35	Of course it is nice to get a recommendation. On the other hand, all doctors, including me, feel that they can decide for themselves… I am in charge and I am also responsible.	Senior attending, intervention group
Theme 4E: prediction models do not consider other comorbidity		
36	The recommendation is probably only aimed at PONV, so I do believe that you should continue to consider which patient you have in front of you and what drugs you are going to administer.	Resident, intervention group
37	You may consider giving the patient dexamethasone as prophylaxis, but it may be contraindicated for specific patients or specific procedures.	Senior attending, care-as-usual group
Theme 4F: the predicted risk does not reflect the underlying mechanisms of PONV		
38	You can only treat a patient when you know the actual cause of the problem. Without that, the predicted risk will not do you any good, you need to know which factors contributed to that particular risk.	Senior attending, care-as-usual group
39	You need to know which factors contributed to that particular risk and then a recommendation may follow. However, as the treating physician you may regard this recommendation solely as an advice.	Senior attending, care-as-usual group
Theme 4G: willingness to use decision support may be dependent on familiarity		
40	We already have a protocol which antiemetic drugs to administer, so in its essence a predicted probability should suffice.	Junior attending, care-as-usual group
41	When you are sufficiently informed on its background, you can use the recommendation to your advantage. The question remains whether all the efforts which precede the implementation are actually worth their while.	Senior attending, care-as-usual group
42	I believe I would be inclined to administer more PONV prophylaxis, because you know that the predicted risk is based on an extensive calculation using several factors.	Junior attending, intervention group
43	On one hand it is nice to treat a patient based on a true evidence-based recommendation, on the other hand all doctors want to decide for themselves…So I have mixed feelings about this. I believe it will be a matter of getting used to it. At a certain point it will become a custom, and especially when it is has been proven to work, you would be a fool not to follow the recommendation.	Senior attending, intervention group

Abbreviation: PONV, postoperative nausea and vomiting.

3.6. Structured survey

In the original RCT, there were baseline differences in the characteristics of the physicians across the two groups (Table 5) [6]. Although none of these differences were statistically significant (also due to small numbers), the differences seemed large and clinically relevant and were the probable cause of the baseline differences at the patient level in the original RCT. Of the 57 physicians analyzed in the original RCT, 53 (93%) completed the survey [intervention group 29 (94%) and care-as-usual 24 (92%)]. Overall, the physicians of the intervention group had higher overall rank scores than the physicians of the care-as-usual group [median 31 (IQR 17–29) vs. 25 (IQR 24–37); $P < 0.05$]. This difference in rank scores indicated that intervention group physicians had a more positive attitude toward PONV prevention and the risk-dependent administration of PONV prophylaxis (Table 6). Similar to the results of the interviews, the post hoc

Table 5. Baseline characteristics of physicians from the survey

Characteristics	Care-as-usual group ($n = 26$)[a]	Intervention group ($n = 31$)[a]
Number of patients treated, median (IQR)	170 (128–300)	162 (120–207)
Age,[b] y; mean (SD)	43 (9)	43 (10)
Female sex, *n* (%)	11 (42)	15 (48)
Entered during study, *n* (%)	5 (19)	8 (26)
Left department during study, *n* (%)	4 (15)	7 (23)
Speciality		
Cardiac anesthesia,[b] *n* (%)	2 (8)	2 (6)
Pediatric anesthesia,[b] *n* (%)	3 (12)	4 (13)
Pain medicine,[b] *n* (%)	1 (4)	4 (13)
Senior resident,[b] *n* (%)	12 (46)	11 (35)
Entered as senior resident during study, *n* (%)	4 (15)	4 (13)
Senior resident became attending anesthesiologist during study, *n* (%)	5 (19)	4 (13)
Risk (%) threshold for administering PONV prophylaxis,[b] median (IQR)	30 (30–40)	30 (20–50)

Abbreviations: IQR, interquartile range; PONV, postoperative nausea and vomiting; SD, standard deviation.

[a] Number of physicians who participated in the cluster-randomized trial and were eligible for the survey.

[b] Characteristic was documented at the moment of inclusion in the study.

analysis on adding a recommendation to the predicted risk indicated that the intervention group physicians had a greater preference for the recommendation, which was statistically significant (median score intervention group 1 and care-as-usual group 0; $P < 0.05$).

