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# Expected individual benefit of prophylactic platelet transfusions in hemato-oncology patients based on bleeding risks

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## Abstract

**Background:** Prophylactic platelet transfusions prevent bleeding in hemato-oncology patients, but it is unclear how any benefit varies between patients. Our aim was to assess if patients with different baseline risks for bleeding benefit differently from a prophylactic platelet transfusion strategy.

**Study design and methods:** Using the data from the randomized controlled TOPPS trial (Trial of Platelet Prophylaxis), we developed a prediction model for World Health Organization grades 2, 3, and 4 bleeding risk (defined as at least one bleeding episode in a 30 days period) and grouped patients in four risk-quartiles based on this predicted baseline risk. Predictors in the model were baseline platelet count, age, diagnosis, disease modifying treatment, disease status, previous stem cell transplantation, and the randomization arm.

**Results:** The model had a c-statistic of 0.58 (95% confidence interval [CI] 0.54–0.64). There was little variation in predicted risks (quartiles 46%, 47%, and 51%), but prophylactic platelet transfusions gave a risk reduction in all risk quartiles. The absolute risk difference (ARD) was 3.4% (CI –12.2 to 18.9) in the lowest risk

**Abbreviations:** ARD, absolute risk difference; CI, Confidence Interval; OR, odds ratio; SCT, stem cell transplantation; TOPPS, Trial of Platelet Prophylaxis; WHO, World Health Organization.

Jaap Jan Zwaginga and Johanna G. van der Bom are the last authors.

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quartile (quartile 1), 7.4% (95% CI -8.4 to 23.3) in quartile 2, 6.8% (95% CI -9.1 to 22.9) in quartile 3, and 12.8% (CI -3.1 to 28.7) in the highest risk quartile (quartile 4).

**Conclusion:** In our study, generally accepted bleeding risk predictors had limited predictive power (expressed by the low c-statistic), and, given the wide confidence intervals of predicted ARD, could not aid in identifying subgroups of patients who might benefit more (or less) from prophylactic platelet transfusion.

#### KEYWORDS

platelet transfusion, transfusion practices (oncology-hematology)

## 1 | INTRODUCTION

Patients with hematological malignancies often develop thrombocytopenia as a direct consequence of their disease and/or treatment regime. Thrombocytopenia is weakly associated with bleeding, varying from skin bleeds to major bleeding in organs, among others cerebral hemorrhage.<sup>1</sup>

Current guidelines recommend to administer prophylactic platelet transfusions to patients with hematological disorders at a platelet count threshold of  $<10 \times 10^9/L$  to prevent bleeding.<sup>2-6</sup> Guidelines also recommend to consider giving prophylactic transfusions at higher platelet count thresholds if patients have an expected higher bleeding risk, or to withhold prophylactic transfusions if the bleeding risk is relatively low, for example in autologous stem cell recipients.<sup>2,3</sup> The quantification of bleeding risks, however, is not standardized, resulting in considerable variation in transfusion strategies in clinical practice.<sup>2-7</sup>

In the randomized controlled TOPPS trial (Trial of Platelet Prophylaxis), it was found that prophylactic platelet transfusions reduce bleedings with a World Health Organization (WHO) bleeding grade of 2, 3, or 4, compared to non-prophylactic platelet transfusions (i.e. therapeutic).<sup>8,9</sup> What is more, this beneficial effect differed between subgroups of patients with the least effect for patients receiving autologous stem cell transplantation (SCT).<sup>10</sup> Other clinical variables, like fever and sex, also seemed to influence the effect of prophylactic platelet transfusion on bleeding in this trial.<sup>11</sup>

Overall, there remains limited quantitative evidence on how prophylactic platelet transfusions reduce the bleeding risk differently in patients with likely diverse a priori bleeding risks. Where trial results give a quantification of the effect of transfusion strategies for the “average” patient in the trial population, in practice this “average” patient does not exist. Average effects from a

trial do not necessarily apply to individual patients, in whom the actual treatment effect may differ (heterogeneity of treatment effect).<sup>12,13</sup> Traditionally, heterogeneity of treatment effects is investigated by comparing subgroups of patients based on a single variable. However, combining multiple patient characteristics might enable a better personalized prediction of the effect of prophylactic platelet transfusions. For example, one can imagine that a female patient with acute leukemia who has a platelet count of  $45 \times 10^9/L$  before treatment receiving intensive cytoreductive chemotherapy will benefit more from a prophylactic platelet transfusion strategy than a male who receives an autologous SCT to treat lymphoma with a platelet count of  $155 \times 10^9/L$  at the day of admission. All these, and other, clinical factors when combined can contribute to a bleeding risk, and patients with different bleeding risks may benefit differently from platelet transfusions. To know this at the start of an intensive treatment regime, such as a SCT or chemotherapy, could potentially lead to more personalized prophylactic platelet transfusion strategies.

We therefore aimed to quantify effects of a prophylactic platelet transfusion strategy compared with a therapeutic platelet transfusion strategy on the occurrence of WHO grade 2, 3 or 4 bleeding stratified by predicted baseline bleeding risks of patients with hemato-oncological diseases.

## 2 | METHODS

For this study, we used the data of the TOPPS trial. The design was described previously.<sup>8,14</sup> In short, 600 hemato-oncological patients were randomized in a prophylactic arm receiving platelet transfusions based on a threshold of  $10 \times 10^9/L$ , and a therapeutic (or no-prophylaxis) arm receiving platelet transfusions in case of active bleeding. The primary outcome was the occurrence of WHO grade 2, 3, or 4 bleedings. The dataset for the analysis consisted of

all 598 patients who were also included in the analysis of the TOPPS trial, of whom 47% (279 patients) developed at least one WHO grade 2, 3, or 4 bleeding during 30-day follow-up. Because we used previously collected data of one of the largest datasets for this subject, and larger trials are not likely performed in the future, no formal sample size calculation was performed for this post-hoc analysis of randomized control trial data.

