IOSR Journal of Multidisciplinary Research (IOSR -JMR)
ISSN: 3048-7439 Volume 3, Issue 3, Series 1, May. - June. (2026), PP 01-10
www.iosrjournals.org

Patient Blood Management In Oncology: A Comprehensive Review Of Strategies, Evidence, And Clinical Practice

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Date of Submission: 26-04-2026 Date of Acceptance: 06-05-2026

I. Introduction

Hematopoietic system is severely burdened by cancer and cancer treatment. One of the most frequent as well as clinically important, complications of malignancy and its treatment is anaemia, which occurs in an estimated 3075% of cancer patients, based on tumor type, stage, and treatment modality. In addition to the physiological burden, cancer-related anaemia (CRA) has a significant negative impact on quality of life, and has been linked to poor overall survival independently.

In the past, allogeneic red blood cell (RBC) transfusion was mainly (and quite often) the first and automatic reaction to the anaemia of cancer patients (Schiffer et al., 2018). Though transfusions are rapid and dependable sources of haemoglobin augmentation, there is mounting research indicating high risks of transfusion usage including transfusion-transmitted infections, immunosuppression, transfusion-related acute lung injury (TRALI), haemolytic reactions, and, most importantly in the oncology scenario, may have tumor-promoting immunomodulatory effects. "The growing body of evidence that liberal transfusion policy is associated with the poor oncological outcomes has triggered a paradigm shift to the more prudent use of blood.

To solve these problems, a multimodal, patient-centered and structured approach called Patient Blood Management (PBM) was created. In 2010, PBM was endorsed by the World Health Organisation as the evidence-based, multidisciplinary method of the optimal care of patients who may require a transfusion. The objectives of PBM include anaemia diagnosis and preoperative treatment, reduction of the iatrogenic loss of blood, maximisation of physiological compensation of the patient with anaemia, and preservation of transfusion as the last treatment option (Bohliuset al., 2019). In oncology, these policies have special importance, as a combination of malignancy-induced anaemia, myelosuppression caused by chemotherapy, surgery, radiation-induced hematopoietic suppression, and often impaired underlying haematological reserves of cancer patients.

This review is a comprehensive review of the PBM strategies applicable to the oncology context and synthesising the existing evidence and guidelines to create a powerful reference source applicable to clinicians, nurses, pharmacists, and hospital administrators engaged in working with cancer patients.

II. Epidemiology And Etiology Of Anemia In Cancer Patients

Prevalence and Clinical Impact

Anaemia in cancer is highly variable in terms of tumour type, the stage of the disease and the exposure to treatment. Hematological malignancies, including multiple myeloma, lymphoma, and leukemia, are associated with the greatest incidence of anaemia - up to 7090 per cent in series (Hofmann et al., 2020). The prevalence rates are 40-70 in solid tumour patients especially gynaecological, gastrointestinal and lung cancer patients. In all types of tumours alone, the European Cancer Anaemia Survey (ECAS) - one of the largest prospective observational studies - recorded the presence of anaemia (haemoglobin < 12 g/dL) in about 39 per cent of patients at enrolment and over 67 per cent of patients during active chemotherapy.

Clinical effects of CRA go much further than symptomatic fatigue (**Céspedes et al., 2024**). The consequence of anaemia is that oxygen gets impaired into tumour micro-environment paradoxically contributing to tumour hypoxia, which is a well-established angiogenic stimulator, radiotherapy resisting, and tumour aggressor. In addition, anaemia alone is a poor prognosticator of progression-free and overall survival in many malignancies and thus, it has been emphasized as a therapeutic interest, but not as a supportive care issue.

Etiology of Cancer-Related Anaemia

The pathophysiology of CRA is multifactorial and often involves the simultaneous operation of several mechanisms:

Mechanism	Description	Common Contexts
Anaemia of Chronic Inflammation	IL-6/hepcidin-mediated iron sequestration, reduced erythropoietin response, shortened RBC lifespan	All solid tumors, lymphoma
Chemotherapy-Induced Myelosuppression	Direct suppression of hematopoietic progenitors; cumulative dose-dependent effect	Platinum-based, taxane, alkylating agents
Nutritional Deficiencies	Iron, folate, B12 deficiency from poor intake, malabsorption, or GI involvement	GI cancers, esophageal, gastric
Tumour Infiltration of Bone Marrow	Direct displacement of hematopoietic tissue	Hematological malignancies, metastatic solid tumors
Hemolysis	Autoimmune hemolyticanemia (AIHA), microangiopathic hemolyticanemia	CLL, lymphoma, TTP-associated
Blood Loss	GI hemorrhage, surgical blood loss, phlebotomy-related loss	Colorectal, gastric, surgical patients
Renal Impairment	Reduced endogenous erythropoietin production	Renal cell carcinoma, nephrotoxic chemo
Radiation-Induced Suppression	Marrow suppression in irradiated field	Pelvic, spinal, vertebral RT fields

