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ORIGINAL RESEARCH

Cost-Effectiveness and Budget Impact Analyses of Patient Blood Management in a Cardiovascular Surgery Department at Ankara Bilkent City Hospital in Turkey

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ABSTRACT

Introduction: Anemia and transfusion of blood products are risk factors associated with poor patient outcomes across all elective surgeries. Patient blood management (PBM) is a patient-centered approach to optimize patient's endogenous red cell mass, to minimize blood loss in patients undergoing surgery, and to harness and optimize patient-specific physiological tolerance to anemia. This study aimed to assess (1) the impact of PBM on blood product usage in cardiovascular surgeries in a state hospital setting, (2) cost-effectiveness of PBM with a model based on transfusion of red blood cells (RBCs) in cardiovascular surgeries, and (3) the budget impact of PBM implementation based on transfusion of RBCs.

Methods: Cost-effectiveness and budget impact models, based on the numbers of avoided transfusions and avoided complications after implementation of the PBM program, were compared between pre- and post-PBM periods at the cardiovascular surgery department of Ankara Bilkent City Hospital between February 11, 2019 and July 24, 2022. The probabilities of transfusions and complications with and without PBM were taken from recent meta-analyses. Data from the Ankara Bilkent City Hospital transfusion center informed the pre- and post-PBM calculations. Costs were calculated from the Social Security Institution's perspective.

Results: There was a 21% decrease in the use of RBCs and a 23.7% decrease in use of all blood products after the implementation of PBM. The number of RBC packs per patient reduced by 0.88 packs (21%). The cost saving from reduction of RBC transfusions per patient was 518.68 Turkish lira (TRY) and for the hospital it was 1,635,948 TRY. Fewer complications and lower costs in favor of the post-PBM arm were demonstrated in the cost-effectiveness analysis. On the basis of the budget impact model, in 20 months, the hospital's cardiovascular surgery department saved 6,596,934 TRY (€342,302).

Conclusion: This hospital-based study demonstrated that PBM is a budget-saving and cost-effective option in Turkey.

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PLAIN LANGUAGE SUMMARY

When undergoing elective surgery, patients who develop anemia or who need a transfusion of blood products may develop further complications. This study aimed to understand the impact of patient blood management on blood usage in cardiovascular surgeries. Patient blood management is a patient-centered approach that aims to optimize a patient's red cell mass, minimize blood loss in patients undergoing surgery, and maximize a patient's tolerance to anemia. In addition, this study assessed the cost-effectiveness of patient blood management using an economic model based on red blood cells in cardiovascular surgeries and assessed the impact of patient blood management on budget. The patient blood management program resulted in a 21% decrease in use of red blood cells and 23.7% decrease in use of all blood products. The cost savings from reduction of red blood cells transfusions per patient were 518.68 Turkish lira and cost savings for the hospital were 1,635,948 Turkish lira. Fewer complications and lower costs were demonstrated after implementation of patient blood management in the cost-effectiveness analysis. Between December 2020 and July 2022, the hospital's cardiovascular surgery department saved 6,596,934 Turkish lira (€342,302). Overall, this hospital-based study has shown that patient blood management is a budget-saving and cost-effective option in Turkey.

Keywords: Budget impact; Cost-effectiveness; Patient blood management; Turkey

Key Summary Points

Why carry out this study?

Anemia and transfusion of blood products are risk factors associated with poor patient outcomes across all elective surgeries.

Patient blood management (PBM), a patient-centered approach, aims to optimize the patient's red cell mass, to minimize blood loss in patients undergoing surgery, and to harness and optimize patient-specific physiological tolerance to anemia.

The study assessed the impact, cost-effectiveness, and budget impact of PBM on blood usage in cardiovascular surgeries in a state hospital setting in Turkey.

What was learned from the study?

An overall 21% reduction in the use of red blood cells and 23.7% reduction in the use of all blood products were observed leading to a cost reduction of 518.68 Turkish lira (TRY) per patient and 1,635,948 TRY for the hospital.

PBM has been demonstrated to be cost-effective, leading to budget savings in this hospital setting.

