# Molecular Insights in Transmission of Cancer From an Organ Donor to Four Transplant Recipients

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## ABSTRACT

Organ donors are systematically screened for infection, whereas screening for malignancy is less rigorous. The true incidence of donor-transmitted malignancies is unknown due to a lack of universal tumor testing in the posttransplant setting. Donor-transmitted malignancy may occur even when not suspected based on donor or recipient factors, including age and time to cancer diagnosis. We describe the detection of a gastrointestinal adenocarcinoma transmitted from a young donor to 4 transplant recipients. Multidimensional histopathologic and genomic profiling showed a *CDH1* mutation and *MET* amplification, consistent with gastric origin. At the time of writing, one patient in this series remains alive and without evidence of cancer after prompt organ explant after cancer was reported in other recipients. Because identification of a donor-derived malignancy changes management, our recommendation is to routinely perform short tandem repeat testing (or a comparable assay) immediately upon diagnosis of cancer in any organ transplant recipient. Routine testing for a donor-origin cancer and centralized reporting of outcomes are necessary to establish a robust evidence base for the future development of clinical practice guidelines.

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## Background

Reporting on transmission of HIV and hepatitis C virus from an organ donor to transplant recipients[1] spurred the uptake of routine nucleic acid testing on organ donor sera,[2] leading to a significant decline in viral transmission. Increased awareness among oncologists is needed to address the equally important risk of malignancy transmission. The first step is to better define the scope of the problem while optimizing management for patients who do develop donor-transmitted cancers. Donor-transmitted malignancy was first recognized ≥50 years ago.[3,4] Early case series were informative yet mostly descriptive because they lacked a denominator.[5–7] With the creation of national databases, recent estimates put the risk of cancer transmission at between 0.01% and 0.05% per solid organ transplant.[8,9] This risk may be increasing along with donor age and obesity. Meanwhile, there is an ongoing concern for underreporting—and importantly, underdetection—because the etiology of cancer in an organ recipient is not routinely investigated unless donor origin is suspected.[10,11]

Others have described cancer transmission to 4 allograft recipients, although molecular profiling was not previously emphasized.[12,13] Matser et al[13] recently documented transmission of occult breast cancer to 4 recipients, 16 months to 6 years after transplantation. Donor-transmitted melanoma has been reported as late as 32 years after a donor had a melanoma excised.[14] Similar patients with donor-transmitted malignancy with long latent periods are likely missed in the absence of universal testing, following the assumption that metastatic cancer has originated in cells of the immunosuppressed host. Notably, there are 3 main categories of cancers that can develop in an organ transplant recipient: donor-transmitted cancers, in which cancerous


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cells are transferred from the donor to the recipient(s) at the time of organ transplantation; a broader category of donor-origin or donor-derived cancers, which includes cancers that arise in donor cells after transplantation; and recipient-origin cancers. Although the latter category—cancer that originates in the recipient's own cells—is the most common (and notoriously difficult to treat), both forms of donor-derived cancers have important therapeutic implications. Reduction of immunosuppression and organ explant, with or without checkpoint immunotherapy, can result in host alloimmune clearance of the malignant cells and an opportunity for retransplant. Thus, it is crucial to determine whether a cancer is donor-derived—both for the individual patient and/or for other organ recipients with the same donor in the case of a donor-transmitted malignancy. We highlight analysis of short tandem repeats (STRs) of microsatellites (units of repeated nucleotides) at polymorphic loci as one method of distringuishing between donor and recipient DNA profiles to diagnose donor-derived cancer, which may profoundly impact clinical management and chances for survival.[15]

## Case Presentations

### Organ Donor

The donor was an overweight man aged 34 years with multiple psychiatric diagnoses who was nonverbal and living in a group home. Cause of death was recorded as anoxia secondary to cardiac arrest, attributed to extensive polypharmacy and recent medication changes. The patient was in asystole when medics arrived; return of spontaneous circulation was achieved, he was intubated, and a hypothermia protocol was initiated. He had no known personal or family history of cancer. Extensive laboratory testing and imaging, including a chest radiograph and an abdominal ultrasound, did not uncover contraindications to organ donation (supplemental eTables 1 and 2, available with this article at JNCCN.org). He met brain death criteria after 4 days, with organ recovery 41 hours later. Organs were distributed to 4 recipients.