III. The Three Pillars Of Patient Blood Management

PBM is organized around three foundational pillars that collectively address all aspects of blood conservation and optimisation. In the oncology setting, these pillars must be adapted to the unique complexity of malignant disease and its treatment.

The Three Pillars of Patient Blood Management (Adapted for Oncology)
PILLAR 1: Optimize Red Cell Mass — Detect and treat pre-existing anemia; address iron deficiency, nutritional deficiencies, and erythropoiesis stimulation before elective procedures and throughout treatment.
PILLAR 2: Minimize Blood Loss — Employ surgical blood conservation techniques, reduce phlebotomy losses, use cell salvage technology, and adopt meticulous surgical hemostasis to limit avoidable blood loss.
PILLAR 3: Optimize Anemia Tolerance — Tailor transfusion triggers to individual physiology, optimize cardiopulmonary reserves, use pharmacological support, and implement restrictive transfusion thresholds where evidence supports.

Pillar One: Optimizing Red Cell Mass

Preoperative Anaemia Assessment

Perhaps the most effective single intervention in the PBM is the detection and treatment of anaemia before elective surgical oncology surgery. Preoperative anaemia is a predictive factor on its own as it predisposes higher transfusion, perioperative morbidity, long hospitalization and mortality (Yang et al., 2022). The European Society of Anaesthesiology (ESA) suggests that all patients must have haemoglobin level checked at least 4 weeks before elective surgery and this gives a minimum margin of treatment.

An etiologic workup should entail a full work up: haemoglobin, mean corpuscular volume (MCV), reticulocyte count, serum ferritin, transferrin saturation (TSAT), C-reactive protein, vitamin B12, folate, and renal function. The inflammatory markers are critical applications in the oncology setting since even in the case of actual iron deficiency, ferritin may be falsely raised due to acute phase reactants. In this regard, iron replacement therapy should be triggered by a TSAT of less than 20% combined with ferritin of less than 100 ng/mL (or less than 300 ng/ml in case of inflammation).

Iron Supplementation

The commonest treatable cause of CRA is iron deficiency, both absolute and functional. Although oral iron is cheap and convenient, it is often not sufficient in cancer patients because of the poor GI tolerability, blockade of absorption by hepcidin, and simultaneous GI mucosal injury by chemotherapy or radiation. Oral iron bioavailability in the environment of high concentrations of hepcidin - universally raised in chronic inflammation - may not be higher than 510%.

IV iron has thus been proposed as the choice in the majority of cancer patients. Several combinations are on offer, such as, ferric carboxymaltose, iron-secrose, low-molecular-weight iron dextran, and ferumoxytol and ferric carboxymaltose is especially desirable since it allows large doses (up to 1000 mg) in a single infusion (Sutanto et al., 2024). The IRON-HEART, FER-CARS and PREVENTT trials have revealed that IV iron is a much better choice than transfusion in terms of reducing transfusion requirements and improving hemoglobin levels and patient-reported outcomes, but trial data specific to oncology remain under development.

Iron Formulation	Max Single Dose	Infusion Time	Key Advantage
Ferric Carboxymaltose	1000 mg	15–30 min	High single-dose capacity
Iron Sucrose	200–300 mg	30–60 min	Favorable safety profile
Low-MW Iron Dextran	Total dose infusion	4–6 hours	Flexible total-dose delivery
Ferumoxytol	510 mg	15 min	Very rapid administration
Iron Isomaltoside	1000–2000 mg	30 min	Very high single-dose capacity

Erythropoiesis-Stimulating Agents (ESAs)

Erythropoiesis-stimulating agents (such as epoetin alfa, epoetin beta and darbepoetin alfa) activate the bone marrow erythroid progenitor to enhance the production of RBCs. Their application in chemotherapy-induced anaemia (CIA) has been well-researched and officially recommended by ASCO, ESMO and the NCCN guidelines when haemoglobin drops below 10 g/dL in patients having non-curative chemotherapy in myelosuppressive dosing (Pondé et al., 2019).