INTRODUCTION

Anemia is a frequently overlooked health condition with potential serious implications. Preoperative anemia is an important risk factor for poor outcomes for patients undergoing surgery [1–4]. The prevalence of preoperative anemia varies among surgical indications, and it has been reported that the impact on orthopedic and cardiac surgery is high [5–8]. Current evidence clearly indicates that preoperative anemia is an independent risk factor for increased postoperative morbidity, mortality, and length of stay in hospital [9–12]. Anemia also increases the risk of transfusion and number of red blood cells (RBCs) transfused during the perioperative phase [13]. Generally, it is accepted and supported by evidence that blood transfusion increases perioperative mortality and morbidity considerably [3, 4, 13–24].

Patient blood management (PBM), defined as "the timely application of evidence-based medical and surgical concepts designed to

maintain hemoglobin concentration, optimize hemostasis and minimize blood loss in an effort to improve patient outcome" [25], has been used at the national and institutional levels since the beginning of the millennium [13, 26]. The implementation of PBM programs enables the avoidance and reduction in transfusions by addressing modifiable risk factors that may result in transfusion long before a transfusion may even be considered, and it improves patient outcomes whilst reducing cost [13, 27, 28].

Unnecessary blood transfusions are of major concern, not only because of the negative impact on the health status of patients but also on the spending of healthcare budgets [24, 29, 30]. In a recent literature review of observational retrospective studies [31] covering the blood transfusion practices during 2012–2018, it was found that only 8.2% of patients did not receive unnecessary units and 45.4% of RBC transfusions were unnecessary, and similar results were observed in Turkey. A study by Unal et al. [32] concluded that RBC transfusion in Turkey was inappropriate in 99% (150/151) of patients preoperatively, in 23% (211/926) of patients intraoperatively, and in 43% (308/716) of patients postoperatively.

As previously discussed by Tatar et al. [33], PBM has begun to be considered more extensively in Turkey in recent years. The study by Unal et al. [32] is of special importance because the researchers have taken, for the first time, a clear picture of blood use in Turkey. On the basis of a comprehensive analysis of current transfusion practices in Turkey, they concluded that blood use was not in compliance with guidelines and evidence-based transfusion practices [32]. In line with the literature and expectations, cardiovascular and thoracic surgery had the highest transfusion rate in Turkey (32.8%) followed by orthopedic surgery (25.4%). During the perioperative course of these surgeries, a quarter of patients received at least one unit of a blood component.

The first hospital-based PBM example in Turkey is from the Numune Teaching and Training Hospital where a PBM program was initiated in the cardiovascular surgery department in 2016. Budak et al. [34] evaluated the results of this program and compared the pre- and post-PBM program results on transfusion for coronary artery bypass graft (CABG) surgery. They concluded that there was a 26.8% decrease ($p < 0.01$) in the transfusion rates of the PBM group. The program not only reduced transfusion rates but also reduced costs, mortality, and length of stay in hospital [35]. In line with global trends, the task force appointed by the Turkish Society of Cardiovascular Surgery, Turkish Society of Cardiology, and Society of Cardio-Vascular-Thoracic Anesthesia and Intensive Care has also concluded that perioperative anemia should be defined, evaluated, and managed to minimize the use of blood products in patients undergoing cardiac surgery [36].

The current study is the second study investigating the cost-effectiveness and budget impact of PBM in the Turkish healthcare context. A cost-effectiveness analysis evaluates whether an intervention provides value relative to an existing intervention and a budget impact analysis evaluates whether the high-value intervention is affordable. In the first study [33], complication probabilities derived from a recent meta-analysis [37] were used to assess the cost-effectiveness of PBM in non-cardiac and cardiac surgery with a simulated cohort of 10,000 patients in Turkey. In addition, a budget impact analysis model was developed to estimate potential cost savings of PBM from the Turkish Social Insurance Organization's (SSI) perspective. Here, we will analyze the cost-effectiveness and budget impact of PBM based on its potential impact on RBC transfusions and complications expected from transfusions. In addition, a pre- and post-PBM comparison was made with the data from Ankara Bilkent City Hospital. This study has three aims: (1) to assess the impact of PBM on blood usage in cardiovascular surgeries in a state hospital setting, (2) to assess the cost-effectiveness of PBM with a model based on transfusion of RBCs in cardiovascular surgeries, and (3) to assess the budget impact of PBM implementation based on transfusion of RBCs.

