



Post-transplant malignancy: Focusing on virus-associated etiologies, pathogenesis, evidence-based management algorithms, present status of adoptive immunotherapy and future directions

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Abstract

Modern immunosuppression has led to a decrease in rejection rates and improved survival rates after solid organ transplantation. Increasing the potency of immunosuppression promotes post-transplant viral infections and associated cancers by impairing immune response against viruses and cancer immunoe-diting. This review reflects the magnitude, etiology and immunological characteristics of various virus-related post-transplant malignancies, emphasizing the need for future research. A multidisciplinary and strategic approach may serve best but overall literature evidence targeting it is sparse. However, the authors attempted to provide a more detailed update of the literature consensus for the prevention, diagnosis, management and surveillance of post-transplant viral infections and associated malignancies, with a focus on the current role of adoptive immunotherapy and the way forward. In order to achieve long-term patient and graft survival as well as superior post-transplant outcomes, collaborative research on

holistic care of organ recipients is imperative.

Key Words: Post-transplant malignancy management; Post-transplant virus-associated malignancy; Cancer; Kidney transplantation; Solid organ transplantation; Virus

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Core Tip: Post-transplant malignancy poses a serious threat with increased risk in organ recipients, varying with the intensity of net immunosuppression. Various virus infections are either causative or associative or promote the development of post-transplant malignancies. It is crucial to be aware of different viral infections so as to pre-emptively screen viral infections and survey for post-transplant cancers, helping early diagnosis, thereby favoring improved outcomes and graft survival. Transplant clinicians must be up to date on current management strategies with the vital role of immunosuppression reduction and options like antivirals, rituximab, chemotherapy, adoptive immunotherapy, topical therapy and surgery based on individual case characteristics.

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INTRODUCTION

Post-transplant infections and malignancies are on the rise with increasing efficacy of immunosuppression[1,2]. Several population-based registries found a 2–5-fold increase in cancer risk after transplantation[3–7].

Although multifactorial, most of these cancers are attributed to a viral cause (known or suspected) and immunosuppression plays a significant role, as it suppresses the immune response to oncoviruses and impairs cancer immunosurveillance[3,8]. Eight to ten percent of kidney transplant recipients' deaths are due to post-transplant cancers, the third leading cause of mortality after cardiovascular disease and infection in organ recipients[9,10].

Diverse types of malignancies can develop after transplantation, with some incurring a significant increase in incidence (lymphoma, non-melanoma skin cancer, lung, colon and liver) and others are not (ovarian, brain, breast, prostate and cervical malignancy) as mentioned in Table 1[9,11,12]. Table 2 emphasizes the burden of cancer, especially related to viral infections during the post-transplant period.

Currently, there is varied agreement regarding the prevention, diagnosis, treatment and surveillance of post-transplant cancers, especially in relation to viral infections. Additionally, the introduction of adoptive immunotherapy (AI) has resulted in the dilemma of treatment management alternatives.

This article focuses on the up-to-date information of the various post-transplant virus-associated etiologies and their pathogenetic differences compared to the general population with respect to post-transplant malignancy. It also mentions in detail about comprehensive consensus regarding the management of post-transplant malignancy, pertaining to viral infections, in light of recent research findings, including the role of AI. Furthermore, this article highlights the need of future research with the purpose of developing a tailored therapeutic strategy for each patient based on existing risk factors and diagnostic techniques.

VARIOUS VIRAL INFECTIONS THAT MAY INDUCE/PROMOTE/ASSOCIATED WITH POST-TRANSPLANT MALIGNANCY

Various viruses that have been associated with causing[13–17] or promoting[18–19] post-transplant malignancies as given in Table 3.

Skin cancers (commonly found post-transplant and those related with viral infections)

The commonest cancer following kidney transplantation is skin cancer, which is more aggressive than in the general population and nearly affects 50% of post-transplant patients[20]. Non-melanoma skin cancers (NMSCs) are the most common type, reported in up to 82% of patients within 20 years of transplantation[21,22]. Ninety percent of all NMSCs are squamous cell carcinoma (SCC) and basal cell carcinoma (BCC)[23,24]. Post-transplant recipients in comparison to the general population, have a 65–250-fold and 10-fold increased risk of developing SCC and BCC, respectively[20]. Various studies have reported that the ratio of BCC to SCC in the general population (5:1) is reversed in organ recipients (1:4 to 1:5)[23,24]. BCC, SCC, Kaposi's sarcoma (KS) and malignant melanoma constitute up to 90%–95% of all skin cancers in

Table 1 Post-transplant cancers standardized incidence ratio compared to general population[12]

Standardized incidence ratio compared to general population	Post-transplant cancers
> 5	NMSC, PTLT, lip, RCC and KS
2-5	Melanoma, thyroid cancer, leukemia and multiple myeloma
< 2	Breast, brain, lung and prostate cancer

NMSC: Non-melanomatous skin cancers; PTLT: Post-transplant lymphoproliferative disorders; RCC: Renal cell carcinoma; KS: Kaposi's sarcoma.

Table 2 Post-transplant malignancy meta-analysis standardized incidence ratio in relation to viral infections[2,140]

Cancers associated with post-transplant viral infections	Meta-analysis SIR
EBV-associated	
Hodgkin's lymphoma	3.89 (2.42-6.26)
NHL	8.07 (6.40-10.2)
HHV8-associated	
Kaposi's sarcoma	208 (114-369)
HBV/HCV-associated	
Hepatocellular	2.13 (1.16-3.91)
HPV-associated	
Cervical	2.13 (1.37-3.30)
Vulva & vagina	22.8 (15.8-32.7)
Penis	15.8 (5.79-34.4)
Anus	4.85 (1.36-17.3)
Oropharynx	3.23 (2.4-4.35)
Non-melanocytic skin cancer	28.6 (9.39-87.2)

EBV: Epstein-Barr virus; SIR: Standardized incidence ratio; NHL: Non-Hodgkin's lymphoma; HHV8: Human herpes virus 8; HBV: Hepatitis B virus; HCV: Hepatitis C virus; HPV: Human papilloma virus.

transplant recipients[25,26]. Rare skin cancers include cutaneous lymphoma, Merkel cell carcinoma, vascular cutaneous tumor (angiosarcoma), mesenchymal cutaneous tumors and adnexal gland carcinoma.

Even though human papilloma virus (HPV) is frequently detected in warts, hair follicles, and keratotic lesions, both in patients with and without skin tumors, there is no conclusive evidence linking HPV to skin tumor development in transplanted patients[27,28]. Oncogenic (HPV types 16 and 18) and non-oncogenic (HPV types 6 and 11) HPV DNA is found in 65%–90% of SCC in organ recipients, but its carcinogenic role is still unclear[27].

Novel polyoma virus has been identified in human Merkel cell carcinoma (hence the name Merkel cell virus or MCV) with possible causation[29].

The skin cancers of organ recipients tend to be more aggressive, present at a younger age, and involve multiple primary sites as opposed to those of the general population.

Multiple factors contribute to the etiology of skin cancer, including immunosuppression, intensity of immunosuppression, UV radiation exposure, white race, older age, a history of skin cancer, human herpes virus (HHV) 8 and possibly HPV 16/18 and MCV[30].