## 2.1 | Predictors of bleeding risk

We developed a model to predict the risk of WHO grade 2, 3, or 4 bleeding within 30 days after randomization. To improve the stability of this model, we selected a limited number of baseline characteristics for inclusion in the model. The selection was made based on (i) prior research that showed associations between the variables and the outcome, (ii) the completeness of the data, (iii) expert opinion. Selected variables were age at randomization, platelet count on day of randomization, sex, diagnosis (acute leukemia versus other), disease modifying treatment (chemotherapy/allogeneic SCT versus autologous SCT), disease status (new diagnosis versus relapsed disease), the presence of a SCT in medical history, and the

randomization arm.<sup>8,11,15-18</sup> The randomization arm was added because ignoring treatments that affect the outcome in the prediction model can lead to an inaccurate predicted probability.<sup>15,19</sup> Thus, adding the randomization arm improves the prediction of the treatment effect in a heterogeneity of treatment effect analysis. Although proof of interactions cannot be obtained with the present sample size, based on clinical reasoning, interaction terms were included for the likely deemed interactions between prophylactic platelet transfusions and diagnosis, as well as for prophylaxis and treatment.

## 2.2 | Missing data

Missing values were imputed. Given the low numbers of missing values (in total six subjects had one missing variable, Table 1), we imputed the modal value for missing categorical values. For the continuous variable platelet count, the subsequent value within 3 days of the randomization date of the same patient was used. If the value was unknown for these days, we imputed the median observed value of the other patients. To check robustness of the findings we performed sensitivity analyses in the subjects without missing values ( $n = 592$ ).

**TABLE 1** Baseline characteristics of randomized patients comparing characteristics for patients based on the occurrence of World Health Organization (WHO) grade 2, 3, or 4 bleeding

	Total cohort ( $n = 598$ )	No WHO grade 2, 3 or 4 bleeding ( $n = 319$ )	WHO grade 2, 3 or 4 bleeding ( $n = 279$ )	<i>p</i> -value*
Age at inclusion (years) <sup>a</sup>	58 (49–63)	57 (49–63)	59 (51–64)	.1044
Platelet count day inclusion ( $\times 10^9/L$ ) <sup>a,b</sup>	41 (30–50)	41 (31–51)	40 (29–50)	.3391
Male sex (%)	387 (65%)	223 (70%)	164 (59%)	.005
Diagnosis (%)				.421
Lymphoma/myeloma/other	482 (81%)	261 (82%)	221 (79%)	
Acute leukemia	116 (19%)	58 (18%)	58 (21%)	
Disease modifying treatment (%)				.726
Autologous stem cell transplantation (SCT)	420 (70%)	226 (71%)	194 (70%)	
Chemotherapy/allogeneic SCT	178 (30%)	93 (29%)	85 (30%)	
Disease status (%) <sup>b</sup>				.407
New diagnosis	397 (66%)	207 (65%)	190 (68%)	
Relapsed disease	201 (34%)	112 (35%)	89 (32%)	
Stem cell transplantation in history (%) <sup>b</sup>	45 (8%)	26 (8%)	19 (7%)	.535
Randomization arm (%)				.070
Therapeutic arm	300 (50%)	149 (47%)	151 (54%)	
Prophylactic arm	298 (50%)	170 (53%)	128 (46%)	

Note: In total, 6 values were missing and imputed (one value per patient): platelet count was imputed for 3 patients, disease status for 1 patient and SCT in history for 2 patients.

\**p*-value refers to Kruskal-Wallis equality-of-populations rank test when median is reported and Pearson's chi-squared for equality of proportions.

<sup>a</sup>Median (interquartile range).

<sup>b</sup>Statistical test.

## 2.3 | Development of bleeding risk prediction model

We developed a logistic regression model to predict the risk of WHO grade 2, 3, or 4 bleeding within 30 days after randomization.<sup>20</sup> To correct for optimism, we performed “shrinkage” of all regression coefficients using penalized Ridge regression. The goal of this is to attempt to create a model that is better applicable to external datasets. Shrinkage in this respect diminishes the effect of all variables, which are likely over-optimistic in the original dataset.<sup>21</sup> The linearity assumption was visually checked for continuous variables; no quadratic terms or splines were deemed necessary.

After development of the model, we calculated the individual predicted 30-day risk of bleeding. For this step, to calculate the risk in absence of prophylactic transfusions for the complete population, we assumed a therapeutic platelet transfusion strategy for all patients, irrespective of their actual treatment allocation. This was necessary to be able to compare the risk with and without prophylaxis for the heterogeneity of treatment effect analysis described below, and enabled usage of the complete dataset for more power. All steps below were executed for a model without shrinkage (binary logistic regression) and for the penalized model (Ridge regression). Below, the results of the penalized model are presented; results for the crude model are presented in the Appendix S1.

## 2.4 | Model predictive performance

Performance of the model was expressed via the discriminative ability of the model (c-statistic), and as a visualization of the comparison between the predicted probability against the observed risk of bleeding (calibration plot).