METHODS

Ankara Bilkent City Hospital was established in February 2019 with the merger of Ankara's largest state teaching and research hospitals. This large complex has 4050 hospital beds with 735 outpatient clinics and 131 operating theatres. A PBM program commenced in September 2020 at the hospital's cardiovascular surgery department. The transfusion center of the hospital is the largest in Turkey. In the period 2019–2021, 366,338 blood transfusions were performed in the hospital. The transfusion center has data for the number of transfusions and wasted blood products per department. A PBM protocol was implemented in the cardiovascular surgery department which covered the pre-, peri-, and postoperative phases of PBM as outlined in Table 1. The transfusion threshold was reached when hemoglobin levels were 8 g/dL, and platelet count was below 100,000. Fibrinogen and coagulation factor levels were carefully monitored and replaced when necessary. Cryoprecipitate was decided by fibrinogen levels below the cutoff of 1.5 g/dL. Patients undergoing urgent surgery with an international normalized ratio below 2.5 received coagulation factors; frozen plasma was only used in addition to coagulation factor transfusion for ongoing bleeding.

Hospital blood usage data was collected for the pre-PBM period (from February 11, 2019 to October 2, 2020) and the post-PBM period (from December 2, 2020 to July 24, 2022). A 2-month break was given between periods to take into account the organizational adaptation procedures to implement the protocol. Research guidelines for Turkey indicate that ethics approval was not required for the study design employed here. The study used an economic modelling approach with aggregate figures, not patient-level data. The statistical data used presented no interference and therefore ethics committee approval was waived. Appropriate permissions to use aggregate data from the cardiovascular surgery department were obtained from Dr. Şanal as the head of the transfusion center.

Cost-effectiveness and budget impact models were based on the potential impact of transfusion of RBCs during cardiovascular operations. The pre- and post-PBM comparisons were made using the transfusion center's data. A decision tree was constructed to assess the cost-effectiveness of PBM based on transfusion and non-transfusion status of patients before and after the implementation of the PBM program (Fig. 1). The TreeAge© program (TreeAge Software, LLC, MA, USA) was used for this purpose. The endpoints of the study were avoided transfusion-based complications (sepsis, renal failure, myocardial infarction, and stroke), and results were presented as incremental cost per incremental avoided complication.

As can be seen from the model, after the first separation between pre- and post-PBM, patients are disaggregated by their transfusion status. Transfusion rates are taken from a recent meta-analysis by Althoff et al. [38]. The complication branches of the decision tree in Fig. 1 cover the patients who are faced or not faced with a complication after a transfusion event. Complication rates were taken from Ferraris et al. [39]. Table 2 summarizes the clinical parameters used in the cost-effectiveness model. Results are presented as incremental cost per incremental avoided complication.

All cost estimations were made from the payer's perspective as required by the SSI. The major cost parameters in the model were cost of PBM, cost of transfusion, and cost of treating complications. Cost of PBM covered cost of ferric carboxymaltose and its administration (two vials per patient) and laboratory tests to detect anemia. A healthcare resource utilization questionnaire form was developed to estimate the treatment costs of complications. The questionnaire covered the type of resources used to treat the relevant complication with patient percentages and units. SSI guidelines and price tariffs were used to calculate the payments made by the SSI. Notably, the utilization of prothrombin complex concentrates (PCC) was not estimated. PCC are acquired in certain periods (twice a year) independent of the availability, meaning there are time periods when the product may or may not be available in the pharmacy. In our social security