Epstein-Barr virus/HHV 4

Epstein-Barr virus (EBV) is a member of the gamma herpesvirus family, and is an encapsulated single-stranded DNA virus and ubiquitous. There are two strains infecting humans, EBV-1 and 2 (previously called EBV A and B). In the USA and Europe, EBV-1 predominates, whereas in Africa and New Guinea, both EBV strains are equally prevalent[31]. EBV spreads *via* saliva (and possible transmission through sexual intercourse), before spreading to circulating B cells through infection of the oropharyngeal epithelium[32]. EBV seroprevalence is 100% by age 4 years and 89% by 19 years in developing and developed nations and varies with socioeconomic status[33,34].

Kidney transplant recipients are susceptible to acute infection or reactivation of a latent virus, with clinical manifestations ranging from non-neoplastic viral replication (asymptomatic viremia, infectious mononucleosis) to neoplastic viral proliferations, like post-transplant lymphoproliferative disorder (PTLD) and smooth muscle tumors[35,36].

Table 3 Different viruses associated/related to post-kidney transplant tumours/cancers

Virus	Associated/related post-kidney transplant tumours/cancers
EBV	PTLD, smooth muscle tumours
HPV	Squamous cell carcinoma
HHV8	Kaposi's sarcoma, multiple myeloma
HIV	Plasmablastic lymphoma, Merkel cell carcinoma
HBV/HCV	Hepatocellular carcinoma
BK polyomavirus	Urothelial, renal cell and collecting duct carcinoma
CMV	Gastrointestinal tumours, nephrogenic adenoma

EBV: Epstein-Barr virus; PTLD: Post-transplant lymphoproliferative disorders; HPV: Human papilloma virus; HHV8: Human herpes virus 8; HIV: Human immunodeficiency virus; HBV: Hepatitis B virus; HCV: Hepatitis C virus; CMV: Cytomegalovirus.

Table 4 Risk factors associated with post-transplant lymphoproliferative disorders [35,45,52,141,142]

Risk factors of PTLD in KT	Likely cause/association
Recipient age < 10 yr	A greater likelihood of being seronegative for EBV
Recipient age > 60 yr	Associated finding in various studies
EBV seropositive donor to EBV seronegative negative recipient (EBV D+/R-)	90% are donor derived and 10–76-fold higher incidence of early PTLD
Bimodal peak	First peak (with higher incidence) in first 2 years and 2 nd peak between 5 to 10 years post-transplant
Intensity of immunosuppression and use of T cell depleting antibodies (ATG and/or OKT3), belatacept	Reduction in cancer immunosurveillance
Treated acute rejection within first year after transplantation with depleting antibodies	Reduction in cancer immunosurveillance
Simultaneous pancreas–kidney transplantation	Association
HLA mismatches (especially HLA B and DR mismatches)	Likely, due to higher associated risk of rejection and use of increased net immunosuppression

PTLD: Post-transplant lymphoproliferative disorders; KT: Kidney transplantation; EBV: Epstein-Barr virus; HLA: Human leukocyte antigen; ATG: Antithymocyte globulin; OKT3: Trade name of Monomurab CD3 (a murine monoclonal antibody reacting with CD3 molecule on human T lymphocyte).

Asymptomatic low-level, high-level, or the absence of viremia may exhibit no distinguishable symptoms and usually detected through screening with EBV polymerase chain reaction[37]. In a few studies, renal dysfunction, patient and graft survival are no different between groups (absent, low or high viral loads), whereas others report a higher incidence of opportunistic infections with increasing viral loads[37,38]. EBV seronegative at transplantation, prior history of PTLD and non-Caucasians are risk factors for EBV viremia[37].

Other manifestation of EBV includes EBV-associated Guillain-Barre syndrome[39], gastric carcinoma[40], smooth muscle tumors[41], hemophagocytic syndrome[42] and autoimmune hemolytic anemia[43].

EBV-related PTLD, is the most serious sequel in organ recipients by the virus and cumulative incidence varies with 1%–5%, 2%–10% and 5%–20% in kidney, heart and lung and intestinal and multivisceral transplant recipients[44]. Other manifestations include an 11.8-fold increased risk of non-Hodgkin's lymphoma in kidney transplant recipient compared to the age-matched non-transplant group[45].

PTLDs, mostly (65%–80%) present as extranodal masses and vary histologically as infectious mononucleosis-like, plasmacytic hyperplasia, florid follicular hyperplasia, polymorphic, monomorphic PTLD (B- and T-/NK-cell types) or classical Hodgkin's lymphoma PTLD[46]. Risk factors associated with PTLD in kidney transplantation are listed in Table 4. Early PTLD (< 1 year post-transplant) is usually seen in EBV-seronegative recipients, polymorphic, with graft involvement (in 57%) and responds to reduction in immunosuppression (RIS). Late PTLD is usually monomorphic, disseminated and extranodal (graft involvement - only 10%) and resistant to RIS[47–50].

The most common sites of PTLD involvement are the gastrointestinal tract (15%–30%), lungs, skin (5%–10%), liver, central nervous system (CNS) (20%–25%, usually late PTLD), and the allograft (20%–25%, often culminating in allograft loss)[50]. CNS PTLD often has poor prognosis, and has the highest incidence in kidney transplant recipients[35,51,52].

HPV

HPV is a double-stranded DNA virus that can infect the keratinized skin (basal epithelium), mucous membranes, and the cervical transformation zone and spread *via* direct contact transmission (person to person). HPV types 6, 11, 16 and 18 are implicated in low- and high-grade neoplasia[28,53-55]. HPV has been linked to precancerous lesions (cervical intraepithelial neoplasia and anal intraepithelial neoplasia), lesions with low malignant potential like cutaneous, anogenital warts and certain cancers [cervical, anal, vulvar/vaginal/penile squamous cell cancers, rarely oropharyngeal (head and neck) cancers][56].

There is higher risk of HPV-associated malignancies, extensive and treatment-refractory warts on the cutaneous and anogenital areas in transplanted patients (reactivation of old or new infection) compared to age matched non-transplant individuals[3,57].

HPV rarely causes viremia (in immunocompetent as well as immunodeficiency states) but lack of cell-mediated immunity at infected sites, especially in transplant recipients, leads to its persistence, extensive warts that are not responsive to treatment, and increased probability of cancers[58,59].

Persistent infection with HPV 16 and 18 is associated with premalignant and malignant lesions of the cervix, anus, vulva, penis or scrotum. Lesions are typically asymptomatic, may present with abnormal bleeding, ulcer/nodule/wart-like features, local pruritus, pelvic pain, and dyspareunia in some cases[60-62].

There has been links of HPV association with oropharyngeal and lung SCC but with conflicting results[3,63,64].

HHV8 or KS herpesvirus

HHV8, a DNA gamma-herpes virus, has four variants: sporadic or classic (first description by Kaposi), endemic (in sub-Saharan Africa), epidemic (associated with HIV), and iatrogenic (in immunosuppressed transplant recipients)[65].

Virus can be transmitted *via* saliva (primarily), sexually (semen/vaginal secretion), vertically (breast milk), intravenously (drug use or blood products) or through transplantation.

Like EBV[66], HHV8 invades B cells, macrophages, lymphoepithelial cells and epithelium, can persist lifelong in a latent form, or reactivate when immunosuppressed to enter a lytic form leading to viremia[67,68]. In organ transplant recipients, lytic reactivation of virus due to immunosuppression (iatrogenic) may lead to uncontrolled monoclonal/oligoclonal proliferation of latently infected lymphoepithelial cells or proliferation of post-germinal center where B cell maturation happens.[67,68].