## 2.5 | Heterogeneity of treatment effect analysis

To assess the heterogeneity of treatment effects, patients were stratified in four quartiles by their predicted baseline risk. Within the quartiles, we examined heterogeneity of the effect of prophylactic versus therapeutic transfusions by estimating the odds ratio (OR) and the absolute risk difference (ARD) with 95% confidence intervals (95% CI) between the predicted number of bleedings with and without prophylactic transfusions. These confidence intervals are to be considered as a measure of precision only. They were not used for formal statistical testing, given the application of Ridge penalization, and the exploratory nature of this study.

## 3 | RESULTS

The baseline characteristics of participants in the TOPPS-trial are presented in Table 1. A minority of patients was diagnosed with acute leukemia (19%) and most patients

**TABLE 2** Multivariable analysis for primary outcome of WHO grade 2, 3, or 4 bleeding: Odds ratios and 95% confidence intervals (CI), for both the crude model as the model after ridge penalization

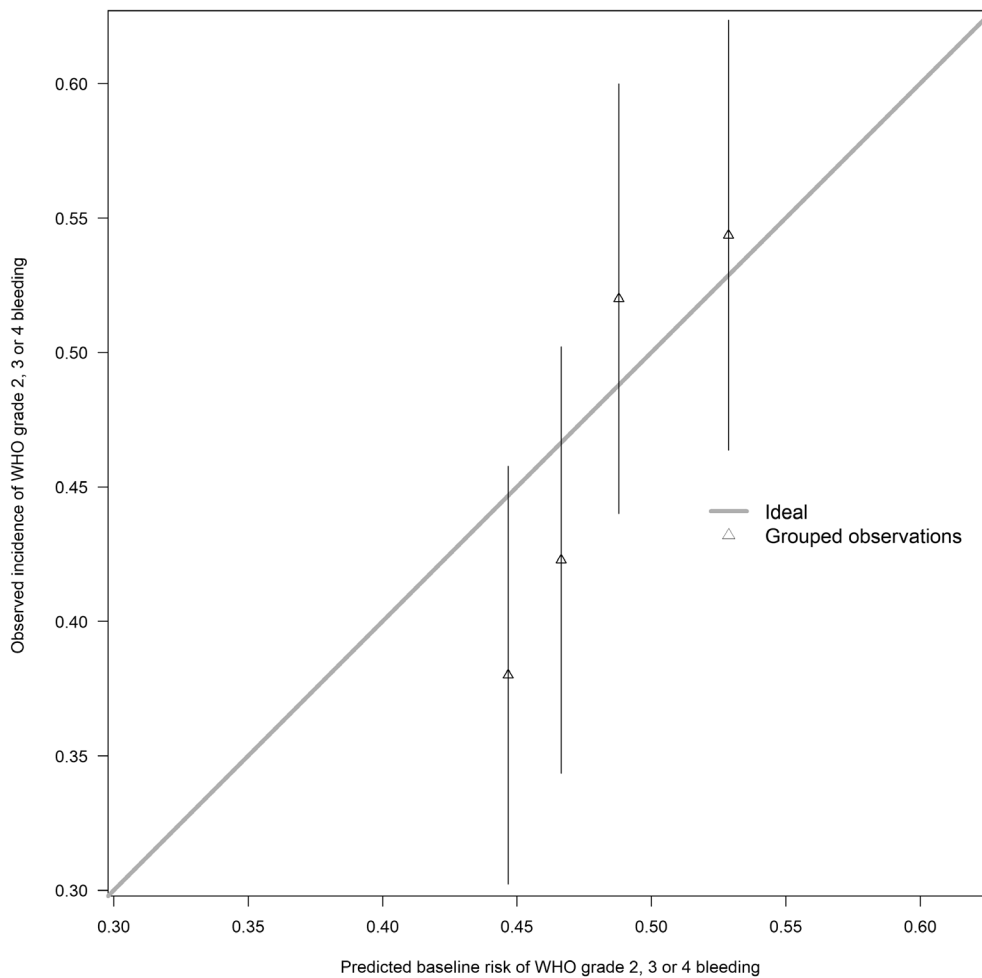
	Crude model OR (95% CI)	Odds ratio penalized model <sup>a</sup>
Age at inclusion	1.01 (0.99–1.02)	1.00 (0.99–1.02)
Platelet count on day inclusion	1.00 (0.99–1.01)	1.00 (0.99–1.01)
Female sex (ref = male)	1.65 (1.17–2.33)	1.27 (0.90–1.80)
Diagnosis acute leukemia (ref = lymphoma/myeloma/other)	0.92 (0.37–2.31)	1.00 (0.40–2.49)
Disease modifying treatment chemotherapy or allogeneic SCT (ref = Autologous SCT)	0.74 (0.34–1.61)	0.96 (0.44–2.09)
Disease status- relapsed disease (ref = new diagnosis)	0.96 (0.66–1.38)	0.96 (0.67–1.39)
SCT in history (ref = no)	0.82 (0.42–1.60)	0.92 (0.47–1.80)
Randomization arm (ref = therapeutic)	0.93 (0.63–1.38)	0.81 (0.55–1.19)
Interaction term randomization arm and diagnosis	1.45 (0.40–5.20)	1.22 (0.34–4.40)
Interaction term randomization arm and disease modifying treatment	1.72 (0.57–5.19)	1.16 (0.38–3.49)

Abbreviations: ref, reference category; SCT, stem cell transplantation; WHO, World Health Organization.