Table 1 Patient blood management at Ankara Bilkent City Hospital

Preoperative phase	Perioperative phase	Postoperative phase
Staff training	Goal-directed coagulation (impaired platelet function, surgical bleeding, etc.)	Transfusion monitoring
Transfusion monitoring	Goal-directed perfusion (low blood pressure or anemia may not be indicative of blood transfusion every time; the important thing is the oxygen that penetrates the tissue)	Intravenous fluid restriction
Intravenous fluid restriction	Minimally invasive surgery	Fibrinogen concentrate administration
Preoperative anemia treatment (ferric carboxymaltose)	Routine tranexamic acid administration	Goal-directed coagulation tests
Revision and adaptation of international guidelines	Cerebral/somatic oximetry	
Cooperation with cardiology		
	Topical hemostatic agents	
	Minimally invasive extracorporeal circulation circuits	
	Microplegia	
	Retrograde autologous priming vacuum-assisted venous drainage	
	Ultrafiltration	
	Cytokine absorption	
	Recirculation of waste blood	

reimbursement system, patients can receive PCC only when they are hospitalized and the product is available in the center. Therefore, it was not possible to foresee the exact utilization of PCC.

For transfusion cost, the SSI price for erythrocyte suspension payment to Red Crescent was used. According to the records of Ankara Bilkent City Hospital, 4.23 packs of RBCs were used per patient in the pre-PBM period and 3.35 packs in the post-PBM period. Calculation of the transfusion cost assumed that 5 and 4 packs were used during the pre- and post-PBM periods, respectively. Table 3 shows the costs of transfusion and treatment of complications. The costs in the treatment branches of the model are shown in Table 4.

One-way sensitivity analyses were conducted for selected model parameters to observe the changes in the results and to assess the robustness of the model (Supplementary Material). In this analysis, the number of avoided complications, probability of transfusion with PBM, and probability of complications with transfusion were taken as the potential variables that could have an impact on the results (Tables S1–3, Fig. S1). The model values were decreased and increased by 20% to observe the changes in results.

The budget impact model was based on the costs of treating perioperative complications before and after the program. The number of avoided complications with the implementation of PBM in the cardiovascular surgery department of Ankara Bilkent City Hospital was