Table 6. Median ranking scores from the survey for the physicians of both study groups

Topics	Cronbach's alpha	Care-as-usual group ($n = 24$)[a]	Intervention group ($n = 29$)[a]
Topic 1: perceived burden of PONV	0.89	22 (13–30)	33 (18–41)
Topic 2: professional risk stratification	0.74	18 (15–29)	39 (18–46)
Topic 3: making decisions on prophylaxis	0.72	24 (17–36)	30 (25–34)
Topic 4: attitude toward prediction models	0.49	29 (17–32)	29 (17–41)
Overall ranking score		25 (17–29)[b]	31 (24–37)[b]
Ranking score for topics 1–3[c]		22 (17–28)	34 (25–39)

Abbreviation: PONV, postoperative nausea and vomiting.

Data represent the medians (interquartile ranges) of the physicians' rankings scores within a study group for that topic. The scores indicate a ranking on a scale from 1 to 53 (the number of physicians who completed the survey). Higher ranking scores indicate physicians who have more favorable attitude toward the topic as compared with physicians with lower ranking scores.

[a] Physicians who completed the survey.

[b] $P < 0.05$.

[c] As there was no difference between groups for "Attitudes toward prediction models" and the topic had a low internal consistency, the combined rank score for the other three topics without "Attitudes toward prediction models and decision support" was also reported.

3.6.1. Adjusting the cluster-randomized trial analysis

When the original regression analyses were adjusted for the overall rank score of the survey, results were similar to the original results for both the primary and secondary outcomes (see Appendix B at www.jclinepi.com, Table 5). There was no association between the overall rank score itself and the incidence of PONV [odds ratio, 1.00; 95% confidence interval (CI): 1.00, 1.01] or the administration of prophylactic antiemetics (rate ratio, 1.00; 95% CI: 1.00, 1.01).

4. Discussion

We studied how the implementation and use of an assistive prediction model allowed physicians to apply risk-tailored prevention or treatment strategies and identified facilitators and barriers for risk-tailored management. In our example study, the implementation of the prediction model for PONV facilitated physicians in three ways: the physicians became more aware of the outcome PONV, were better informed on its risk factors, and had a more positive attitude toward preemptive management of PONV. Nevertheless, the facilitating effect of the prediction model on actual behavior—and thus patient outcomes—was modest. Physicians reported several barriers for using risk predictions from a prediction model, which may have

Box 1 Summary box

Barriers for using risk prediction models in clinical practice

The predicted outcome is not a main area of attention for the physicians.

The decision-making process of physicians is intuitive rather than analytical.

The probabilistic knowledge of the outcome is difficult to use in decision making, certainly when the probability estimate it is not accompanied by corresponding (e.g., therapeutic) management recommendations (assistive prediction model).

A prediction model does not weigh the benefits and risks of prophylactic drugs with regard to the patient's comorbidity.

Recommendations for a successful implementation of a prediction model in clinical practice

Adding an actionable recommendation to the predicted risk (directive prediction model).

Presentation of the predicted risk should be automated and smoothly integrated with the physician's workflow.

The reasoning and research evidence of the underlying prediction model to show how risks are actually estimated should also be available to physicians.

A prediction model will be better perceived by physicians when it predicts outcomes that are relevant to them and their patients.

counteracted the facilitating effect (see Box 1). First, the predicted outcome—that is, PONV—was not a main area of attention for most physicians. Second, the physicians did not use a conscious process for making decisions on PONV prophylaxis. Third, the presentation of only outcome risks or probabilities—that is, without further therapeutic management guidance—made it difficult to link the proper management to the predicted risks in individual patients. Fourth, a prediction model does not weigh the benefits and risks of prophylactic drugs with regard to the patient's comorbidity. The physicians argued that administration of PONV prophylaxis should remain an individualized decision made by a physician not by a model. Furthermore, physicians who indicated to be more inclined to treat PONV prophylactically did not administer more prophylaxis to their patients than physicians with a lesser inclination. This suggests that the facilitating effects of the prediction model were too modest to overcome the reported barriers, which also agrees with the original results of the study, as described elsewhere [6].