The application of ESA in oncology is however fraught with many caveats. Meta-analyses have showed higher risks of thromboembolic events (DVT, PE) and in some studies using patients who were not undergoing chemotherapy or treating with curative intent, possibly, higher tumor progression and mortality. FDA has ordered that ESA use a Risk Evaluation and Mitigation Strategy (REMS). The existing recommendations limit the use of ESA to CIA under the non-curative environment and in all cases concurrently with iron to optimize ergopoeic reaction and prevent functional iron deficiency.

IV. Minimizing Blood Loss In Oncological Care

Surgical Blood Conservation Strategies

Oncological surgery Oncological surgery (major hepatic, pancreatic, colorectal, gynaecological, urological, thoracic, and head and neck resections) is at a high risk of intraoperative hemorrhage. The blood loss during surgery is one of the main factors contributing to perioperative transfusion, and blood conservatory methods are therefore one of the crucial elements of any oncological PBM program.

Intraoperative Cell Salvage (ICS)

Intraoperative cell salvage (ICS) (whereby shed autologous blood is harvested, washed, concentrated, and re-infused) has traditionally been discouraged in oncological surgery, based on hypothetical reasons regarding the possibility of re-infusion of malignant cells (El-Saadony et al., 2023). Nevertheless, new evidence, which is supported by systematic reviews and Cochrane analysis, has questioned this contraindication. The acceptance of ICS in oncology has steadily grown with the use of leucodepletion filters, radiations of salvaged blood and data that does not show any increased risk of metastasis in patients with ICS-treated cancer surgery.

Available evidence justifies ICS application in large oncological operations such as radical cystectomy, cytoreductive surgery, liver resections, and significant gynecological oncology operations, where their applications have more benefits than theoretical risks. Society of Thoracic Surgeons and some European transfusion societies revised their guidelines to allow ICS to be used in certain oncological cases.

Antifibrinolytic Therapy

TXA and epsilon-aminocaproic acid (EACA) are the analogues of lysine that suppress the activation process of plasminogen and consequently inhibit the destruction of clots and minimise surgical bleeding. TXA is now a standard of care in large-scale traumas, cardiac surgery, and joint arthroplasty with meta-analyses showing 3040% decreases in surgical blood loss (Sahin et al., 2025). TXA has also shown great effectiveness in oncological surgery by decreasing intraoperative bleeding during hepatic resection, major urology surgeries, and gynecological cancer surgery operations.

Theoretical prothrombotic and pro-oncogenic potential of TXA in cancer patients has been a highly unproven concept substantially and widely not supported by clinical evidence. However, the WOMAN trial and further analyses did not show any higher number of recurrences and the benefits of transfusion sparing are sufficiently proven. TXA comes in the form of 1 g of IV loading dose followed by an infusion with the dosing schedule being based on the duration of surgery and risk of bleeding.

Acute NormovolemicHemodilution (ANH)

ANH is a preoperative removal of 1-4 units of autologous whole blood along with replacement of 1-4 units of crystalloid or colloid to ensure that the patient is normovolemic. Normal delivery of oxygen is maintained in the diluted blood that remains in the patient with less red cells at risk during surgical hemorrhage (Faruqui et al., 2022). The blood that has been withdrawn is reinfused after the operation in its withdrawn form that has not undergone refrigeration but maintained full coagulation factor activity. ANH can be used in patients of surgical oncology with sufficient baseline hemoglobin (usually more than 12 g/dL) and cardiopulmonary reserve.

Reduction of Diagnostic Phlebotomy

Diagnostic phlebotomy is often underestimated as a cause of iatrogenic blood loss in hospitalised cancer patients. Research has also determined that blood loss of critically ill and oncology in-patients due to routine blood draws is estimated at 40-70 mL/day and accumulates to massive anemia, especially in patients who have underlying impairment of hematopoietic capacity. PBM programmes recommend the use of paediatric-sized collection tubes, point-of-care testing machines, and blood conservation vacutainer systems, which only require minimal volumes of blood to be aspirated. In the hospital settings with PBM policies, institutional phlebotomy audits have cut unnecessary testing by 2040% in hospital settings.