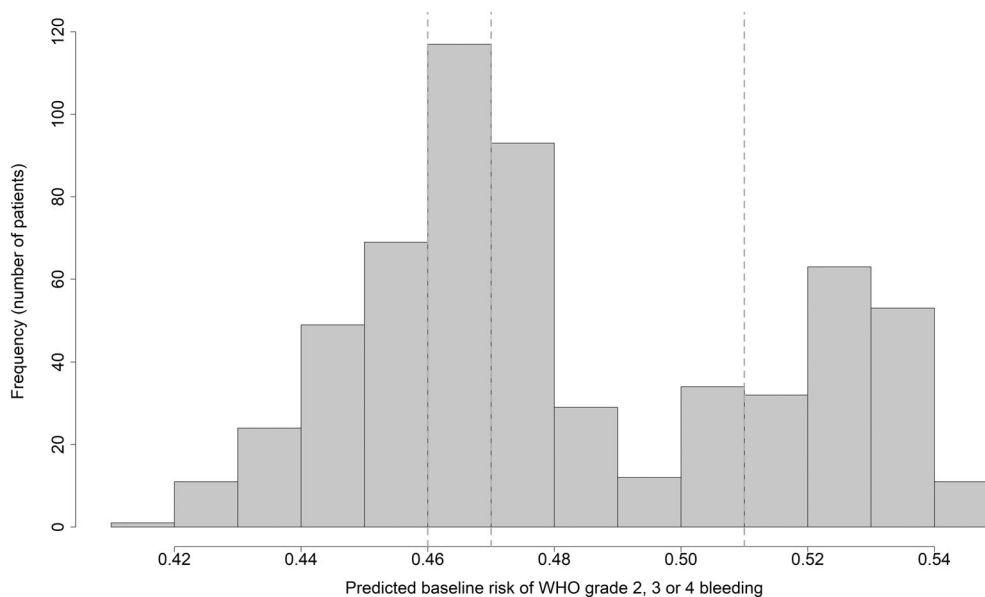
<sup>a</sup>Ridge penalization method, confidence intervals are only to be interpreted as an indication of precision, not as a statistical test.

received an autologous SCT (70%). Relapsed disease occurred in approximately 1/3 of patients, and 8% had a bone marrow transplantation in the past. About 65% of patients were men, the median age was 58 years and the

median platelet count at day of inclusion was  $41 \times 10^9/L$ . Women had more bleeding events (55%, compared to 42% of men) and as reported earlier,<sup>8</sup> the incidence of WHO bleeding grade 2, 3 or 4 was higher in the



**FIGURE 1** The triangles in this calibration plot of the predictions of World Health Organization grade 2, 3, and 4 bleedings indicate the predicted probabilities and observed frequencies for all four risk quartiles (based on assumption of a therapeutic transfusion strategy). The diagonal line represents ideal calibration, when observed and predicted probabilities are identical. The calibration slope is 2.04 (0.76–3.32) with an intercept of  $-0.06$  ( $-0.22$  to  $0.10$ ). The c-statistic is 0.58 (0.53–0.62)



**FIGURE 2** Predicted absolute risk of World Health Organization grade 2, 3, or 4 bleeding (based on assumption of a therapeutic transfusion strategy) is represented as the absolute risk of outcome on the x-axis and the frequency of each absolute risk category (0.41–0.42, 0.42–0.43, etc.) in the trial population on the y-axis. The dotted lines represent the cut-off for the four quartiles of predicted risk on bleeding



therapeutic arm (50%) compared with the prophylactic arm (43%). Results from Table 1 were not used for variable selection for our prediction model (variable selection was pre-specified), but are only descriptive.

Table 2 shows the OR for WHO grade 2, 3 or 4 bleeding for all selected variables in the multivariable model, with accompanying 95% CIs. After correcting for optimism via penalization, the point estimates of most variables were approximating an OR of 1. The complete model with intercept and all regression coefficients is presented in the Appendix S1, as is the crude model before penalization.

The c-statistic of the model after penalization and internal validation was 0.58 (95% CI 0.54 to 0.63), indicating that when two random patients with different bleeding outcomes are chosen, in 58% the predicted bleeding risk was lower in the patient without bleeding compared to the patient with a bleeding event.<sup>22</sup> The calibration plot of our model is presented in Figure 1, the slope of the plot was 2.04 (0.76 to 3.32) with an intercept of  $-0.06$  ( $-0.22$  to  $0.10$ ). A good calibration would have a slope approximating 1. However, due to shrinkage of the prediction model, predicted probabilities were shrunken towards the group average and consequently the model appears to be underfitted (i.e. calibration slope  $>1$ ) as is expected after penalization.

Figure 2 shows the distribution of predicted baseline risk; all risks varied between 41% and 55%. Based on quartiles, four bleeding risk groups were defined:  $<46\%$  (risk quartile 1), 46–47% (risk quartile 2), 47–51% (risk quartile 3) and  $>51\%$  (risk quartile 4).

Figure 3 presents incidence rates of WHO grade 2, 3 or 4 bleedings, the OR's and risk differences when comparing the prophylactic strategy versus the therapeutic-only strategy for all patients. In all quartiles of baseline risk, the observed incidence of bleeding was higher if patients received therapeutic platelet transfusions (panel A). In panel B the OR's per quartile are displayed along with the overall OR of the trial. For all quartiles, the OR is  $<1$ , indicating a general benefit of prophylactic transfusions. The first risk quartile has an OR closer to 1, namely 0.87 (95% CI 0.45–1.68) compared to the overall OR (overall OR 0.74, 95% CI 0.54–1.03). In the fourth risk quartile the OR is more extreme compared to the overall OR, namely 0.59 (95% CI 0.31–1.14). The ARD (panel C) hence was most pronounced in the highest bleeding risk quartile (12.8%, 95% CI  $-3.1$  to 28.7). This could indicate that patients in the highest risk quartile might benefit most from the prophylactic platelet transfusions, but given the wide confidence intervals this conclusion cannot be drawn on these current data. The ARDs in the other risk quartiles were 3.4% (95% CI  $-12.2$  to 18.9), 7.4% (95% CI  $-8.4$  to 23.3), and 6.8% (95% CI  $-9.1$  to 22.9) respectively for risk quartiles 1, 2 and 3.