From this example study, we can learn how physicians may act on the use of risk prediction models to guide their decision making in individual patients. The data suggest that the clinical decision-making process may be much more intuitive than physicians realize. In other words, it may well be that physicians are typically habitual in their actions and little decision making is involved. In cognitive psychology literature, this intuitive, nonanalytical process of decision making is referred to as a "system 1" process, as opposed to conscious and analytical reasoning, referred to as a "system 2" process [15–17]. Humans have a higher capacity for reasoning when they use the rapid system 1 processes instead of the much slower system 2 processes. The results of our study further indicate that only presenting the model's predicted risks—without corresponding treatment recommendations—will generally force doctors to use system 2 type reasoning. Physicians have to become more reflective to integrate their clinical experience with the probabilistic information from the prediction model and translate this into a meaningful decision on subsequent actions and management, weighing all benefits and harms for a particular patient. This may actually be a difficult and cognitively demanding task, which makes the prediction tool seem less useful to physicians.

One might argue that this process is exactly what clinical judgment is about and that it is a physician's job to make such complicated decisions [18–20]. However, in our study, the physicians also reported that the outcome PONV was not a main area of attention. This barrier (see Box 1) may work in two ways. First, "attention" refers to information processes and task performance as it is used in human factors and ergonomics and is related to workload [21,22]. Clinical decision making is an intricate task performed within a system with a high degree of competing information and a multitude of tasks [23–25]. Consequently, integrating an outcome risk into an otherwise intuitive decision process requires a lot of "attention" in an already demanding environment. Second, PONV as an area of attention may refer to the physicians' knowledge of this particular condition or the perception of an outcome with limited patient burden [26]. In anesthesiology, PONV is considered the "big little problem"—that is, frequent but not life threatening—in a network of other anticipated and possibly more severe consequences [27,28]. It is imaginable that physicians will prioritize their attention to preventable problems with a higher perceived burden than to preventable problems with a lower perceived burden [29].

In addition, when the perceived burden is lower, the possible benefit is also lower and is thus more easily outweighed by the risk of adverse effects of treatment. Specific comorbidity may increase the risk of adverse treatment effects for individual patients—for example, dexamethasone use in diabetic patients or immunocompromised patients—yet the prediction model does not account for the comorbidities that are related to the adverse effects. When physicians believe that the predictive tool does not facilitate individualized decision making (the fourth barrier, see Box 1), they will be even less inclined to spend their time and attention to use the predicted outcome risks in their decisions.

The concept of how the three barriers may hinder physicians from using prediction models in their clinical decisions leads us to several recommendations for a successful implementation of a predictive tool in clinical practice and thus for the conduct of impact trials (see Box 1).

First, the demand that a predictive tool poses on the attention of physicians may be reduced by adding treatment recommendations to the presented predicted risks or risk categories, as it reduces the cognitive effort required to translate the predicted risk into a clinical decision. Prompted by the results of this qualitative study, we recently performed an add-on study to the cluster RCT, in which we actually added therapeutic recommendations to specific categories of predicted outcome risk—that is, a directive implementation approach. The directive approach had indeed a much larger effect on the decision making as well as on the reduction in outcome incidence than the assistive implementation approach had in the preceding cluster RCT [30].

Adding therapeutic recommendations to predicted risks to increase the uptake of decision support has been recommended before by various authors, including by ourselves [1,31–36]. However, these recommendations were either made in a more qualitative, editorial way, or came from systematic reviews that compared large numbers of studies for the features that facilitated implementation of decision support. We believe that our article adds novel concepts to this literature. In contrast to the systematic reviews that compared a large variety of clinical problems and settings, our series of studies (cluster RCT, this manuscript, and the before–after study) provide a head-to-head comparison of decision support without and with treatment recommendations within the same clinical setting. Moreover, most of the

scientific evidence on adding recommendations links the use of recommendations to a change in behavior without providing an actual explanation why. Our results indicate that it is not per se the ease of use of a recommendation that facilitates implementation but that a predicted risk without a recommendation prevents uptake by physicians to a greater extent.