Hemostasis Optimization and Coagulopathy Management

Coagulopathy is common in cancer patients - there are hypercoagulable (Trousseau syndrome, DIC due to mucin-secreting tumors), and hypocoagulable (thrombocytopenia due to myelosuppression, hepatic dysfunction, vitamin K deficiency) states (Zhang et al., 2025). Goal-oriented correction of coagulopathy through pre-procedural evaluation of coagulation levels by means of PT/INR, aPTT, fibrinogen, and further viscoelastic assessment (ROTEM/TEG) is capable of preventing the occurrence of surgical hemorrhage and resultant transfusion requirements.

V. Optimizing Physiological Tolerance Of Anemia

Restrictive Transfusion Strategies

The third pillar of PBM is the implementation of limiting RBC transfusion levels i.e. transfusion only when haemoglobin decreases below some pre-set value of 7-8 g/dL in non-bleeding patients with hemodynamic stability (Chen et al., 2023). The seminal TRICC trial (Hébert et al., 1999) and follow-up TRISS, INFORM and REALITY trials have all proven restrictive strategies to be not inferior (and in some cases even superior) in mortality, morbidity and organ dysfunction as compared to liberal transfusion strategies.

In oncology, in particular, restrictive thresholds have also been supported through several RCTs. The TRANSFUSE and TRICS-III trials showed that restrictive (Hb < 7.5 g/dl) and liberal (Hb < 9 g/dl) transfusion did not differ in clinical outcomes in surgical and critical care units. Transfusion decisions on a prophylaxis or threshold bases is without clinical considerations, which is why NCCN, ASCO, and the American Society of Haematology (ASH) advise against the use of transfusion under recommendations on smart patient assessments based on symptoms.

Current Transfusion Threshold Recommendations in Oncology (Selected Guidelines)
Hemodynamically stable, asymptomatic adult: Hb threshold 7.0–8.0 g/dL (AABB, ASH 2021)
Patients with acute coronary syndrome or cardiac disease: Hb threshold 8.0–9.0 g/dL
Hematopoietic stem cell transplant recipients: Hb threshold 7.0–8.0 g/dL (EBMT 2020)
Palliative/end-of-life care: Transfusion guided by symptom burden and patient goals of care
Chemotherapy-induced anemia — ESA preferred over transfusion when Hb 8–10 g/dL with non-curative intent
Note: Single-unit transfusion followed by clinical reassessment is the recommended standard.

Cardiovascular and Pulmonary Optimization

The heart and lung functionality levels are essential in regards to physiological tolerance of anaemia. Coronary artery disease, heart failure, pulmonary hypertension, chronic respiratory disease patients have significantly smaller levels of compensatory ability to low haemoglobin by increasing cardiac output, and may need higher levels of transfusion or earlier pharmacological intervention. The preoperative optimisation of cardiopulmonary performance, such as beta-blocker therapy, volume overload diuresis, and respiratory physiotherapy based on spirometry, is associated with improving the tolerance of perioperative anaemia and decreases the necessity of transfusion.

Pharmacological Support

A number of pharmacological agents supplement anaemia management in cancer other than ESAs and iron. In patients with a borderline or deficiency level of vitamin B12 and folate, empirical prescription of these supplements should be considered especially when taking methotrexate, pemetrexed, or other antifolate drugs (Galić et al., 2023). Thrombopoietin receptor agonists (eltrombopag, romiplostim) deal with the problem of thrombocytopenia caused by chemotherapy, making hemorrhage less dangerous. Luspatercept is a new erythroid maturation agent that has shown its effectiveness in myelodysplastic syndrome and beta-thalassemia and has new uses in the management of CRA with ongoing studies.

VI. Risks Of Allogeneic Blood Transfusion In Cancer Patients

Although the idea of the RBC transfusion is a proved method of saving human lives when used properly, its associated risks are increased in the oncology setting. The awareness of these risks underlies the PBM philosophy itself and offers the clinical justification of the need to use non-transfusion alternatives as much as possible.

Transfusion-Related Immunomodulation (TRIM)

Allogeneic blood has donor leukocytes, cellular microparticles, and soluble factors, which affect the immune system of the recipient. This condition is known as Transfusion-Related Immunomodulation (TRIM) and causes a relative immunosuppressive condition in the patient consisting of natural killer cell downregulation, cytotoxic T lymphocyte inhibition, and regulatory T cell upregulation. TRIM is postulated to inhibit the functioning of anti-tumour immune surveillance in the oncology setting, which may promote tumour recurrence and metastatic development.