As a sensitivity analysis, we performed a complete case analysis using information about the 592 subjects with complete information. Results were comparable to those of the analysis of all 598 subjects (see Appendix S1).

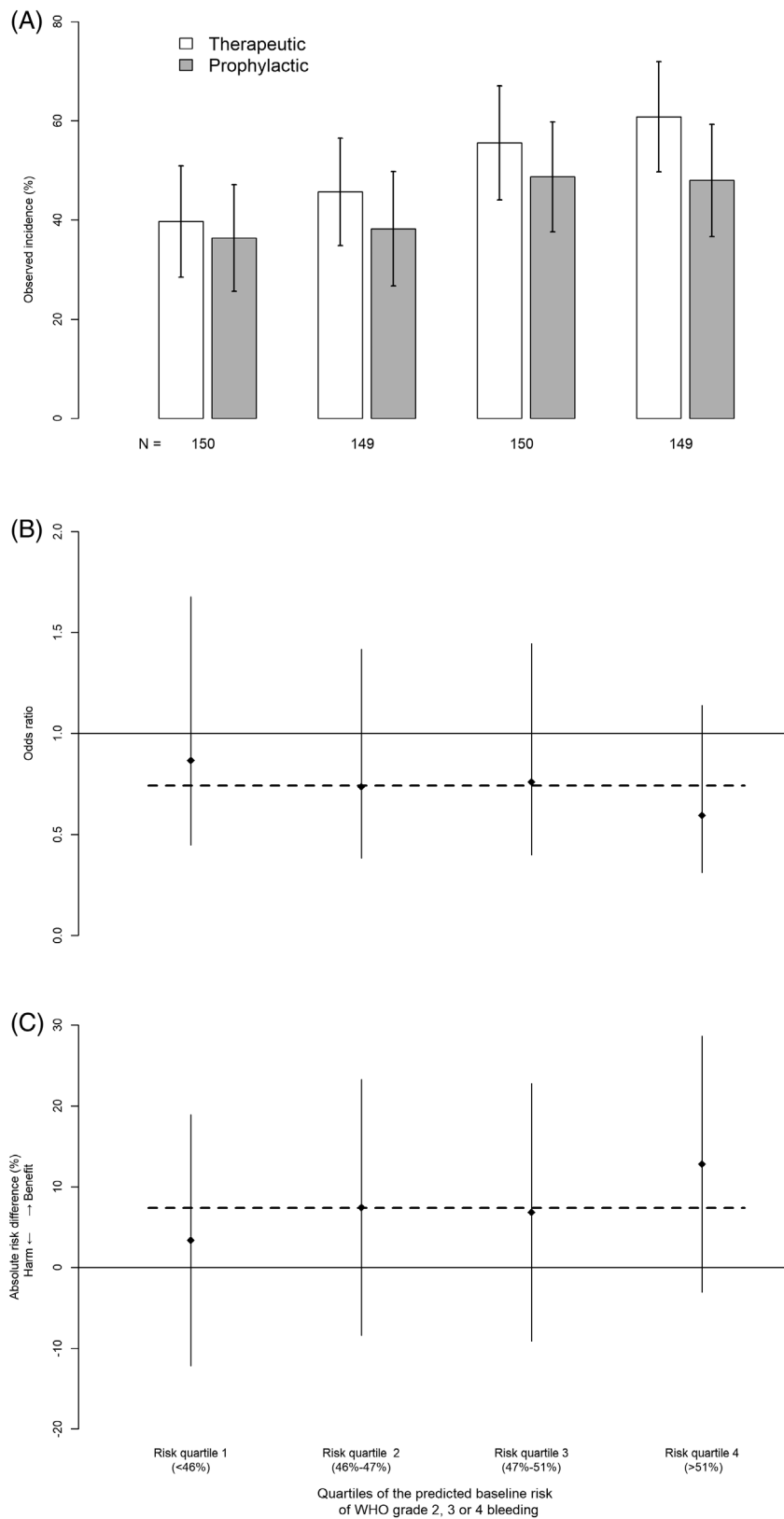
## 4 | DISCUSSION

In this post-hoc analysis of the TOPPS trial, we aimed to assess if patients with different baseline risks for WHO grade 2, 3, or 4 bleeding might benefit differently from prophylactic platelet transfusions. We found that a combination of generally accepted predictors of bleeding risk did not have much predictive power, as indicated by the low c-statistic and the small variation in risks across the risk quartiles. Although the ARD was most substantial in patients with the highest baseline bleeding risks, these differences were not statistically significant. Based on these analyses, we cannot at baseline identify subgroups of patients who benefit more or less than the average effect found in the TOPPS trial.