Second, automatic provision of the predicted risk that is smoothly integrated with the physician's workflow may also be a key factor to reduce the required amount of attention and promote the use of the predicted outcome risks [33,34,37−40]. Third, a predictive tool may better aid physicians in making individualized decisions when the reasoning and research evidence that resides behind the tool is also presented to the physicians [33,34,37,39,41]. When physicians are better informed of which factors actually contribute to a predicted risk for a particular outcome, it is easier for them to understand how the predicted risk relates to their clinical experience. It was beyond the scope of this article to determine whether making physicians better informed would indeed improve their decision making or that the preference of the physicians for more information was an expression of overconfidence [18,19,42−44]. Finally, a predictive tool will likely be better perceived by physicians when it predicts outcomes that are relevant to them and their patients.

There are several limitations to our study. First, the results do provide a plausible—but not definitive—explanation for the ''no-effect-result'' of our cluster RCT. Second, the internal consistency for topic four (i.e., ''Attitude toward prediction models'') was relatively low. Consequently, topic four was of much less importance to the survey than the other three topics of the survey, as their internal consistencies were good (Cronbach's alpha between 0.70 and 0.90). The results of the survey thus mainly reflect the first three topics (i.e., ''Perceived burden of PONV''; ''Professional risk stratification''; and ''Making decisions on prophylaxis''). Third, we do not know what the role of the identified barriers was in specific decisions on PONV prophylaxis for individual patients. For example, we do not know how specific comorbidities or predictive factors influenced the physicians' decision making for individual patients or under what workload conditions those decisions were made. Fourth, we performed the interviews and surveys at the end of the RCT. That poses the problem that the interviews are based on hindsight and that not everything may be accurately recollected by the physicians. Fortunately, at the time of the interviews and surveys, the physicians were still making decisions on PONV prophylaxis in their daily practice, yet without the prediction model. Their responses to most of the questions likely still represented their actual decision making. Fifth, we discussed that integrating clinical experience with the probabilistic knowledge from the prediction model may be a demanding task. We cannot discern from our results whether this task is demanding because the physicians find it to be ''simply too much work'' or because the physicians do not know how their clinical experience may be integrated with the predicted risk.

In summary, we studied facilitators and barriers in the use of clinical prediction and decision models using a large randomized study on the implementation of a prediction model for PONV. Conscious integration of a predicted risk into the doctor's decision-making process may be difficult when the decision-making process is mostly intuitive and implicit. In a high-workload environment, such integration may require too much attention from a physician to actually integrate clinical and probabilistic knowledge. When one wishes to implement a prediction model to improve clinical practice, an important consideration is how to accommodate the new information in the physicians' workflow and how to ease the demand of attention on the physicians. Adding actionable patient-management recommendations to the predicted risk categories and providing physicians with the reasoning behind the predicted risks are the first steps to reduce such demand and improve the uptake of clinical prediction models in practice.

Supplementary data

Supplementary data related to this article can be found at http://dx.doi.org/10.1016/j.jclinepi.2015.09.008.

References

[1] Reilly BM, Evans AT. Translating clinical research into clinical practice: impact of using prediction rules to make decisions. Ann Intern Med 2006;144:201−9. Available at http://www.ncbi.nlm.nih.gov/pubmed/16461965. Accessed August 3, 2011.

[2] Toll DB, Janssen KJM, Vergouwe Y, Moons KGM. Validation, updating and impact of clinical prediction rules: a review. J Clin Epidemiol 2008;61:1085−94.

[3] Hlatky MA, Greenland P, Arnett DK, Ballantyne CM, Criqui MH, Elkind MS, et al. Criteria for evaluation of novel markers of cardiovascular risk: a scientific statement from the American Heart Association. Circulation 2009;119:2408−16.

[4] Moons KGM, Kengne AP, Grobbee DE, Royston P, Vergouwe Y, Altman DG, et al. Risk prediction models: II. External validation, model updating, and impact assessment. Heart 2012;98:691−8.

[5] Haskins R, Osmotherly PG, Rivett DA. Validation and impact analysis of prognostic clinical prediction rules for low back pain is needed: a systematic review. J Clin Epidemiol 2015;68:821−32.

[6] Kappen TH, Moons KGM, van Wolfswinkel L, Kalkman CJ, Vergouwe Y, van Klei WA. Impact of risk assessments on prophylactic antiemetic prescription and the incidence of postoperative nausea and vomiting: a cluster-randomized trial. Anesthesiology 2014;120:343−54.