Lymphatic-endothelium-derived cells infected with HHV8 form multicentric neoplasm classically known as KS[69,70]. HHV8 induced neoplastic and non-neoplastic manifestation post-transplant can be derived from latent virus, seroconversion from positive donor to seronegative recipient[71], proliferation of seeded HHV8⁺ cells[72,73] or KS tumor in transplanted organs[74] while in an immunosuppressed state.

HHV8 is not ubiquitous like EBV, but seroprevalence is higher than 50% in some endemic regions (sub-Saharan Africa, Caribbean, Latin America, Mediterranean, and Middle East) and matches post-transplant KS (PT-KS) herpesvirus-associated pathologies in such regions[75].

KS risk is low in transplant recipients but 200–500-fold higher than in the general population[76,77]. Besides the key risk factor of HHV8 seropositivity, other factors include ethnicity (higher in seroprevalent geographic regions), receipt of lymphocyte depleting agents, HLA-B mismatch, older age and lung transplantation[76,78-82].

PT-KS has a higher incidence in kidney transplant compared to other solid organ transplantations (SOTs) (liver and heart) and rare in hematopoietic stem cell transplantation (HSCT). This condition usually manifests early after transplantation (median 2.5 years) as cutaneous or mucosal lesions, but 25%–50% have visceral manifestations[82] with mortality ranging from 8% to 14%. Disseminated disease is associated with thrombocytopenia, anemia, and abnormalities of bone marrow progenitor cells and widespread involvement (cutaneous, mucosal and visceral). Al-Khader *et al*[83] proposed clinical staging of PT-KS that assesses extent of disease and guides treatment. Few studies have shown that cytomegalovirus (CMV) infection can reactivate HHV8, and initiate onset and/or recurrence of KS[83,84].

Post-transplantation, HHV8 can also cause other lymphoproliferative disease such as primary effusion lymphoma, multicentric Castleman disease[85,86] and other non-malignant complications like plasmacytic B-cell proliferation, bone marrow failure and hepatitis[82,87].

HIV

Observations concerning the impact of HIV infection post-transplantation have been largely based on the experiences of recipients who previously had HIV infection and underwent transplantation. Transplant outcomes in HIV-positive recipients are almost similar to those in non-HIV-positive recipients with few differences[88,89].

KS prevalence in HIV-positive patients on antiretroviral therapy (ART) is 0.18%–0.46%, while it increases to 0.50%–0.66% in transplanted patients[90].

People with HIV [Standardized incidence ratio (SIR) = 4.95%] and organ recipients (SIR = 3.28%) had a greater risk of developing new cancers compared to general population[91].

SOT in HIV-positive patients carries a low risk of recurrence or *de novo* cancer. HPV-associated neoplasia (cervical, anal and atypia) had a higher risk in a few studies, however, this requires confirmation in future studies[92].

EBV-associated PTLN/lymphoma has similar prevalence in organ recipients with HIV[89].

Compared to non-HIV recipients, incidence of tuberculosis and fungal infections appears to be greater in HIV-infected recipients during the post-transplant period[93].

Hepatocellular carcinoma related to hepatitis B and hepatitis C viruses

In a United States registry data (223 660 recipients, 1987–2005), *de novo* hepatocellular carcinoma (HCC) post-

transplantation was evaluated among non-liver (kidney, heart and lung) and liver transplant recipients[94].

In non-liver recipients, the study reported *de novo* post-transplant HCC incidence of 6.5 per 100 000 person-years. Hepatitis B surface antigenemia [hazard ratio (HR): 9.7], hepatitis C virus (HCV) infection (HR: 6.9), and diabetes mellitus (DM) (HR: 2.8) are risk factors independently linked with HCC incidence. Incidence of HCC was greater in those with HCV (SIR = 3.4) or hepatitis B surface antigenemia (SIR = 6.5), but comparable with general population (SIR = 0.8).

In liver recipients, *de novo* post-transplant HCC incidence was 25 per 100 000 person-years. Advancing age, male sex (HR: 4.6), HCV infection (HR: 3.1), and DM (HR: 2.7) were independently associated risk factors. Overall, the incidence of HCC was higher (SIR = 3.4), but particularly among individuals with HCV (SIR = 5.0) or DM (SIR = 6.2).

Due to the high endemic prevalence of hepatitis B virus (HBV) infection in Taiwan, HCC is a major malignancy in general as well as in the post-transplant population, favoring hepatitis virus antigenemia as a potential causative factor [95]. HCV infection is also related to post-transplant cirrhosis and thereby increasing the risk of post-transplant HCC[96].

Various other studies of different ethnicities also found that HBV and HCV infection post-kidney transplantation was a significant risk factor for HCC[97,98].

Polyomavirus

The polyomavirus (BKV) is a ubiquitous polyoma virus that causes asymptomatic infection in childhood and has a seroprevalence of 70%–80% in adults. It develops latency in organs such as the kidneys, ureters, spleen or brain[99]. Its non-oncological manifestations in kidney recipients are ureteral stenosis, vasculopathy, tubulopathy, hemorrhagic cystitis, and interstitial nephritis[100,101]. BKV-related malignancies in kidney recipients include urothelial carcinoma of the renal pelvis, renal cell carcinoma, and collecting duct cancer [99,102–105].

CMV

Rarely, CMV has been associated with *de novo* gastrointestinal tumors and nephrogenic adenoma following renal transplantation. Its causal role is unclear[106,107].

PATHOGENESIS OF POST-TRANSPLANT MALIGNANCIES

Pathogenesis and transplant specific risk factors for post-transplant malignancies are multifactorial but mainly include immunosuppression and decreased immunosurveillance.

Cancer immunoediting involves three phases (Figure 1)[108–110]: Elimination phase (cancer immunosurveillance); equilibrium phase (cancer persistence/dormancy); and escape phase (cancer progression). Immunosuppression has an impact on all phases.

In post-transplant patients exposed to viral infections, UV radiation, carcinogens or chronic inflammation, some healthy cells transform into highly immunogenic tumor/transformed cells. These tumor cells may revert to normal tissue *via* a mechanism of intrinsic tumor suppression (repair, apoptosis or senescence), which may become weak due to the effects of modern era immunosuppression.

As soon as these highly immunogenic transformed cells evade the intrinsic tumor suppression mechanism, they enter the elimination phase (cancer immunosurveillance). During the elimination phase, innate and adaptive immunity (NK and T cells) offers protection against the development of cancer (known as extrinsic tumor suppression). If the phase of elimination concludes successfully, the body restores healthy tissue but is weakened by immunosuppression.

When transformed cells escape the elimination phase, they enter an equilibrium state (cancer persistence/dormancy), in which adaptive immunity (T cells, interleukin-2, interferon-) works to maintain such cells in a dormant state. In the event that dormancy occurs efficiently, it prevents outgrowth of transformed cells or occult tumors/cancers throughout life and represents the end stage of cancer immunoediting but is altered by immunosuppression. Tumor immunogenicity is edited during the elimination phase by constant immune selection. Antigen loss variants, flaws in antigen processing or presentation, immune effector cell resistance, and the generation of an immunosuppressive microenvironment within the tumor are some of the editing mechanisms. Genetic instability and tumor heterogeneity increase as editing proceeds, and highly immunogenic tumor cells become less immunogenic and immunoevasive tumor cells.