Originally, we expected that a combination of variables could predict bleeding risk accurately, and that patients with higher bleeding risk would show a larger benefit of prophylactic transfusion. This hypothesis was based on analyses suggesting that several baseline characteristics are associated with the outcome of bleeding in hematological patients in single variable subgroup analyses.<sup>2,10,11</sup> From this analysis, also a limited benefit for prophylactic platelet transfusions was shown for patients receiving an autologous SCT as compared to those patients receiving chemotherapy or an allogeneic SCT.<sup>10,23,24</sup>

However, our combined analysis of the earlier suggested baseline risk factors for bleeding in our study, was not strongly related with bleeding. Looking at e.g. platelet count, we included the baseline value because our aim was to predict bleeding at baseline. We hypothesized that a “low platelet count at baseline” might be predictive of “low platelet counts during admission,” the latter known to be associated with bleeding risk.<sup>8,11,23,25</sup> More specific, both disease modifying treatments and diagnosis in the context of all other baseline risk factors, did not relevantly influence the predicted bleeding risk. Our bleeding risk prediction model therefore has a poor discriminative ability.<sup>26</sup> This is reflected in the low c-statistic, but also in the small range of predicted risks, namely between 41% and 55%. There are several possible explanations for this lack of predictive power reported in our analysis.

First, a potential explanation for the poor discriminative ability of the model is that our baseline characteristics contained mostly dichotomized variables. Incorporating more continuous baseline variables leads to more



**FIGURE 3** Event rates (A), odds ratios (B) and absolute risk differences (C) are presented for all four risk quartiles, comparing a prophylactically and therapeutically platelet transfusion strategy with respect to World Health Organization grade 2, 3, or 4 bleeding. Vertical lines represent 95% confidence intervals, horizontal dotted lines represent overall trial results. A positive absolute risk reduction represents the risk decrease for a prophylactic platelet transfusion strategy as compared to a therapeutic platelet transfusion strategy

variation in predicted risks, but besides age and platelet count, no other continuous variables at baseline were selected beforehand to be likely predictors.

A second possible explanation may be that the sample size was not sufficient to capture the differences to actually identify the nuances in predictive values.



Thirdly, an important explanation could be that, although the included variables were shown to be associated with bleeding in isolation, bleeding is obviously influenced by additional factors than baseline demographics alone. Instead, bleeding risk might be much better predicted by combining the baseline characteristics with characteristics that vary during treatment. Examples of such time-varying variables, which were not included in our model, are nadirs and averages of low platelet counts during admission, transfusion yields, but also a range of clinical factors such as concurrent infections and mucositis. In addition to clinical variables, biomarkers of platelet function, coagulation, or endothelial function that reflect hemostasis could add to the predictive performance of the model. Such biomarkers could be baseline values as well (either inherited or acquired), or time varying during treatment. Thus, further research of time-varying variations should preferably also focus on biomarkers for hemostasis, as potential predictors for bleeding in our patients.<sup>27-30</sup>

However, adding such dynamic characteristics was not part of the present research question while time-dependent modeling likely needs even larger data sets than even that of the TOPPS trial. When such datasets become available in the future, the predictive performance and the clinical applicability of such time-varying bleeding prediction models, that require more frequent re-evaluation of bleeding risk compared to a baseline bleeding risk model, needs to be shown.

In our model, all patients regardless of the predicted bleeding risk benefited from the prophylactic transfusions. The ARDs varied between 3.4% for quartile 1 (patients with the lowest predicted risk) and 12.8% for patients in quartile 4. Although beforehand a larger benefit in the highest risk groups was expected, with the small range of predicted bleeding risk and the wide confidence intervals and based on the included baseline characteristics solely, we cannot conclude that the benefit for patients truly differs between the risk quartiles. Our findings, despite of the limitations of our risk prediction model, can be of importance for clinicians to realize that in our study of almost 600 participants even a combination of baseline risk factors could not distinguish between subgroups with different prophylaxis effects. Of course if in future better bleeding risk discrimination becomes possible, the benefit of prophylactic platelet transfusions needs to be differentially assessed again.

There are some additional limitations that should be considered in our analysis. Firstly, in both our current as well as the original subgroup analysis of the TOPPS RCT—as in any study—, unmeasured confounding of the subgroup effect is possible, meaning that an observed subgroup effect cannot be causally attributed to the subgroup.<sup>31</sup> The

ORs we present in Table 2 only serve a prediction purpose, and should not be mistaken as evidence for a real causal (in this regard a weak protective) effect of the variable on the risk of bleeding. In that regard, it is also important to clarify that in a shrunken prediction model, the wide confidence interval of the variable “randomization arm” as presented in Table 2 does not mean that the original results of the TOPPS trial should be viewed differently.

A further intrinsic limitation of our study is that our predictive model was developed and tested in the same dataset. Although necessary because qualitative good and large datasets are not easily available, this can lead to an over-optimistic model.<sup>32,33</sup> We tried to minimize this “overfitting” by applying Ridge penalization. This technique shrinks the regression coefficients towards zero, which aims to result in a more reliable model when applied to other datasets. This strategy to (partly) correct the optimism of the model, comes at the cost of having predicted risks that are too close to the group average risk. Indeed, there was overfitting of the data in the original logistic regression model, and substantial shrinkage was needed. Earlier studies suggest that the more shrinkage is needed, the harder it will be to estimate the amount of shrinkage that is required.<sup>21</sup> What is more, Ridge regression confidence intervals do not have their usual interpretation and are solely reported to show the spreading of the results. All in all, similar as the crude model, the predictive performance of the penalized model remained poor (respectively 0.59, 95% CI 0.55–0.64 and 0.58, 95% CI 0.53–0.62). Therefore, we conclude that independent of additional penalization, baseline risk factors are suboptimal for predicting relevant bleeding.

The decision to divide patients in quartiles based on their predicted risk was made because such a risk categorization is described in literature before.<sup>20</sup> Looking at more than four groups, moreover, is likely increasingly impractical for clinical practice. Furthermore, more numerous categories would negatively affect the power of analyses leading to probably no additional information from such.