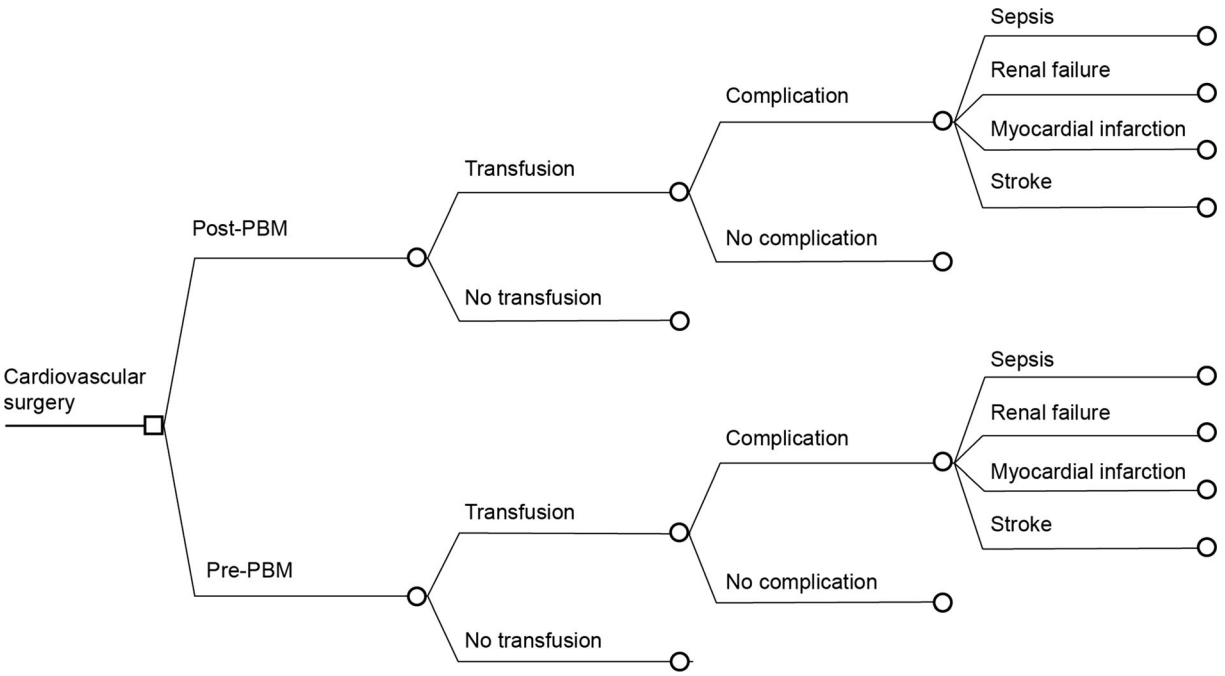

Fig. 1 Cost-effectiveness model for patient blood management based on transfusion-related complications. *PBM* patient blood management

Table 2 Clinical parameters used in the cost-effectiveness and budget impact models

Parameter	Pre-PBM period	Post-PBM period
Transfusion rate (%)[a]	55.32	39.12

Complication[b]	Complication with transfusion	*N*[c]	Complication probability with transfusion
Sepsis	10.8%	1897	0.5455
Renal failure	3.9%	685	0.1970
Myocardial infarction	3.7%	650	0.1869
Stroke	1.4%	246	0.0707
Total	–	3478	–

PBM patient blood management
[a]Transfusion rate based on Althoff et al. [38]
[b]Taken from propensity-matched comparisons because the impact of confounding factors was considered in this analysis [39]
[c]Number of patients in each category was calculated by multiplying the percentage of patients with transfusion-related complication by the total number of patients in the analysis (17,567)

Table 3 Cost of transfusion and treatment of complications

	Cost (TRY)
Costs of transfusion	
Transfusion cost (per pack)	15.84
RBC per pack	502.85
Pre-PBM transfusion cost (5 packs)	2593.43
Post-PBM transfusion cost (4 packs)	2074.74
Cost of transfusion with PBM	4596.36
Cost of transfusion without PBM	2593.43
Cost of PBM	2521.62
Costs of treatment of complications	
Sepsis	14,781.30
Renal failure	646,837.50
Myocardial infarction	37,527.07
Stroke	137,672.11

PBM patient blood management, *RBC* red blood cell, *TRY* Turkish lira

based on the probabilities of complications calculated from Ferraris et al. [39].

RESULTS

Impact of PBM on Cardiovascular Surgery Department's Blood Usage and Transfusion Cost

Table 5 and Fig. 2 compare use of blood products at Ankara Bilkent City Hospital for the pre- and post-PBM periods. Overall, 2084 patients used blood products in the pre-PBM and 3154 patients in the post-PBM periods. There was a decline in the number of products per patient except for apheresis platelets and cryoprecipitate. For RBCs, this decreased by 21% and for the whole blood products by 23.7%. In our analysis, only the changes in the erythrocyte suspension were considered. The number of erythrocyte packs per patient declined by 0.88 (21%); this finding aligns with that reported in the literature [38].

With the implementation of PBM, the RBC transfusion cost per patient declined from 2593.43 Turkish lira (TRY) to 2074.74 TRY (20% decrease) with 518.69 TRY cost savings per patient. This indicates that 1,635,948 TRY (518.69 × 3154) was saved only from transfusion of RBCs with the implementation of PBM at Ankara Bilkent City Hospital. The number of wasted products also declined between the two periods: in the pre-PBM period 217 blood products were destroyed (34 erythrocyte sus-

Table 4 Costs of complications according to the treatment branches in the model

Treatment branch	Complication	Cost (TRY)
Transfusion without PBM	Transfusion + sepsis	17,374.73
	Transfusion + renal failure	649,430.93
	Transfusion + myocardial infarction	40,120.50
	Transfusion + stroke	140,265.54
Transfusion with PBM	PBM + transfusion + sepsis	19,377.67
	PBM + transfusion + renal failure	651,433.86
	PBM + transfusion + myocardial infarction	42,123.43
	PBM + transfusion + stroke	142,268.47