[7] Kappen TH, Vergouwe Y, van Klei WA, van Wolfswinkel L, Kalkman CJ, Moons KGM. Adaptation of clinical prediction models for application in local settings. Med Decis Making 2012;32:E1−10.

[8] Fernández-Guisasola J, Gómez-Arnau JI, Cabrera Y, del Valle SG. Association between nitrous oxide and the incidence of postoperative nausea and vomiting in adults: a systematic review and meta-analysis. Anaesthesia 2010;65:379−87.

[9] Gan TJ, Diemunsch P, Habib AS, Kovac A, Kranke P, Meyer TA, et al. Consensus guidelines for the management of postoperative nausea and vomiting. Anesth Analg 2014;118:85−113.

[10] Apfel CC, Korttila K, Abdalla M, Kerger H, Turan A, Vedder I, et al. A factorial trial of six interventions for the prevention of postoperative nausea and vomiting. N Engl J Med 2004;350:2441−51.
[11] Carlisle JB, Stevenson CA. Drugs for preventing postoperative nausea and vomiting. Cochrane Database Syst Rev 2006;CD004125.
[12] Charmaz K. Chapter 5. In: Silverman D, editor. Constructing grounded theory: a practical guide through qualitative analysis. Sage Publications; 2006:208. Available at http://books.google.com/books?id=v1qP1KbXz1AC&pgis=1. Accessed June 30, 2015.
[13] Mason M. Sample size and saturation in PhD studies using qualitative interviews. Forum Qual Soc Res 2010;11(3). Available at http://www.qualitative-research.net/index.php/fqs/article/viewArticle/1428. Accessed November 13, 2014.
[14] Draucker CB, Martsolf DS, Ross R, Rusk TB. Theoretical sampling and category development in grounded theory. Qual Health Res 2007;17:1137−48.
[15] Stanovich KE. Who is rational?: studies of individual differences in reasoning. Mahwah: Lawrence Erlbaum Associates; 1999.
[16] Kahneman D, Frederick S. Representativeness revisited: attribute substitution in intuitive judgment. In: Gilovich T, Griffin D, Kahneman D, editors. Heuristics and biases: the psychology of intuitive judgment. Cambridge, UK: Cambridge Univ. Press; 2002:49−81. Available at http://commonsenseatheism.com/wp-content/uploads/2011/04/Kahneman-Frederick-Representativeness-revisited.pdf. Accessed May 4, 2014.
[17] Evans JSBT. Dual-processing accounts of reasoning, judgment, and social cognition. Annu Rev Psychol 2008;59:255−78.
[18] Malterud K. Reflexivity and metapositions: strategies for appraisal of clinical evidence. J Eval Clin Pract 2002;8:121−6. Available at http://www.ncbi.nlm.nih.gov/pubmed/12180360. Accessed May 28, 2014.
[19] Croskerry P. A universal model of diagnostic reasoning. Acad Med 2009;84:1022−8.
[20] Tonelli MR. The challenge of evidence in clinical medicine. J Eval Clin Pract 2010;16:384−9.
[21] Wickens CD. Multiple resources and performance prediction. Theor Issues Ergon 2002;3:159−77.
[22] Wickens CD. Multiple resources and mental workload. Hum Factors 2008;50:449−55.
[23] Gaba DM, Lee T. Measuring the workload of the anesthesiologist. Anesth Analg 1990;71:354−61. Available at http://www.ncbi.nlm.nih.gov/pubmed/2400118. Accessed May 4, 2014.
[24] Loeb RG. A measure of intraoperative attention to monitor displays. Anesth Analg 1993;76:337−41. Available at http://www.ncbi.nlm.nih.gov/pubmed/8424512. Accessed May 4, 2014.
[25] Stevenson RA, Schlesinger JJ, Wallace MT. Effects of divided attention and operating room noise on perception of pulse oximeter pitch changes: a laboratory study. Anesthesiology 2013;118:376−81.
[26] Lewis KL, Thompson JM. Health care professionals' perceptions and knowledge of infection control practices in a community hospital. Health Care Manag (Frederick) 2009;28:230−8.
[27] Kapur PA. The big "little problem". Anesth Analg 1991;73:243−5. Available at http://www.ncbi.nlm.nih.gov/pubmed/1831014. Accessed May 4, 2014.