Strengths of this study are that this study is the first to investigate if the beneficial effect of prophylactic platelet transfusions in hemato-oncological patients differs in patients with varying baseline bleeding risks, the latter based on a combination of readily available patient characteristics. Also, a strong suit of our analysis is that instead of a subgroup analysis based on a single variable, we considered many characteristics that likely influence each other, which can lead a more accurate prediction of personalized treatment effects.<sup>12,13</sup> This allows for a more comprehensive evaluation of bleeding risk prediction in this population. In addition, with this technique, besides the OR, we were able to estimate ARDs, which is described to be of greater clinical relevance compared to

a relative scale.<sup>12</sup> Another strength is the fact that we predefined all included variables and analysis, instead of statistical selection procedures, to avoid overfitting.<sup>34</sup> Lastly, a major asset of our study is that it is performed in a high quality RCT dataset. Indeed, with 598 patients the TOPPs study is one of the largest studies investigating platelet prophylaxis in this patient population.<sup>8</sup>

In summary, baseline risk factors have low discriminative ability to predict bleeding. With the limitations of the poor prediction of our model leading to uncertainty of our conclusions, patients in all risk groups seemed to benefit from a prophylactic platelet transfusion strategy. While patients in a higher risk group seem to benefit more, we could not provide statistical evidence for this. Future models that incorporate dynamic (time-dependent) clinical characteristics and biomarkers of hemostasis and endothelial disruption may support better prediction of bleeding, and influence the expected individual benefit for patients with different bleeding risk in time. However, so far and based on this study, we are unable to identify patients with more or less benefit of prophylaxis. Therefore, prophylactic platelet transfusions should remain a standard practice for most hemato-oncological patients who receive intensive therapy although recognizing that many patients continue to experience bleeding events despite prophylaxis.

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## CONFLICT OF INTEREST

JJZ is in a scientific advisory council of Sanofi and received a speaker's fee. LLC, CCD, SFF-G, RHHG, SJS, and JGvdB have disclosed no conflicts of interest.

## ETHICS STATEMENT

The original study protocol was approved by independent ethics committees in the United Kingdom and Australia. The current statistical analysis plan was approved by the science committee of the department of Clinical Epidemiology of the Leiden University Medical Center, in Leiden, the Netherlands. The main trial was registered on Controlled-Trials.com number, ISRCTN08758735.

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## REFERENCES

1. Slichter SJ, Kaufman RM, Assmann SF, McCullough J, Triulzi DJ, Strauss RG, et al. Dose of prophylactic platelet transfusions and prevention of hemorrhage. *N Engl J Med*. 2010;362:600–13.
2. Estcourt LJ, Birchall J, Allard S, Bassey SJ, Hersey P, Kerr JP, et al. Guidelines for the use of platelet transfusions. *Br J Haematol*. 2017;176:365–94.
3. Schiffer CA, Bohlke K, Delaney M, Hume H, Magdalinski AJ, McCullough JJ, et al. Platelet transfusion for patients with cancer: American Society of Clinical Oncology clinical practice guideline update. *J Clin Oncol*. 2018;36:283–99.
4. Kaufman RM, Djulbegovic B, Gernsheimer T, Kleinman S, Tinmouth AT, Capocelli KE, et al. Platelet transfusion: a clinical practice guideline from the AABB. *Ann Intern Med*. 2015;162:205–13.
5. Padhi S, Kemmis-Betty S, Rajesh S, Hill J, Murphy MF. Guideline development, G blood transfusion: summary of NICE guidance. *BMJ*. 2015;351:h5832.
6. Bloedtransfusiebeleid, Federate Medisch Specialisten. [https://richtlijnendatabase.nl/richtlijn/bloedtransfusiebeleid/startpagina\\_-\\_bloedtransfusiebeleid.html](https://richtlijnendatabase.nl/richtlijn/bloedtransfusiebeleid/startpagina_-_bloedtransfusiebeleid.html), accessed 26 May 2020 (translation: Blood Transfusion Guideline, Federation Medical Specialists).
7. Kreuger AL, Middelburg RA, Zwaginga JJ, Bom JG, Kerkhoffs JLH. Clinical practice of platelet transfusions in haemato-oncology. *Vox Sang*. 2015;109:91–4.
8. Stanworth SJ, Estcourt LJ, Powter G, Kahan BC, Dyer C, Choo L, et al. A no-prophylaxis platelet-transfusion strategy for hematologic cancers. *N Engl J Med*. 2013;368:1771–80.
9. Miller AB, Hoogstraten B, Staquet M, Winkler A. Reporting results of cancer treatment. *Cancer*. 1981;47:207–14.
10. Stanworth SJ, Estcourt LJ, Llewelyn CA, Murphy MF, Wood EM, Investigators TS. Impact of prophylactic platelet transfusions on bleeding events in patients with hematologic malignancies: a subgroup analysis of a randomized trial. *Transfusion*. 2014;54:2385–93.
11. Stanworth SJ, Hudson CL, Estcourt LJ, Johnson RJ, Wood EM, Invest TS. Risk of bleeding and use of platelet transfusions in patients with hematologic malignancies: recurrent event analysis. *Haematologica*. 2015;100:740–7.
12. Dahabreh IJ, Hayward R, Kent DM. Using group data to treat individuals: understanding heterogeneous treatment effects in the age of precision medicine and patient-centred evidence. *Int J Epidemiol*. 2016;45:2184–93.