PBM patient blood management, *TRY* Turkish lira

Table 5 Utilization of blood products in the pre- and post-PBM periods at Ankara Bilkent City Hospital

Blood product	Pre-PBM period		Post-PBM period	
	Number	Per patient (n = 2084)	Number	Per patient (n = 3154)
Erythrocyte suspension	8822	4.23	10,574	3.35
Fresh frozen plasma	7319	3.51	6793	2.15
Apheresis platelets	20	0.001	51	0.016
Pooled platelets	954	0.46	930	0.29
Cryoprecipitate	1338	0.64	2948	0.93
Total	18,453	8.85	21,296	6.75

PBM patient blood management

pension, 148 fresh frozen plasma, 1 pooled thrombocytes, and 34 cryoprecipitate), whereas this reduced to 168 for the post-PBM period (22.6% decline) (20 erythrocyte suspension, 68 fresh frozen plasma, 2 pooled thrombocytes, and 78 cryoprecipitate).

Cost-Effectiveness Analysis

The implementation of the PBM program in the post-PBM period dominated the pre-PBM period in the cost-effectiveness analysis (Table S4). With the implementation of PBM, 68 complications were avoided, resulting in cost savings of 11,765 TRY. The results of the one-way sensitivity analysis have shown that the cost-effectiveness analysis results were robust (Supplementary Material).

Budget Impact Analysis

Transfusion probabilities for pre- and post-PBM periods were taken from Althoff et al. [38], and complication probabilities after transfusion were taken from Ferraris et al. [39]. There was a difference in the number of cases between the two periods with more patients in the post-PBM period. To avoid calculation misinterpretations, the number of cases for the post-PBM period was fixed to the number of patients in the pre-

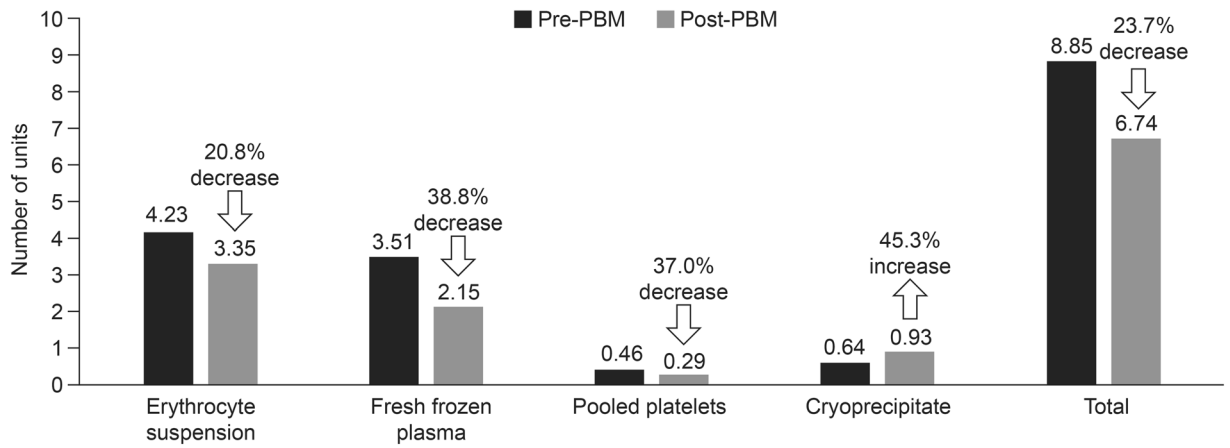

Fig. 2 Utilization of blood products per patient in the pre- and post-PBM periods at Ankara Bilkent City Hospital. *PBM* patient blood management