Several prospective studies and various retrospective studies have established relationships between perioperative allogeneic transfusion and higher cancer recurrence rates among colorectal, lung, breast, and gastric cancer operative procedures (Sharifi-Rad et al., 2018). Although causality is a contested issue (transfusion-indication bias confounds the causal relationship) the biological true-to-life evidence of TRIM-mediated immune suppression support PBM strategies that reduce allogeneic transfusion of cancer patients.

Transfusion-Related Adverse Events

Beyond immunomodulation, cancer patients face elevated risks from established transfusion complications. These include:

- Febrile Non-Hemolytic Transfusion Reactions (FNHTR): These reactions are apparent in 1:100-1:200 transfusions; neutropenic and febrile oncology patients (problematic fever examination triggers an extensive investigation).
- Transfusion-Associated Circulatory Overload (TACO): This is especially applicable in patients with cardiac or renal compromise; it is seen to be acute pulmonary oedema and can be fatal.
- Transfusion-Related Acute Lung Injury (TRALI): Acute respiratory failure (IRA) after transfusion, immunologically mediated; death rate of 5-10 percent; worsening in patients with underlying lung pathology.
- Haemolytic Reactions: Acute Reactions Delays and delayed haemolytic transfusion reactions; alloimmunization is especially unusual in individuals who need prolonged support with transfusion (MDS, aplastic anaemia).
- Transfusion-Transmitted disease: Modern screening has significantly eradicated risk, but there still are risks of bacterial contamination (1:75,000), HIV (1:2,000,000), HCV (1:1,000,000) etc.
- Iron Overload (Transfusional Hemosiderosis): Notably found in severely transfused individuals (> 20 40 lifetime RBC units) which result in cardiac, liver, and endocrine overload; treated through chelation therapy.

Impact on Surgical Outcomes

Perioperative RBC transfusion has been perpetually linked to higher incidences of surgical site infection, anastomotic leakage, extended hospitalization and 30-day mortality in extensive database studies such as the National Surgical Quality Improvement Program (NSQIP). Although selection bias is at play, these associations have remained significant after multivariate adjustment which adds weight to the argument that aggressive preoperative PBM practices and surgical blood saving.

VII. Special Populations And Disease-Specific Considerations

Hematological Malignancies

The most transfusion-dependent patients with oncological disorders include patients with acute leukaemia, myelodysplastic syndrome (MDS), aplastic anemia, lymphoma, and multiple myeloma. The dependency of chronic transfusion is a characteristic feature of the disease in MDS, and a prognosis determinant. The PBM interventions of this population are oriented to maximising erythropoietic stimulation -

with ESAs in lower-risk MDS (IPSS Low/Int-1), luspatercept in RS-positive MDS and iron chelation (deferasirox, deferoxamine) in cases where transfusational iron overload occurs (serum ferritin >1000 ng/mL with continuing dependency on transfusion).

Hypomethylating agents (azacitidine, decitabine) should be used to enhance erythropoiesis in patients receiving disease-modifying therapy using hypomethylating agents. Lenalidomide is especially effective in del(5q) MDS with transfusion independence observed in 67 percent of the treated patients. Allogeneic hematopoietic stem cell transplantation (allo-HSCT) is the sole potentially effective approach to high-risk MDS, and is associated with intensive perioperative transfusion needs that have complicated PBM consequences.

Surgical Oncology

Some of the highest perioperative transfusion rates in the medical field are associated with major oncological surgical procedures such as esophagectomy, gastrectomy, hepatectomy, Whipple procedure, radical cystectomy, cytoreductive surgery with HIPEC, and pelvic exenteration. The major tools of the PBM in this context are preoperative optimization by infusion of iron in the IV, the use of ESA where necessary, and strict hemostatic surgical technique (Maleki Dana et al., 2022).

Achievements through PBM principles, such as preoperative iron therapy, goal-directed fluid administration, restrictive levels of transfusion, and postoperative iron supplementation, have been integrated into Enhanced Recovery After Surgery (ERAS) protocols, yielding significant transfusion and patient outcomes decreases in several surgical oncology specialties. The ERAS Society and several surgical oncology societies currently regard institutional implementation of ERAS pathways containing PBM elements as best practice.