### Heart Recipient

The recipient of the heart was a man aged 69 years with ischemic cardiomyopathy. On posttransplant day (PTD) 131, he was diagnosed with cancer in the setting of acute graft rejection. As of March 22, 2019, the United Network for Organ Sharing (UNOS) Organ Procurement and Transplantation Network (OPTN) database listed the malignancy as adenocarcinoma (not otherwise specified) and donor-related status as unknown. He was reported to have died of cancer on PTD 143.

### Liver Recipient

The recipient of the liver was a man aged 54 years with alcoholic cirrhosis. On PTD 140, he developed acute elevation of liver function enzymes. A liver biopsy showed cholestasis and pericholangitis. Abdominal ultrasound, magnetic resonance cholangiopancreatography, and chest radiograph were negative for malignancy. On PTD 184, he underwent repeat orthotopic liver transplantation for presumed ischemic cholangiopathy. Adenocarcinoma was discovered in the liver explant (Figure 1A). PET and CT scans completed 242 days after the initial transplant (58 days after cancer diagnosis) revealed multiple hypermetabolic foci compatible in appearance with post-transplant lymphoproliferative disease (PTLD) (Figure 2A, B). On PTD 247 the patient required a pericardiectomy, and the pericardial fluid was shown to contain adenocarcinoma. He remained on tacrolimus and prednisone, but mycophenolate was discontinued. Due to his declining performance status, chemotherapy was never initiated and he died on PTD 293.

### Left Kidney Recipient

The recipient of the left kidney was a man aged 63 years with a history of multifocal urothelial carcinoma in situ, status post bilateral nephroureterectomy and cystoprostatectomy with ileal conduit urinary diversion. On PTD 143, he was admitted for anorexia, emesis, abdominal pain, distention, diarrhea, and malaise. CT imaging showed multifocal metastatic disease (Figure 2C, D) and cytology yielded adenocarcinoma (Figure 1B). Immunosuppression was withdrawn and hemodialysis was resumed. Capecitabine was initiated on PTD 186. Over the next few months, the patient's CA 19-9 tumor marker dropped from 5,568 to 201 units per milliliter. However, on PTD 256, CT scans revealed new spinal metastases, confirmed to be adenocarcinoma. He received spinal radiation, and then capecitabine was restarted. The patient subsequently developed an erythematous rash to the left thigh and scrotal edema. Biopsy of the rash on PTD 668 again showed adenocarcinoma. Capecitabine was stopped. On PTD 725, he underwent transplant nephrectomy, revealing antibody-mediated rejection with significant chronic changes but without evidence of acute cellular rejection or malignancy. The rash persisted with posterior spread. Pembrolizumab was initiated on PTD 751 but did not immediately improve symptoms of anorexia, emesis, diffuse pain, and dizziness. Before response assessment, the patient died on PTD 812 of uncertain causes. An autopsy was not performed.

### Right Kidney and Pancreas Recipient

The recipient of the right kidney and pancreas was a women aged 41 years with end-stage renal disease secondary to type 1 diabetes mellitus. On PTD 151, she had