Table 6 Budget impact of implementing PBM at Ankara Bilkent City Hospital

	Pre-PBM period	Post-PBM period
Expected complications		
Sepsis	125	88
Renal failure	45	32
Myocardial infarction	43	30
Stroke	16	11
Total expected complications	229	161
Treatment costs (TRY)		
Sepsis	1,840,418	1,301,467
Renal failure	29,083,032	20,566,309
Myocardial infarction	1,600,760	1,131,991
Stroke	2,222,050	1,571,341
Total complication costs	34,746,260	24,571,108
Total cost of transfusion	2,989,880	1,691,455
Cost of PBM	0	4,876,643.4
Total costs	37,736,140	31,139,207
Total saving (TRY)		6,596,934
Total saving (€)		324,302

Exchange rate (February 19, 2023): 1 € = 20.3419 TRY
PBM patient blood management, *TRY* Turkish lira

PBM period (2084 patients). After adjustment, the number of patients receiving a transfusion decreased from 1153 in the pre-PBM period to 815 in the post-PBM period (Table S5).

Complication probabilities after transfusion were taken from the results of the meta-analysis by Ferraris et al. (Table 2) [39]. Based on this data, the number of expected complications for each period were estimated as shown in Table 6. The number of expected complications decreased from 229 in the pre-PBM period to 161 in the post-PBM period.

Table 6 presents the budget impact of implementing PBM at Ankara Bilkent City Hospital. In 20 months, the hospital has saved 6,596,934 TRY by implementing PBM in one department by avoiding treatment costs of complications and transfusions. When cost savings from avoided blood transfusion were added (1,635,948 TRY), this figure reached 8,232,882 TRY (€404,725).

DISCUSSION

The impact of PBM on cardiovascular operations has been explored in a number of studies with different perspectives and aims [15, 19, 40–44]. These studies have concluded that there were statistically meaningful reductions in the number of RBC transfusions, number of RBC units per patient, morbidity, and length of stay in hospital after implementation of a PBM program.

This study, utilizing data from the Ankara Bilkent City Hospital transfusion center, found a 23.7% decline in the use of blood products after the implementation of the PBM program. Between the pre-PBM and post-PBM periods, RBC use per patient decreased from 4.23 units to 3.35 units (0.88 units, 21% decline), and transfusion cost per patient declined from 2593.43 TRY to 2074.74 TRY (20% decrease). Accordingly, from the SSI perspective, the hospital saved 1,635,948 TRY from transfusion of RBCs alone.

The reduction in the number of transfused RBC units after implementation of PBM is in line with findings in the literature [13, 19, 26, 45, 46]. As well as transfusion status, the number of transfused units is also an important determinant of mortality and morbidity. For instance, Whitlock et al. in their retrospective cohort study of 346 hospitals in the USA concluded that, after adjusting for other patient comorbidity and demographic factors, transfusion of RBCs was associated with increasing odds of perioperative stroke/myocardial infarction [47]. The odds were twofold for 1 or 2 units, threefold for 3 units, and fivefold for 4 units. Similarly, Paone et al. found that mortality was higher in patients receiving

transfusion (1.3%), even with small amounts of RBC transfusion, than in patients not receiving a transfusion (0.5%; OR 2.44, CI 1.74–3.42; $p < 0.001$) [48]. The reduction in the number of RBC units transfused after the implementation of the PBM program can be accepted as a positive contribution to patient outcomes.

Decreasing numbers of transfusions and units have implications for costs as well [24, 29, 30]. Comparison of transfusion cost among countries and studies is difficult because they can vary according to the estimation method and healthcare system practices. Cost of transfusion in Turkey has been studied by İndelen et al. using the activity-based costing method in a single hospital. The researchers concluded that the cost of erythrocyte suspension was $251.18 per patient for 2019 [49]. As the definition of activity-based costing suggests, this covered all costs including staff salaries, materials, utilities, and other items, which explains why the unit cost used in our study is lower because our study was from the SSI perspective and covered only the cost of RBC acquisition and transfusion costs. If we had applied the findings from İndelen et al. [49], the savings from blood transfusion for Ankara Bilkent City Hospital would have reached 14,890,034 TRY (€731,988). Similar results have been observed in other healthcare systems [19, 45, 46]. For instance, a study by Meybohm et al. found that the reduction of RBC units alone saved €952,660 in four German hospitals: when materials, labor, capital, and other costs were included, this figure reached €3 million per year [19].