13. Kent DM, Steyerberg E, van Klaveren D. Personalized evidence based medicine: predictive approaches to heterogeneous treatment effects. *BMJ*. 2018;363:k4245.
14. Stanworth SJ, Dyer C, Choo L, Bakrania L, Copplesstone A, Llewelyn C, et al. Do all patients with hematologic malignancies and severe thrombocytopenia need prophylactic platelet transfusions? Background, rationale, and design of a clinical trial (trial of platelet prophylaxis) to assess the effectiveness of prophylactic platelet transfusions. *Transfus Med Rev*. 2010;24:163–71.
15. Groenwold RH, Moons KG, Pajouheshnia R, Altman DG, Collins GS, Debray TP, et al. Explicit inclusion of treatment in prognostic modeling was recommended in observational and randomized settings. *J Clin Epidemiol*. 2016;78:90–100.
16. Kim H, Lee JH, Choi SJ, Kim WK, Lee JS, Lee KH. Analysis of fatal intracranial hemorrhage in 792 acute leukemia patients. *Haematologica*. 2004;89:622–4.
17. Zumberg MS, del Rosario ML, Nejame CF, Pollock BH, Garzarella L, Kao KJ, et al. A prospective randomized trial of prophylactic platelet transfusion and bleeding incidence in hematopoietic stem cell transplant recipients: 10,000/L versus 20,000/microL trigger. *Biol Blood Marrow Transplant*. 2002;8:569–76.
18. Friedmann AM, Sengul H, Lehmann H, Schwartz C, Goodman S. Do basic laboratory tests or clinical observations predict bleeding in thrombocytopenic oncology patients? A reevaluation of prophylactic platelet transfusions. *Transfus Med Rev*. 2002;16:34–45.
19. Pajouheshnia R, Groenwold RHH, Peelen LM, Reitsma JB, Moons KGM. When and how to use data from randomised trials to develop or validate prognostic models. *BMJ*. 2019;365: l2154.
20. Fustolo-Gunnink SF, Fijnvandraat K, van Klaveren D, Stanworth SJ, Curley A, Onland W, et al. M preterm neonates benefit from low prophylactic platelet transfusion threshold despite varying risk of bleeding or death. *Blood*. 2019;134: 2354–60.
21. Van Calster B, van Smeden M, De Cock B, Steyerberg EW. Regression shrinkage methods for clinical prediction models do not guarantee improved performance: simulation study. *Stat Methods Med Res*. 2020;29:3166–78.
22. Caetano SJ, Sonpavde G, Pond GR. C-statistic: a brief explanation of its construction, interpretation and limitations. *Eur J Cancer*. 2018;90:130–132.
23. Wandt H, Schaefer-Eckart K, Wendelin K, Pilz B, Wilhelm M, Thalheimer M, et al. Therapeutic platelet transfusion versus routine prophylactic transfusion in patients with haematological malignancies: an open-label, multicentre, randomised study. *Lancet*. 2012;380:1309–16.
24. Kumar A, Mhaskar R, Grossman BJ, Kaufman RM, Tobian AA, Kleinman S, et al. Platelet transfusion: a systematic review of the clinical evidence. *Transfusion*. 2015;55:1116–27. quiz 1115.
25. Cornelissen LL, Kreuger AL, Caram-Deelder C, Middelburg RA, Kerkhoffs JLH, Peter A, et al. Thrombocytopenia and the effect of platelet transfusions on the occurrence of intracranial hemorrhage in patients with acute leukemia—a nested case-control study. *Ann Hematol*. 2021;100:261–71.
26. Steyerberg EW, Harrell FE Jr, Borsboom GJ, Eijkemans MJ, Vergouwe Y, Habbema JD. Internal validation of predictive models: efficiency of some procedures for logistic regression analysis. *J Clin Epidemiol*. 2001;54:774–81.
27. Larsen AM, Leinoe EB, Johansson PI, Birgens H, Ostrowski SR. High syndecan-1 levels in acute myeloid leukemia are associated with bleeding, thrombocytopathy, endothelial cell damage, and leukocytosis. *Leuk Res*. 2013;37:777–83.
28. Leinoe EB, Hoffmann MH, Kjaersgaard E, Nielsen JD, Bergmann OJ, Klausen TW, et al. Prediction of haemorrhage in the early stage of acute myeloid leukaemia by flow cytometric analysis of platelet function. *Br J Haematol*. 2005;128:526–32.
29. Batman B, van Bladel ER, van Hamersveld M, Pasker-de Jong PCM, Korporaal SJA, Urbanus RT, et al. Agonist-induced platelet reactivity correlates with bleeding in haemato-oncological patients. *Vox Sang*. 2018;90:130–2.
30. Vinholt PJ, Knudsen GH, Sperling S, Frederiksen H, Nielsen C. Platelet function tests predict bleeding in patients with acute myeloid leukemia and thrombocytopenia. *Am J Hematol*. 2019; 94:891–901.
31. Groenwold RH, Donders AR, van der Heijden GJ, Hoes AW, Rovers MM. Confounding of subgroup analyses in randomized data. *Arch Intern Med*. 2009;169:1532–4.
32. van Klaveren D, Balan TA, Steyerberg EW, Kent DM. Models with interactions overestimated heterogeneity of treatment effects and were prone to treatment mistargeting. *J Clin Epidemiol*. 2019;114:72–83.
33. Babyak MA. What you see may not be what you get: a brief, nontechnical introduction to overfitting in regression-type models. *Psychosom Med*. 2004;66:411–21.
34. Steyerberg EW, Vergouwe Y. Towards better clinical prediction models: seven steps for development and an ABCD for validation. *Eur Heart J*. 2014;35:1925–31.

## SUPPORTING INFORMATION

Additional supporting information may be found online in the Supporting Information section at the end of this article.

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