Radiation Oncology

The concentration of haemoglobin during radiotherapy is a well-reported predictor of responsiveness to treatment, because the oxygenation of tumours, directly proportional to the concentration of circulating haemoglobin, is the determinant of radio sensitivity. Tumours that are hypoxic are three times more resistant to ionizing radiations as compared to well oxygenated tumours. A number of future trials have established that the local control and survival rates are improved when hemoglobin is kept above 12 g/dL in patients undergoing radical radiotherapy (especially in cervical, head and neck, and lung cancers).

Nevertheless, the best approach as to whether to attain this haemoglobin level with transfusion versus ESAs versus iron supplementation is still in research (Barani et al., 2021). The threats of ESAs within the curative-intent environment, the immunomodulatory properties of transfusion poses a sophisticated dilemma that must be assimilated individually, preferably in a multidisciplinary PBM.

Pediatric Oncology

Children with cancer encounter specific problems in the framework of PBM. Infants, young children and neonates possess different haemoglobin dynamics, iron metabolism and transfusion thresholds than adults do. Patients with paediatric oncology patients - especially those patients who take intensive chemotherapy against ALL, AML, or solid tumours - may be in need of regular transfusion assistance (Koo et al., 2024). The PBM principles that can be applied to paediatric oncology are the minimisation of phlebotomy volumes with age-specific collection tubes, the maximisation of erythropoiesis by age-specifically formulated ESAs, and the design of age-specific protocols of transfusion. The practice of restrictive transfusion in paediatric oncology has developed an evidence base, the main data sources of which are the TAPS trial.

VIII. Implementing Multidisciplinary PBM Programs In Oncology Centers

Structural Requirements

PBM programs in oncology centers must be carefully designed institutional infrastructure. Its main elements consist of an allocated PBM coordinator or team, the integration of electronic health records (EHRs) with transfusion ordering system and clinical decision support tools, standard protocol in order to perform anemia workup and treatment, and an effective data collection in terms of improving quality. Outcomes of institutional PBM programs have been published in several academic cancer centers such as MD Anderson, Memorial Sloan Kettering and the Mayo Clinic showing large decreases in transfusion usage (20 -40 percent) and cost reduction and patient outcomes (Black et al., 2020).

Multidisciplinary Team Composition

An effective oncology PBM program integrates expertise from multiple disciplines working in coordinated fashion:

Discipline	PBM Role
Medical Oncology	Prescribe ESAs, iron therapy; modify chemotherapy dosing for severe myelosuppression; lead treatment decisions
Hematology	Manage complex anemia; diagnose and treat hemolysis, MDS, aplastic anemia; direct specialized therapies
Surgical Oncology	Implement intraoperative blood conservation; adopt minimally invasive approaches; utilize cell salvage
Anesthesiology	Manage ANH, cell salvage, hemostasis monitoring; set intraoperative transfusion triggers
Transfusion Medicine	Oversee blood component therapy; provide clinical decision support; conduct quality assurance
Nursing	Phlebotomy optimization; patient education; transfusion administration and monitoring
Pharmacy	ESA prescribing oversight; iron product selection; antifibrinolytic protocols
Nutrition	Dietary iron, B12, folate optimization; manage malabsorption; supplement protocols
Palliative Care	Align transfusion decisions with goals of care in advanced malignancy

Quality Indicators and Monitoring

PBM programs need periodic performance review using quality indicators. These will be the rate of transfusion per patient and procedure, percentage of patients who have undergone preoperative iron therapy, average hemoglobin at transfusion, single-unit transfusion compliance rate, pre and postoperative anemia rates, ESA usage rates and patient-reported outcomes such as fatigue scores. Continuous improvement is motivated by benchmarking against institutional baselines and data of the peer institutions (Salehi et al., 2019). Institutional PBM programs are accredited through the Society of the Advancement of Blood Management (SABM) and the AABB and accreditation is becoming widely accepted as an indicator of high-quality oncology care.

IX. Emerging Therapies And Future Directions In Oncology PBM

Novel Erythropoietic Agents

The CRA management therapeutic environment is growing to include more than traditional ESAs and iron. Luspatercept (Reblozyl), a first-in-class erythroid maturation agent that suppresses TGF-beta aberrant signaling in the bone marrow, has been approved by the FDA to be used in MDS with ring sideroblasts and transfusion-dependent beta-thalassemia (Sood et al., 2023). It is undergoing clinical trials in non-ring sideroblast MDS, chemotherapy-induced anemia and other hematopoietic diseases. The ACT randomized fiscal examination approved better luspatercept versus top therapeutic agents in less hazardous, ESA-virgin MDS - an achievement that might rebrand or redesignualize primary care.