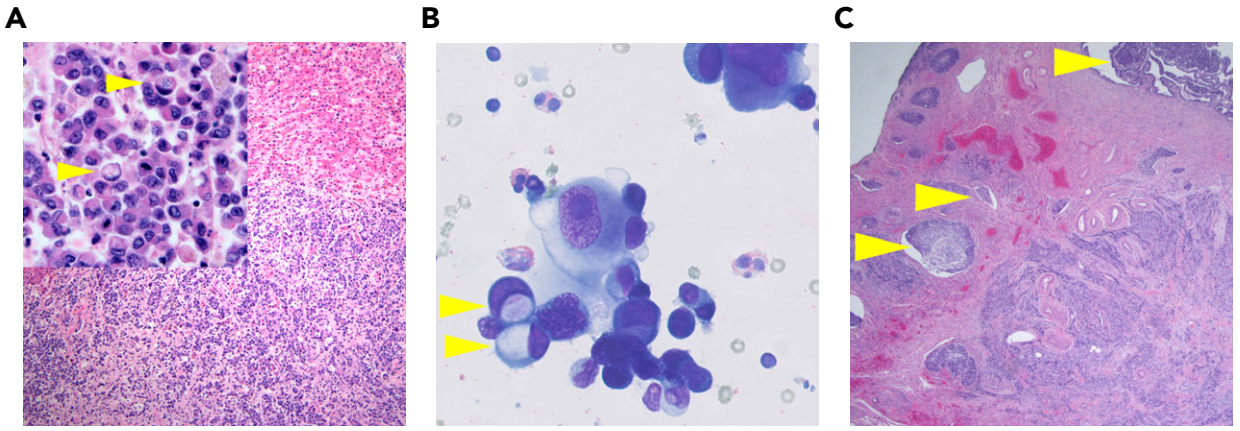


**Figure 1.** Histopathologic features of donor-transmitted cancer in 3 organ recipients. (A) Liver recipient: hematoxylin-eosin (H&E) stain of liver explant exhibiting poorly differentiated adenocarcinoma with signet ring cells (arrows) (original magnifications ×10 and ×40 [inset]). Metastatic adenocarcinoma was also present in 2 of 2 lymph nodes. (B) Left kidney recipient: pleural fluid cytology containing adenocarcinoma cells with intracytoplasmic vacuoles in signet ring cells (arrows) (original magnification ×100). Similar cells were found in ascites fluid and on liver, bone, and skin biopsy. (C) Right kidney/pancreas recipient: H&E stain of right adnexal resection with poorly differentiated carcinoma showing extensive lymphovascular invasion (arrows) in ovary and fallopian tube (original magnification ×2). Graft nephrectomy and graft pancreatectomy showed poorly differentiated adenocarcinoma, including scattered cells displaying signet ring morphology, in the pancreas with spread to peripancreatic lymph nodes, small intestine, and omentum. No tumor was present in the explanted kidney or ureter.

an episode of graft pancreatitis with at least grade II cell-mediated rejection. A PET/CT scan performed on PTD 190, prompted by cancer diagnoses in other organ recipients from the same donor, revealed diffuse nodal and osseous hypermetabolism (Figure 2E, F). Similar to the left kidney recipient, this patient had elevated CA 19-9 and normal carcinoembryonic antigen levels. On PTD 195, she underwent graft nephrectomy and graft pancreatectomy, with adenocarcinoma confirmed in the pathologic specimen (Figure 1C). After a prolonged hospital course, immunosuppression was withdrawn and dialysis was restarted. Chemotherapy was deferred to determine whether her immune system would reject the donor-transmitted cancer. On PTD 234 (39 days postexplant), a PET/CT scan showed marked interval improvement in the previously described hypermetabolic lymph nodes. On PTD 732 (537 days postexplant), the patient had no evidence of recurrent cancer. She received a second deceased donor kidney transplant 749 days postexplant of the cancer-harboring organs. She was maintained on standard triple immunosuppression with prednisone, tacrolimus, and mycophenolate. One year later, she had no signs of malignancy.

## Methods

### Permissions

The University of California, San Francisco (UCSF) Institutional Review Board (IRB) approved the review of records (approval number 17-21991). Records pertaining to the donor and the heart recipient were obtained from the UNOS OPTN online database, UNet. The other 3 organ recipients provided individual research consent for chart review and molecular profiling (IRB number 13-12574).

### Genomic Studies

STR genotyping was performed using the AmpFlSTR Identifiler Kit from Applied Biosystems, followed by capillary electrophoresis. Tumor and germline DNA were subjected to next-generation sequencing (NGS) using the UCSF500 Cancer Gene Panel (from UCSF), which analyzes the exons of 479 genes and select introns of 47 genes. Target enrichment was performed by hybrid-capture (Roche NimbleGen) using custom oligonucleotides. Captured libraries were sequenced on an Illumina HiSeq 2500 in rapid-run mode. Sequence reads were deduplicated for accurate allele frequency determination and copy number calling. Filtering of common germline polymorphisms present in dbSNP, along with technology-specific sequencing artifacts, was performed before data analysis. A MET fluorescence in situ hybridization assay was used to detect *MET* amplification (Empire Genomics). Circulating tumor DNA (ctDNA) was analyzed using the FoundationACT Assay (Roche).