These less immunogenic and immunoevasive tumor cells escape immunosurveillance and progress to clinically apparent cancer. This phase is designated as the escape phase (cancer progression).

Specific carcinogenic mechanisms of various viral infections post-transplant are listed in Table 5[111].

Multidrug immunosuppression in the transplant setting impacts cancer immune editing by a number of mechanisms, as shown in Table 6.

Multifactorial pathogenesis associated with post-transplant malignancy due to decrease immunosurveillance following exposure to viral infections, UV radiation and carcinogens including other related risk factors is summarized in Figure 2 [108].

DIFFERENCES BETWEEN MALIGNANCIES IN ORGAN RECIPIENTS COMPARED TO THE GENERAL POPULATION

Interaction with a healthy immune system (as in general population) selects tumors devoid of tumor-specific antigens, meaning poorly immunogenic or immunoevasive tumors.

Table 5 Viruses and their specific carcinogenic mechanisms

Virus	Carcinogenic mechanisms
EBV	EBV-infected cells generates more interleukin-6, which promotes the proliferation of B-cells, and interleukin-10, an immunosuppressive cytokine that promotes tumour development
HPV	E6 and E7 proteins expressed by HPV suppress p53-mediated apoptosis and increase malignant growth in infected cells
HHV8	Viral proteins encoded by HHV8 inhibit the activation of pro-caspase-8, promotes Ras-PI3K-Akt survival pathway and enhances antiapoptotic Bcl-2 (B-cell lymphoma 2) expression, thereby inhibiting apoptosis and promoting uncontrolled proliferation of infected and endothelial cells
HBV	HBx proteins produced by virus activate the Ras-PI3K-Akt survival pathway and change EGFR signalling. In addition, it modifies the transcriptional activity of c-Myc, c-Fos, and c-Jun and promotes the expression of angiogenic factors, including VEGF and angiopoietin-1. Consequently, this stimulates proliferation and angiogenesis
HCV	Virus-produced non-structural proteins (NS3 and NS5A) promote the Ras-PI3K-Akt survival pathway. NS5A also modulates the signalling mediated by. Consequently, this stimulates proliferation and angiogenesis

EBV: Epstein-Barr virus; HPV: Human papilloma virus; HHV8: Human herpes virus 8; HBV: Hepatitis B virus; HCV: Hepatitis C virus; EGFR: Epidermal growth factor receptor; VEGF: Vascular endothelial growth factor.

Table 6 Immunosuppressive agents, mechanisms of carcinogenesis and cancer risk [9,108,140]

Immuno-suppressive agents	Mechanisms in carcinogenesis	Cancer risk
Polyclonal lymphocyte depleting agents (OKT3/rATG)	Interfere with T-cells, B-cells, NK and DC functions[143-145]	Increased risk of PTLD
Alemtuzumab	Depletes B and T cells	Increased risk[146] NHL (2.5-fold rise) Colorectal cancer (2.5-fold rise) Thyroid cancer (3-fold rise) Mixed results with PTLD association[147,148]
Cyclosporine A	Downregulate T-bet dependent immunosurveillance[149] Inhibit antigen presentation by DC[150]	Suppress immune response against melanomas Impairs elimination of oncogenic viruses and overall increased risk of cancer[151]
Tacrolimus	Inhibit antigen presentation by DC[150]	Impairs elimination of oncogenic viruses Overall increase risk of PTLD and reduced trough levels substantially decline the risk[152]
Azathioprine	selectively depletion of memory T-cells[153]	Linked to late SCC (of skin) and myelodysplastic syndrome [154]
Mycophenolate (MMF/MPA)	Antiproliferative and antioncogenic potential [155]	Protective and reduce the risk of PTLD
mTOR inhibitors	Promotion of CD8 ⁺ central memory T cells[156] Upregulate transcription factor T-bet[157]	Enhance antiviral immunity T-bet regulates cross-talk of innate and adaptive immune cells and has tumour-suppressive activities[158]
	Antioncogenic and antiproliferative role	Overall cancer risk reduction and even regress KS[159]
Belatacept	Inhibitor of T cell proliferation	Unclear though postulated as slight increased risk of oncogenicity[160]

OKT3: Trade name of Monomurab CD3 (a murine monoclonal antibody reacting with CD3 molecule on human T lymphocyte); rATG: Recombinant antithymocyte globulin; NK cells: Natural killer cells, DC: Dendritic cell; PTLD: Post-transplant lymphoproliferative disorders; NHL: Non-Hodgkin's lymphoma; SCC: Squamous cell carcinomas; KS: Kaposi sarcoma.

Tumors formed in immunosuppressed hosts are more immunogenic than in the general population (immunocompetent host) as *de novo* malignancies arise due to permissive effect of immunosuppression by inhibiting cancer immunosurveillance and immunoediting[109,110,112]. RIS and immunotherapy (*i.e.*, adoptive/checkpoint inhibitors) may facilitate immune reconstitution, which can help by clearing immunogenic cancer cells but can raise risk of rejection[113].