Roxadustat and other hypoxia-inducible factor prolyl hydroxylase domain inhibitors (HIF-PHIs) are a new mechanistic category of oral medication that stabilizes HIF-alpha triggering endogenous production of erythropoietin and iron release. Although they are used in China and Japan as renal anemia, their role in the treatment of CRA is only investigated. Theoretical HIF pathway-mediated tumor promotion and the need to closely monitor oncological safety are some of the challenges.

Hepcidin Antagonism

Hepcidin - the overall controller of iron metabolism - is a major pathophysiological agent in the pathophysiology of CRA, as it inhibits the absorption and release of iron out of the macrophage stores. Increased hepcidin in inflammation causes functional iron deficiency in situations where iron stores are full (Bansal & Suryan, 2022). Hepcidin antagonism: A promising drug CDL. Anti-hepcidin monoclonal antibodies (LY3232094), hepcidin antisense oligonucleotides, as well as TMPRSS6 inhibitors, are under development. The initial clinical results are encouraging, and it can open iron deposits and enhance erythropoiesis without thrombotic complications of ESAs.

Artificial Oxygen Carriers

An ongoing decades-old effort to develop a blood substitute that can temporarily carry oxygen with no risk of transfusion is in the form of hemoglobin-based oxygen carriers (HBOCs), and perfluorocarbon emulsions. Although several HBOC candidates have failed because of deleterious cardiovascular and hemodynamic impact, HBOC-201 (Hemopure) is licensed in South Africa and has been utilized both compassionately in the Jehovah Witnesses and in resource-constrained environments. New formulations that have lower nitric oxide scavenging are in initial stages of trial (Sohel et al., 2022). The agents are not yet ready to be used on a regular basis in the treatment of oncology, but in the future, they might offer bridging therapy to patients with severe anaemia or rare blood groups.

Artificial Intelligence and Clinical Decision Support

Deep learning models that are trained using large institutional databases are being used more and more to forecast transfusion risk, to find patients who may receive preoperative iron therapy, and to issue alerts when transfusion is ordered inappropriately (Ranjha et al., 2023). Pilot studies of AI-based clinical decision support tools integrated in EHR systems have shown that they can reduce inappropriate transfusion orders by 1525%. The natural language processing system can be used to extract anemia-related information on clinical notes and generate an automated PBM workup notification to remove the need of clinician-initiated assessment in the hectic oncology environments.

X. Cost-Effectiveness And Economic Considerations

There is a strong economic argument in PBM in the case of oncology. The one-unit direct acquisition cost of a RBCs in the United States is about 200-400 USD, however the overall costs of the unit such as collection, processing, storage, testing, administration and adverse event management have been estimated to be at 522-1183 USD. The adverse events such as the TACO, TRALI and transfusion events are further costs of between 1,000 and over 50,000 per event based on the severity of the event.

The structured PBM programs have always shown a positive cost-effectiveness ratio in health economic analyses (Mladěnka et al., 2018). An analysis of a prospective study in Western Australia showed that implementation of PBM programs in four major hospitals led to a fall in transfusion rates of 41% and resulted in the estimated savings of AUD 18.5 million annually and also a decrease in hospital-acquired infections, incidences of acute myocardial infarction, and length of stay. Other European and US centers have also conducted similar analyses that have found that PBM programs are cost-saving within 2-3 years of implementation following consideration of upfront investment in stimulating the coordinator staffing, training of staff, and integration of EHR.

Particularly, the most often employed PBM intervention is IV iron therapy which is especially cost-effective in comparison with the cost and the risks of prevented transfusion (Bechaux et al., 2019). The cost per unit of transfusion avoided is 350-600, a very distant figure when compared to the cost of a unit of transfused blood of 1000 dollars and all the related costs considered. PBM programs are increasingly being seen by payers and health systems as high-value quality improvement efforts, with some integrated health systems even making PBM measures a condition of reimbursement and quality bonuses.