The results of the cost-effectiveness analysis based on the transfusion and the complications related to transfusion indicated that PBM dominated the non-PBM period. With the implementation of PBM, 68 complications were avoided, resulting in the reduction of 11,765 TRY incremental costs. Sensitivity analysis results have shown that the results were robust (Supplementary Material). Similarly, other cost-effectiveness studies have concluded that PBM was a cost-effective option [15, 50–52].

The budget impact analysis model based on the avoided complications caused by transfusion showed a saving of 6,596,934 TRY (€324,302) between the two periods. When the savings from blood transfusion were added (1,635,948 TRY), this figure reached 8,232,882 TRY (€404,725). In this study, preoperative anemia treatment was assumed to be made by ferric carboxymaltose intravenous infusion. In both this and a previous study [33], ferric carboxymaltose treatment was found to be cost saving. These results are similar to results reported for other countries such as France [53, 54], Spain [55], Greece [56], and Germany [57, 58].

The uptake of PBM in Turkey has been limited probably because there are few examples of PBM implementation at the national level. The Australian PBM program has taken the leading role as an example for implementation of a nationwide program [59]. The turning point for PBM was the resolution of the World Health Organization in 2010 to urge all member states to promote PBM as a new standard of care [60]. However, despite the slow uptake of PBM at the national level, hospital-based programs from different regions and their outcomes have provided enough evidence to support PBM both at the national and institutional levels. This study adds to the growing evidence that PBM reduces perioperative blood loss, perioperative morbidity, mortality, length of stay in hospital, need for transfusion, and as a consequence, costs [61].

This study demonstrated several strengths over previous analyses by including both cost-effectiveness and budget impact models in the analyses, inclusion of material, time, and personnel costs, and inclusion of wasted transfusion products. In addition, the data collected from Ankara Bilkent City Hospital is considered robust and is a good example of PBM, combining real-world data and results from meta-analyses. On the basis of our understanding, this is the first example of its kind in Turkey. The limitations of the study are as follows. First, exposition to transfusion and complication after transfusion probabilities are taken from recent meta-analyses [38, 39]. Therefore, it is inevitable that the limitations of these studies will also be limitations of our study. Althoff et al. stated that additional references may have been missed before the introduction of PBM as a

term, and differences in clinical implementation, treatment duration, study design, and characteristics of included studies may have contributed to the heterogeneity [38]. Ferraris et al. stated that there may be limitations arising from the structure of the database [39]. Second, costs of treatment of complications were calculated by using expert opinions. In the absence of cost data, this is the only way to calculate costs and is commonly used in the literature [52]. Patients included in the study are representative of the real-world setting and were thus a heterogeneous population. Lastly, the COVID-19 pandemic has influenced the number of patients using blood products in the pre- and post-PBM periods.

CONCLUSION

The results of the economic model constructed to assess the cost-effectiveness of PBM in cardiovascular surgery has shown that PBM is a cost-effective option and provides real cost savings compared with no PBM, and they are in line with the previously reported study conducted by the authors. By implementing the PBM program, the administration and the staff of the cardiovascular surgery department of Ankara Bilkent City Hospital have initiated a cost-effective strategy in their department exemplary to other departments within the hospital and the healthcare system as a whole. The findings on blood saving are of utmost importance in times of crisis as recently experienced in Turkey.

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Data Availability. All data generated or analyzed during this study are available within the main manuscript and supplementary materials.

Declarations

Conflict of Interest. Mehtap Tatar provides consultancy to CSL Vifor. Laser Şanal and Serdar Günaydın declare that they have no competing interests.

Ethical Approval. Research guidelines for Turkey indicate that no ethics approval was required for the study design employed here. The study used an economic modelling approach with aggregate figures, not patient-level data. The statistical data used presented no interference and therefore ethics committee approval was waived. Appropriate permissions to use aggregate data from the cardiovascular surgery department were obtained from Dr. Şanal as the head of the transfusion center.

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