Cancer immunoediting/immunosurveillance & effects of MDI in SOT

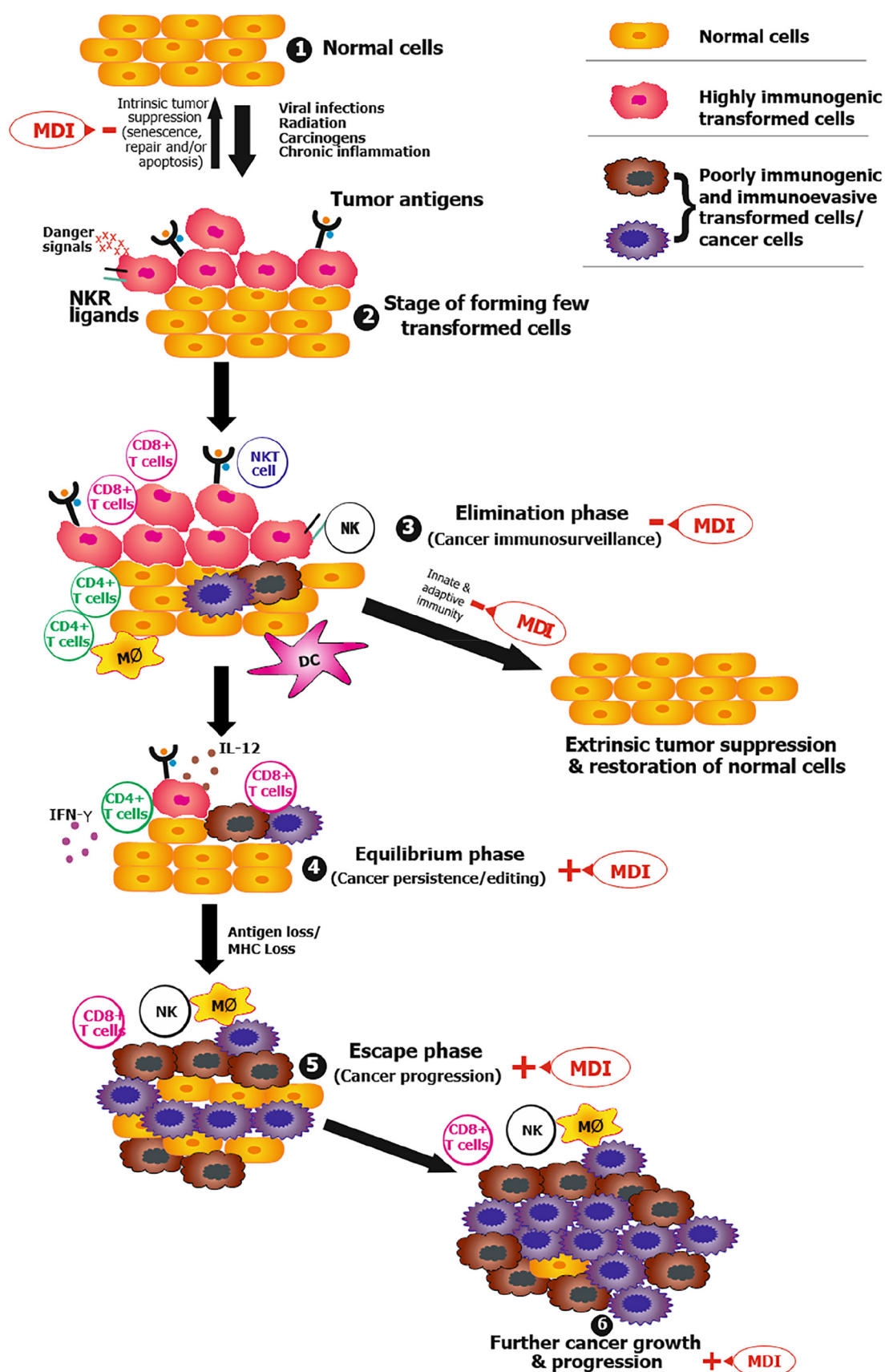


Figure 1 Cancer immunoediting and influence of immunosuppression after transplantation. +: Promote; -: Inhibit; MDI: Multidrug immunosuppression; MHC: Major histocompatibility complex; NK: Natural killer cell; NKR: Natural killer cell receptor; SOT: Solid organ transplant.

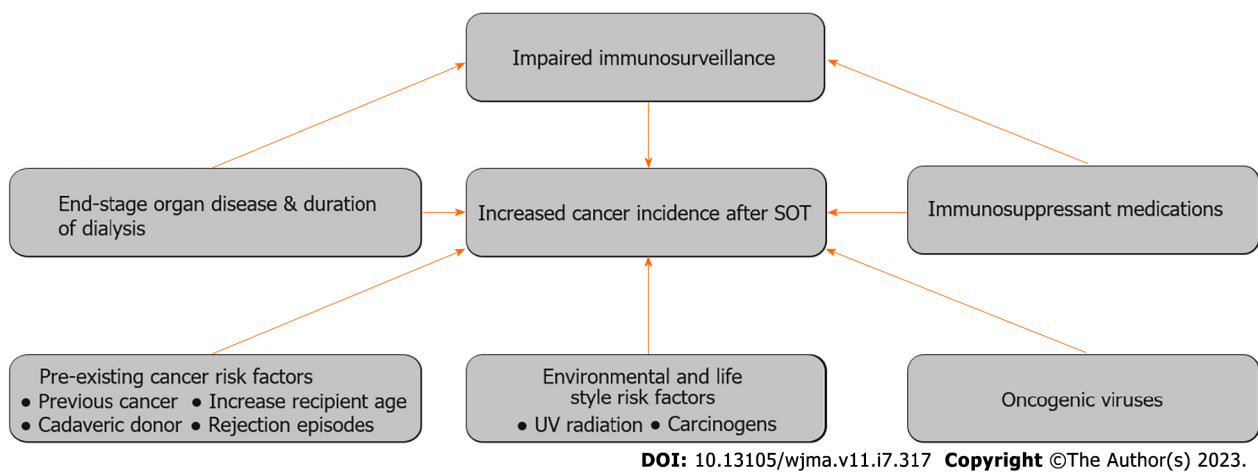


Figure 2 Summary of etiology of increased cancer incidence after transplantation. SOT: Solid organ transplant; UV: Ultraviolet.

SCREENING, DIAGNOSIS, AND TREATMENT OF POST-TRANSPLANT VIRAL INFECTIONS RELATED WITH THE POTENTIAL TO DEVELOP MALIGNANCY

Viral etiology is well known and accepted as a probable association or causation (either promoting or inducing) of a wide variety of post-transplant malignancies. [Table 7](#) highlights screening, diagnosis and treatment of post-transplant viral infections.

DIAGNOSIS OF VARIOUS POST-TRANSPLANT VIRUS-ASSOCIATED MALIGNANCIES

Susceptibility of viral infections post-transplant is proportional to the degree of net immunosuppression and varies greatly due to inherent limitations in the available data. The availability of population registry data for specific viral infections related to the type of organ transplant is insufficient, differs with immunosuppression regimen and geographical distribution, and is, in general, weak worldwide.

After a thorough literature research, we could only find EBV-associated PTLD and HHV8-associated KS risk with different types of organ transplantation as mentioned below. PTLD risk is highest for intestine and multi-organ transplants (12%–17%), followed by lung (6%–10%), heart (3%–5%), liver (2%–3%), and kidney (1.5%–2.5%), being the least[114].

KS incidence varies with organ transplant and is reported as per 100 000 person-years. It was reported as 95.79 [95% confidence interval (95%CI): 42.81–214.31] in kidney, 44.25 (95%CI: 4.78–409.20) in liver, 49.25 (95%CI: 2.48–977.84) in heart and 10.97 (95%CI: 4.12–29.23) in lung [115].

An in-depth detail to diagnose various post-transplant virus associated cancers is outlined in [Table 8](#).

TREATMENT & PREVENTION OF POST-TRANSPLANT MALIGNANCIES

The literature lacks evidence on how many years of immunosuppression post-transplant increases the risk of cancer. Despite uncertainties, the literature consistently indicates that the overall duration and intensity of immunosuppression, rather than individual drugs in the immunosuppressive regimen, lead to an increased risk of cancer. [Table 9](#) describes treatment and prevention of post-transplant cancers.

SURVEILLANCE PROTOCOLS FOR POST-TRANSPLANT MALIGNANCY

Due to the rise in the risk of malignancy, monitoring organ recipients post-transplant is vital. Current data suggest that the liver is an immunologically favorable organ and immunosuppression withdrawal is reported in selected patients who underwent liver transplantation (*i.e.* up to 40% of adults and 60% of pediatric liver recipients)[116]. As data have not been specified in most clinical studies, the usefulness of immunosuppression withdrawal in carefully selected liver transplant recipients has not demonstrated a significant clinical benefit on *de novo* malignancies post-transplantation[116]. Hence, there is risk of carcinogenesis. The surveillance protocol is provided in [Table 10](#).