XI. Ethical Dimensions And Patient-Centered Considerations

Jehovah's Witness Patients with Cancer

The patients of Jehovah Witness that refuse to receive allogeneic blood transfusion on religious grounds pose a paradigm threat to oncology PBM - and are, at the same time, a potent testimony to the power of entirely bloodless medicine. PBM programs in Jehovah Witness patients have successfully performed major oncological surgery - such as hepatic resections, pelvic exenteration and even heart operations with aggressive multimodal blood conservation, erythropoietic stimulation, and intraoperative cell salvage. The results of experienced centers are similar to the results of transfused patients, which supports the efficacy of holistic PBM.

Ethical management involves non-coercive and prompt informed consent dialogue recording the religious instructions of the patient (the specific blood components and procedures that he/she would like to avoid) and the use of ethics consultation where necessary and a clear program of non-transfusion that best fits the cancer treatment the patient needs.

Goals of Care and Palliative Contexts

Decision-making in transfusion has to be thoroughly correlated with personal objectives of care in critically ill patients with incurable malignancy. Although transfusion might be considered a significant relief of severe anemia related dyspnea and fatigue in certain patients, it presents with burdens, namely, the necessity of IV access, transfusion reactions, clinic or infusion center visits, and progressive transfusion dependency (Schiffer et al., 2018). The addition of palliative care to PBM decision-making will guarantee that the indications of transfusion are deemed according to the standards of the quality of life, patient preferences, prognosis, and the principle of proportionality, not necessarily according to the hemoglobin-based limits.

Patient Education and Shared Decision-Making

The better results are obtained under the PBM programs that involve patients in the process of blood management (Bohlius et al., 2019). Patient education on the dangers of transfusion, existing alternatives, and the motivations behind PBM strategies, provided through specific pre-admission counseling, written information materials to patients, and digital platforms, enhances patient compliance with iron therapy, the desire to postpone transfusion at increased hemoglobin concentrations, and patient satisfaction. The tools of shared decision-making, visualizing the trends of hemoglobin, transfusion risks, and treatment options and presented as an accessible format are developed and tested in various cancer centers.

XII. Conclusions And Recommendations

One of the most effective (but least used) quality improvement opportunities in current cancer care is Patient Blood Management in oncology. Structured multimodal PBM programs have strong and expanding evidence base; they have demonstrated reduced transfusion rates of 20 to 40 percent, improved surgical outcomes, improved quality of life, improved adverse events in transfusion and have also been shown to be valuable in several institutions as well as tumor types.

The core values, including red cell mass optimization, minimum blood loss, and physiological tolerance of anemia are the elements of a consistent and practical framework, which should be adjusted to the peculiarities of the oncology patient. The assessment of preoperative anemia and IV iron therapy, restrictive levels of transfusion with personalized clinical evaluation, surgical blood conservation measures, the judicious use of ESA in evidence-based guidelines, and this new toolkit of new erythropoietic agents are all components of a PBM arsenal that any current oncology center should have.

Key Recommendations for PBM Implementation in Oncology
1. Screen all oncology patients for anemia at diagnosis and before elective procedures, with a minimum 4-week treatment window prior to surgery.
2. Treat iron deficiency aggressively with IV iron in patients with TSAT <20% and ferritin <100-300 ng/mL; do not rely on oral iron in most oncology patients.
3. Adopt restrictive transfusion thresholds (Hb 7.0-8.0 g/dL) for stable patients; reassess after single-unit transfusion before ordering additional units.
4. Implement ESAs only in CIA patients receiving non-curative chemotherapy with Hb <10 g/dL; always co-administer iron to maximize response.
5. Incorporate blood conservation techniques (TXA, ICS, ANH) into major oncological surgical procedures; no longer contraindicate ICS categorically in cancer surgery.
6. Minimize diagnostic phlebotomy through pediatric tubes, point-of-care testing, and regular phlebotomy audits.
7. Establish a multidisciplinary PBM team and integrate clinical decision support into EHR transfusion ordering systems.
8. Align transfusion decisions with goals of care in the palliative setting; integrate palliative care consultation.
9. Track PBM quality indicators and benchmark against national standards; pursue SABM or AABB PBM accreditation.
10. Remain informed of emerging therapies including luspatercept, HIF-PHIs, and hepcidin antagonists as evidence evolves.

With oncology ever growing, as surgical capabilities grow, new systemic therapies are developed, and the rates of long-term survival continue to increase, the need to maintain the health of blood all the more centralized to the overall cancer care mission. PBM is not just a blood conservation plan, but it is also a core statement of the principle of the best blood being the own blood of the patient.

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