[28] Macario a, Weinger M, Truong P, Lee M. Which clinical anesthesia outcomes are both common and important to avoid? The perspective of a panel of expert anesthesiologists. Anesth Analg 1999;88:1085−91. Available at http://www.ncbi.nlm.nih.gov/pubmed/10320175. Accessed November 5, 2014.
[29] Ash JS, Sittig DF, Guappone KP, Dykstra RH, Richardson J, Wright A, et al. Recommended practices for computerized clinical decision support and knowledge management in community settings: a qualitative study. BMC Med Inform Decis Mak 2012;12:6.
[30] Kappen TH, Vergouwe Y, Van Wolfswinkel L, Kalkman CJ, Moons KGM, Van Klei WA. Impact of adding therapeutic recommendations to risk assessments from a prediction model for postoperative nausea and vomiting. Br J Anaesth 2015;114:252−60.
[31] Steyerberg EW, Moons KGM, van der Windt DA, Hayden JA, Perel P, Schroter S, et al. Prognosis Research Strategy (PROGRESS) 3: prognostic model research. PLos Med 2013;10:e1001381.
[32] Michie S, Johnston M. Changing clinical behaviour by making guidelines specific. BMJ 2004;328:343−5.
[33] Kawamoto K, Houlihan C a, Balas EA, Lobach DF. Improving clinical practice using clinical decision support systems: a systematic review of trials to identify features critical to success. BMJ 2005;330:765.
[34] Lobach D, Sanders GD, Bright TJ, Wong A, Dhurjati R, Bristow E, et al. Enabling health care decisionmaking through clinical decision support and knowledge management. Evid Rep Technol Assess (Full Rep) 2012;1−784. Available at http://www.ncbi.nlm.nih.gov/pubmed/23126650. Accessed June 12, 2015.
[35] Peiris DP, Joshi R, Webster RJ, Groenestein P, Usherwood TP, Heeley E, et al. An electronic clinical decision support tool to assist primary care providers in cardiovascular disease risk management: development and mixed methods evaluation. J Med Internet Res 2009;11:e51.
[36] Horsky J, Schiff GD, Johnston D, Mercincavage L, Bell D, Middleton B. Interface design principles for usable decision support: a targeted review of best practices for clinical prescribing interventions. J Biomed Inform 2012;45:1202−16.
[37] Varonen H, Kortteisto T, Kaila M. What may help or hinder the implementation of computerized decision support systems (CDSSs): a focus group study with physicians. Fam Pract 2008;25:162−7.
[38] Trivedi MH, Daly EJ, Kern JK, Grannemann BD, Sunderajan P, Claassen CA. Barriers to implementation of a computerized decision support system for depression: an observational report on lessons learned in "real world" clinical settings. BMC Med Inform Decis Mak 2009;9:6.
[39] Kortteisto T, Komulainen J, Mäkelä M, Kunnamo I, Kaila M. Clinical decision support must be useful, functional is not enough: a qualitative study of computer-based clinical decision support in primary care. BMC Health Serv Res 2012;12:349.
[40] Lomotan EA, Hoeksema LJ, Edmonds DE, Ramírez-Garnica G, Shiffman RN, Horwitz LI. Evaluating the use of a computerized clinical decision support system for asthma by pediatric pulmonologists. Int J Med Inform 2012;81:157−65.
[41] McGinn CA, Gagnon M-P, Shaw N, Sicotte C, Mathieu L, Leduc Y, et al. Users' perspectives of key factors to implementing electronic health records in Canada: a Delphi study. BMC Med Inform Decis Mak 2012;12:105.
[42] Berner ES, Graber ML. Overconfidence as a cause of diagnostic error in medicine. Am J Med 2008;121(5 Suppl):S2−23.
[43] Croskerry P, Norman G. Overconfidence in clinical decision making. Am J Med 2008;121(5 Suppl):S24−9.
[44] Miles RW. Fallacious reasoning and complexity as root causes of clinical inertia. J Am Med Dir Assoc 2007;8:349−54.