Table 7 Viral infections post-transplant (associated with the potential to develop a malignancy): Screening, diagnosis, and treatment

Post-transplant virus infections	Screening	Diagnosis	Treatment
HPV anogenital/cutaneous manifestation[28,161]	All 9–26-yr: Before transplant, receive 3 doses of HPV vaccine [nine-valent or quadrivalent vaccine (Gardasil 9 or Gardasil; Merck, Whitehouse Station, New Jersey)] or HPV-bivalent vaccine (Cervarix; GlaxoSmithKline, Rixensart, Belgium) in women	Examination and biopsy of atypical lesions	Cutaneous warts: Topicals (patient applied): Salicylic/lactic acid/imiquimod or cryotherapy (provider-applied)
	Males and females (up to age 45 yr): May also be vaccinated with 3 doses of HPV vaccine (nine-valent)	Anogenital, perianal warts/history of receptive anal intercourse warts: colposcopy/anoscopy	Anogenital warts: topicals (patient applied): podofilox/5% imiquimod cream or cryotherapy/TCA/BCA/podophyllin resin (provider-applied)
	Organ recipient's (15–26 yr): Immunize even if they have anogenital warts		Not responding or extensive or resistant warts: refer to dermatologist
	At each visit: bright light skin examination (including feet)		
	Cervical pap smear (with or without HPV PCR co-test): Every 6 mo in first year and then yearly, post-transplant, in females (> 30 yr), irrespective of HPV vaccination status		
	If rejection treated with T cell depleting agents, resume above schedule		
	Follow in all females irrespective of HPV vaccination status		
EBV viremia/disease	Identify high risk recipients (<i>i.e.</i> EBV D+/R-): EBV viral load once first week, monthly first 3–6 mo, and every 3 mo until the end of the first post-transplant year; Additionally, after treatment of acute rejection[162]	Quantitative EBV load assay [calibrated to World Health Organization IS for EBV DNA] (EBV NAAT)	Reduce immunosuppression with rising EBV loads in EBV-seronegative patients
	EBV disease precedes detectable or rising EBV loads	Whole blood/lymphocyte samples are preferable to plasma (the EBV viral load is greater and becomes detectable sooner), thereby enhancing sensitivity and early detection/reactivation	
	Watch for signs/symptoms: fever, diarrhoea, lymphadenopathy, and allograft dysfunction	Same sample type, assay and laboratory for assessing rise in EBV loads	
HHV8 viremia	Post-transplantation, HHV8 serologic testing is not routinely recommended globally	Serological assays (IFA ELISA) which detect HHV8 antibodies against latent and lytic viral antigens (both)[163]: Issues with such assays are inadequate standardisation, variable sensitivity and specificity among tests (60%–100%), and poor agreement with a predefined reference standard. It is still preferable when compared with quantitative PCR in identifying “at risk” transplant patients in endemic regions	RIS if quantitative PCR elevated/rising and/or absent HHV8 antibodies in “at risk” post-transplant patient or with non-neoplastic KS diseases
	Identify “at risk” before transplant, for HHV8 related disease post-transplant, in endemic zone [<i>i.e.</i> R+ (HHV8 reactivation) and D+/R- (HHV8 primary infection)][163,164]	Serological assay which detect HHV8 DNA by quantitative PCR: Its role are: (1) Predicts the occurrence of non-neoplastic HHV8 related diseases (in HHV8 primary infections and high viral loads); (2) Detect active HHV8 replication; and And (3) monitor response to treatment in post-transplant patients with HHV8 related diseases Issue of serological assays in HHV8 diagnosis: Lack of any serological gold standard assay Direct detection of HHV8 (HHV8 immunohistochemical staining) from involved site is still gold standard for diagnosis	Strictly follow and monitor

Plasmacytic B-cell proliferation (HHV8 associated)[82]		Histopathological confirmation and HHV8 DNAemia confirms the diagnosis	
	Watch for SIS	Biopsy: Shows polyclonal HHV8 B-cell proliferations in lymph nodes/visceral organs	RIS
	Exclude mimickers of signs/symptoms	HHV8 viral load (quantitative PCR)	Rituximab
			Trial of antiviral
Bone marrow failure/HPS (HHV8 associated)[82,165]	Watch for fever, jaundice, severe pancytopenia, plasmacytosis, hepatosplenomegaly, SIS, rash (maculopapular)	Biopsy confirmation of HHV8 in bone marrow/lesions	RIS
	Exclude mimickers of signs/symptoms	HHV8 viral load (quantitative PCR)	Rituximab
			Trial of antiviral
Hepatitis (HHV8 associated)	Elevated liver enzymes, SIS, rash (maculopapular).	HHV8 viral load (quantitative PCR)	RIS
	Exclude mimickers of signs/symptoms	Biopsy confirmation of lesion/organ affected	Trial of antivirals

NAAT: Nucleic acid amplification test; RIS: Reduction in immunosuppression; IFA: Indirect immunofluorescence assay; ELISA: Enzyme-linked immunosorbent assay; PCR: Polymerase chain reaction; IHC: Immunohistochemical staining; TCA: Trichloroacetic acid; BCA: Bichloroacetic acid; SIS: Systemic inflammatory symptoms; HPS: Hemophagocytic syndrome; HPV: Human papilloma virus; HHV8: Human herpes virus 8; EBV: Epstein-Barr virus; IS: International Standard.

Table 8 Post-transplant virus associated malignancy and their diagnosis

Post-transplant viral associated malignancy	Diagnosis
CIN and cervical cancer and (HPV- associated)	Abnormal cervical Pap test/cytology on screening: Colposcopy biopsy of any suspicious lesion[28,161]
AIN and anal cancer (HPV-associated)	Abnormal anal Pap test/cytology on screening: High-resolution anoscopy ± biopsy of any suspicious lesion[28,161]
EBV associated PTLD	Identify “B” symptoms (fever, night sweats and weight-loss) Excision biopsy/core biopsy (in allograft PTLD as excision is not practical) is gold standard for diagnosis[46] Stage PTLD with CT imaging of the chest, abdomen, and pelvis, as well as MRI brain imaging before initiating treatment as in immunocompetent host[166] PET-CT may help in diagnosing occult PTLD, accurate staging in occult cases and sometime evaluating treatment response[167-169]
PT-KS	Examine for cutaneous or mucosal lesions, visceral involvement and haematological manifestations Diagnostic gold standard: HHV8 confirmation in biopsy of KS lesions[170] HPE characteristic of PT-KS: Spindle-shaped cells and immunostaining confirmation with latency-associated nuclear antigen and CD34 positive staining[171,172] Quantitative PCR load of HHV8: Role in supporting diagnosis and monitoring treatment response Confirmation of diagnosis by HPE and HHV8 DNAemia Depending on site involved, disease staging by imaging and invasive procedures (<i>e.g.</i> , bronchoscopy, esophago-gastroduodenoscopy, colonoscopy)[173]
MCD	Watch for lymph node enlargement, systemic inflammatory symptoms Gold standard for diagnosis: Lymphnode biopsy confirmation of HHV8[170] HPE: HHV8+ plasmablasts in follicular mantle zone and vascular hyperplasia Quantitative PCR load of HHV8: Role in supporting diagnosis and monitoring treatment response Confirmation of diagnosis by HPE and HHV8 DNAemia
PEL	Watch for effusion (pleural, peritoneal, pericardial)

Gold standard: Confirmation of HHV8 in pleural/ascitic fluid[170]

HPE characteristic: HHV8+ plasmablasts displaying immunoblastic and anaplastic characteristics

Quantitative PCR load of HHV8: Role in supporting diagnosis and monitoring treatment response

Confirmation of diagnosis by HPE and HHV8 DNAemia

CIN: Cervical intraepithelial neoplasia; HPV: Human papilloma virus; AIN: Anal intraepithelial neoplasia; MCD: Multicentric Castleman disease; PTLD: Post-transplant lymphoproliferative disorders; CT: Computed tomography; MRI: Magnetic resonance imaging; PET-CT: Positron emission tomography-computerized tomography; PCR: Polymerase chain reaction; PEL: Primary effusion lymphoma; PT-KS: Post-transplant Kaposi's sarcoma; HHV8: Human herpes virus 8; HPE: Histopathology examination; EBV: Epstein-Barr virus.

Table 9 Post-transplant malignancies: treatment and prevention

Post-transplant malignancy	Treatment	Prevention
CIN (HPV-associated)[28,161]	Loop electrosurgical excision procedure/cryotherapy/cold knife conization of the lesion	Vaccination as mentioned in Table 3 (screening of HPV)
Cervical cancer (HPV-associated)[28,161]	Microinvasive disease (< 3 mm): conization[174] Up to stage IIA: Chemoradiation[175] Locally advanced: Chemoradiation[176] Metastatic: Chemoradiation (palliation and symptoms alleviation)[177]	Known previous history: Assess for anogenital lesion for cervical/anal lesions prior to transplant Recommend condom use During laser surgery for HPV lesions, cover skin surface, mask and eye protection to prevent reimplantation of virus in electrocautery fumes
AIN (HPV-associated)[28,161]	AIN I (< 1 cm ² at base): Topical 80% TCA[178]/5-fluorouracil[179] or cryotherapy Larger size AIN I, AIN II and III: Infrared coagulation[180,181] or fulguration (anoscopy guided)[181]	
Anal and penile cancer (HPV-associated)[28,161]	Invasive anal carcinoma: Combined-modality therapy [radiotherapy and chemotherapy (5-fluorouracil and mitomycin/cisplatin)][182] Penile cancer: Surgical resection ± chemotherapy (as per stage in immunocompetent)	
PTLD[183]	Differentiate allograft dysfunction from PTLD, before initiating treatment using allograft biopsy RIS: Preferred pre-emptive intervention. Adjust to lowest tolerated immunosuppression, may switch to mTOR inhibitor. Lack of sufficient evidence to suggest any specific RIS protocol or switching to mTOR inhibitor Rituximab monotherapy for progressive disease following RIS and CD20+ PTLD Cytotoxic chemotherapy if progression after rituximab and RIS. R-CHOP 21 regimen: Four sequential cycles of rituximab/ cyclophosphamide, doxorubicin, oncovin, and prednisone every 3 wk[184,185] Children with EBV + PTLD: the low-dose cyclophosphamide and prednisone regimen plus rituximab [186]. CD20- Tcell PTLD, B cell, Burkitt and Hodgkin's lymphoma: same chemotherapy regimen as immunocompetent host CNS PTLD: Chemotherapy regimens are same as used to treat primary CNS lymphoma (PCNSL) in general population/ immunocompetent individuals [187,188]. Regimen with systemic rituximab, dexamethasone and antivirals, if unable to tolerate chemotherapy or disease occurring early post-transplant Start pneumocystis jirovecii prophylaxis: If PTLD treatment administered beyond RIS	EBV viral load surveillance (for EBV D+/R-) as mentioned in screening of EBV Patients (EBV D+/R-) with fluctuating immunosuppression, episodes of rejection, or who have not established a viral "set point" will be monitored for a period beyond the first year EBV viral loads becomes positive 4 to 16 wk prior to development of PTLD[189] Monitor viral load in EBV seropositive recipients in re-transplantation after PTLD
KS	RIS (30% complete remission in few reports)[190]	Pre transplant "at risk" in endemic areas (D+/R- or R+ HHV8 status): Frequent viral load monitoring for 3–6 months and physical examination of skin and mucosal surfaces as a routine, post-transplant

	Switch to mTOR if using CNI (mTOR inhibitor is antiangiogenic, inhibit viral replication pathways)[191,192] and helps recovery of HHV-8-specific cytotoxic T cells[78,82]	RIS if viral loads rising while monitoring and switching to mTOR inhibitors early
	Antivirals (ganciclovir, foscarnet, cidofovir): Not routinely used, as <i>in vivo</i> efficacy is not demonstrated	
	If no response or relapse after above: Oncology consultation and chemotherapy (CHT) (L-anthracyclines)	
	If single skin lesion: Surgical excision or intralesional electrocautery or intralesional chemotherapy can be considered	
MCD	RIS (limited evidence) and/or switch to mTOR from CNI (if possible)	
	Rituximab[193]	
	If aggressive disease, no response/relapse: chemotherapy [R-CHOP/R-CVP (rituximab- cyclophosphamide, doxorubicin, vincristine, prednisone)][82]	
PCL	Primary therapy is CHT [cyclophosphamide, doxorubicin, vincristine, prednisone(CHOP)][194]	
	RIS (limited evidence)	
	If CHT contraindicated/no response or relapse: Intracavitary antivirals(cidofovir)[82]	

CNS: Central nervous system; CHT: Chemotherapy; MCD: Multicentric Castleman disease; RIS: Reduction in immunosuppression; CIN: Cervical intraepithelial neoplasia; HPV: Human papilloma virus; PTLT: Post-transplant lymphoproliferative disorders; EBV: Epstein-Barr virus; KS: Kaposi's sarcoma; CNI: Calcineurin inhibitor.

AI

Principle

Immunosuppression increases the chance of opportunistic infections in the post-transplant period. Limitations of current pharmacological treatment of viral infections in organ recipients include cost, antiviral toxicity, their variable efficacy and even resistance[117]. Most importantly, pharmacotherapies does not aid in pathogen-specific immune reconstitution, and the repeated risk persists after successful cure or eradication of virus. CMV is one potential example of such a pattern [118].

Spiess *et al*[119] first described the efficacy of AI in murine tumors in 1987, and later demonstrating objective tumor response in metastatic melanoma patients[120].

AI uses pathogen/virus-specific T cells to quickly restore immune responses to infectious pathogens/viruses in organ recipients. Apart from eliciting virus-specific cytotoxic responses, AI has specific advantage over pharmacotherapy by establishing long-term T-cell memory and may help preventing recurrent infections and protects against the organ toxicity/myelosuppression associated with some antivirals.

AI has been explored post-HSCT for CMV, EBV and adenovirus and has weak evidence in SOT. Advancement in immunological techniques has minimized alloreactivity and maximized cytotoxicity with AI, thereby, yielding a targeted approach with good safety profile[121-125].

Likely indications of AI

In EBV-positive PTLT: (1) Failed standard therapy with RIS, rituximab, chemotherapy, and/or radiotherapy[126]; and (2) children failed with RIS and rituximab therapy[127]. Delayed response with AI in such cases is possible due to previous use of rituximab.

In CMV: Refractory and resistant CMV[128-132].

Above indications are inferred from partial/complete response in certain subsets of patients post-transplant after AI therapy when searched within the literature.

Technique of AI

Figure 3 illustrates the steps, isolation, and diverse forms of AI[133-137].

Outcomes of AI

AI has been investigated more in HSCT compared to SOT. Most data have come from the variable success of AI in EBV + PTLT disease. Use of AI in CMV disease is sparse and limited to a few cases in SOT. AI needs more evaluation in controlled trials.

Concerns for the widespread use of AI include limitations such as the need for specialized facilities and a specific time to generate, high costs, questionable durability, long-term overall efficacy and safety, the potential for alloreactivity, and reduced ability to mount adequate response with ongoing immunosuppression.

Table 10 Post-transplant malignancy: surveillance protocols[30]

Cancer	Post-transplant surveillance
Skin	Self-skin examination monthly; examination by dermatologist: 6 to 12 monthly[162] (expert opinion)
PTLD (EBV+)	Routine screening of EBV D+/R- by EBV NAAT: once first week, monthly for next 3–6 mo, and every 3 mo till 1 yr after transplantation [162] (expert opinion)
Cervical	Age 25–74 yr: yearly cervical Pap test and pelvic examination[195]; in higher risk category, more frequent Pap test
Hepatocellular	Every 6 mo screening with USG ± α -fetoprotein in high risk (<i>i.e.</i> with cirrhosis) (extrapolation from general population)
Renal	USG screen every 6–12 mo in high risk (<i>i.e.</i> acquired cystic kidney)[196]
Breast	Females < 50 yr: individual decision when to start screening; Females 50–74 yr: every 2 yr screening mammography[197]; [extrapolation from immunocompetent (general) population]
Prostate	Men 55–69 yr: individualized screening approach after discussing potential benefits and harm; Men > 70 yr, avoid routine screening[198] [extrapolation from immunocompetent (general) population]
Bowel	All 45–75 yr: stool immunochemical testing every 2 yr, 5-yearly FEGD and sigmoidoscopy, or 5–10-yearly colonoscopy[199]
Lung	All 55–79 yr who have smoked 1 pack/day for 30 yr or its equivalent (2 packs/day for 15 yr, 3 packs/day 10 yr): yearly low dose CT chest [200] [extrapolation from immunocompetent (general) population]

PTLD: Post-transplant lymphoproliferative disorders; EBV: Epstein–Barr virus; NAAT: Nucleic acid amplification test; USG: Ultrasonography; FEGD: Fibreoptic esophago-gastroduodenoscopy; CT: Computed tomography.

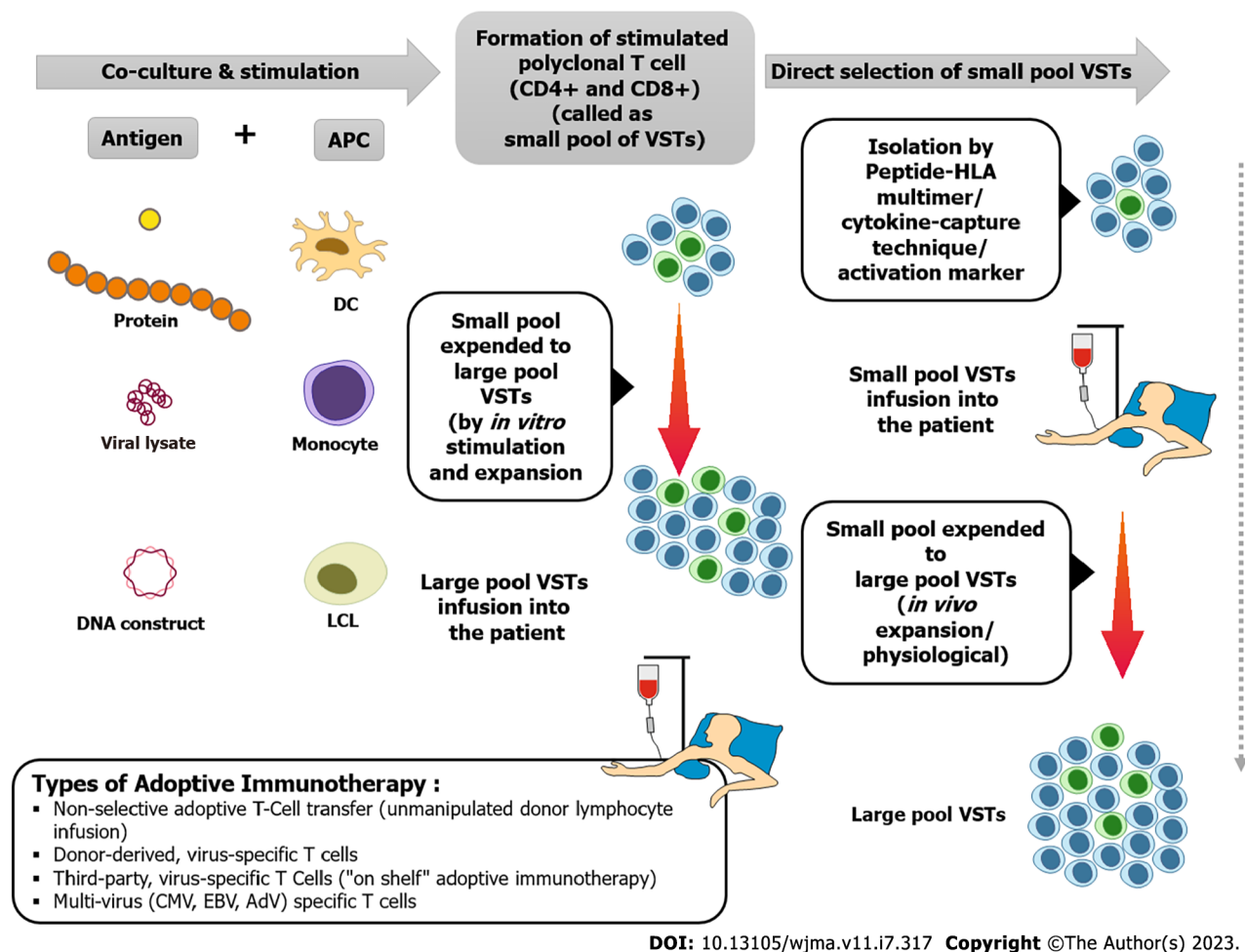


Figure 3 Technique of adoptive immunotherapy (steps, isolation and types of virus-specific T cells). Adv: Adenovirus; APC: Antigen presenting cells; CMV: Cytomegalovirus; DC: Dendritic cells; EBV: Epstein–Barr virus; HLA: Human leukocyte antigen; LCL: Lymphoblastoid cell lines; VSTs: Virus-specific T cells.

FACTORS INFLUENCING THE WAITING PERIOD FOR RE-TRANSPLANTATION AFTER SUCCESSFUL TREATMENT OF THESE MALIGNANCIES

Achievement of complete remission (clinically and radiologically); sustained disease-free status for at least 12–24 mo; presence of seroconversion (virus-specific IgG antibodies); graft nephrectomy in cases of allograft PTLN; and absent or undetectable viral loads after successful treatment of malignancy[50,138,139].

CONCLUSION

Post-transplant malignancy is a considerable risk and cause of significant morbidity and mortality in organ recipients. Strategically reducing immunosuppression is an important step in the management of post-transplant virus-related cancers. Evidence for prevention, treatment and surveillance in post-transplant viral infections and malignancy are extrapolated from findings in the general population. A multidisciplinary team is vital for successful outcome. An individualized approach is the most effective method and treatment to eradicate or cure might not be the ultimate goal in all cases. AI is currently at an initial stage and has inherent logistic problems. Wait time for re-transplantation following the successful treatment of cancer should be assessed on an individual case basis, taking due consideration of the risks associated with renal replacement therapies. Collaborative efforts among all those engaged in the care of post-transplant patients, observing more extensive care studies and multicenter interventional trials, can enrich the evidence base and long-term, quality care of organ recipients.

FOOTNOTES

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