## Results

### Histopathologic Characterization

Tumors in the liver, left kidney, and right kidney/pancreas recipients were all poorly differentiated adenocarcinoma with signet ring features (Figure 1). Tumor cells stained positive for CK7, CK20, and CDX-2 with

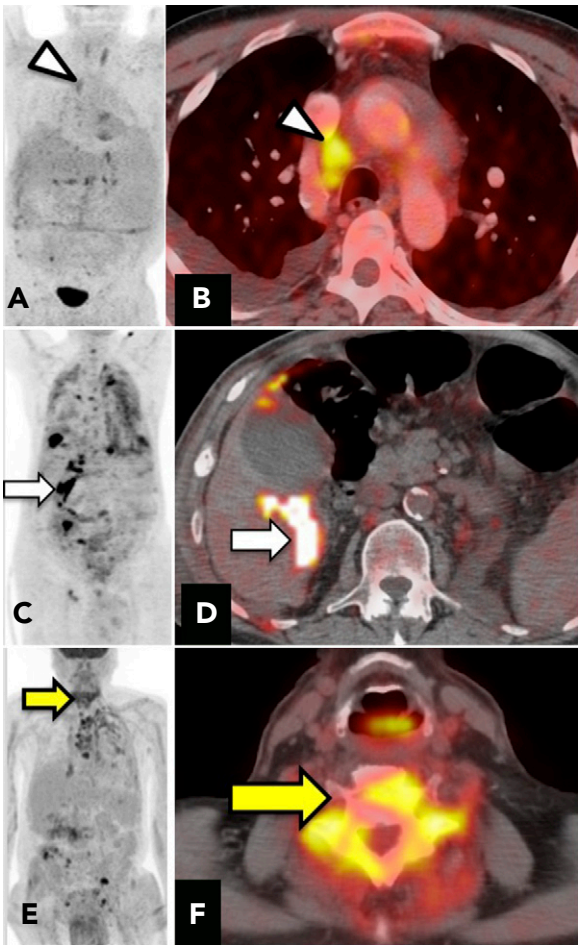


**Figure 2.** Patterns of metastasis on PET/CT imaging. (A) Liver recipient: PTD 242 imaging with hypermetabolic supraclavicular, mediastinal (B), and abdominal lymph nodes and foci in left femoral neck and right ilium. Imaging also visualized diffuse anasarca with pericardial and pleural effusions, hepatic congestion, and small ascites. (C) Left kidney recipient: PTD 154 imaging showing numerous hypermetabolic lesions in the bilateral pleura, right hilar lymph node, liver, peritoneum (D), and spine. (E) Right kidney/pancreas recipient: PTD 190 imaging with diffuse nodal fluorodeoxyglucose uptake involving the inguinal lymph nodes, right pleura, and extensive osseous disease including extensive uptake in the C7 vertebral body (F).
Abbreviation: PTD, posttransplant day.

intact DPC4, suggestive of an upper gastrointestinal primary. Staining was negative for breast, lung, gynecologic malignancy, and melanoma markers. Based on the immunohistochemical profile and consistent with the observed CA 19-9 elevation, the stomach and pancreas were considered the most probable organs of origin.

### Radiographic Appearance

PET/CT imaging of the liver, left kidney, and right kidney/pancreas recipients showed extensive hypermetabolic lymphadenopathy and bone involvement (Figure 2). The radiographic appearance was consistent with PTLD and uncharacteristic of a gastrointestinal primary. The liver and left kidney recipients both developed ascites and malignant pleural and/or pericardial effusions.

### Comparative Genomics

Donor tumor origin was established in the liver and the right kidney/pancreas recipients by STR testing (Figure 3A). In both patients, 15 of 15 STR loci were successfully amplified by PCR. The unknown tumor samples contained alleles from the tumor and admixed normal cells. The liver and the pancreas tumors showed high levels of donor alleles in 13 and 14 loci, respectively (the remaining loci were uninformative). HLA typing suggested that the tumor of the left kidney recipient was donor-transmitted. Two germline DNA samples from the right kidney/pancreas recipient, donor kidney, and recipient blood were also sequenced, with NGS thus reconfirming that the tumor specimen was donor-transmitted.

Tumor sequencing revealed a pathogenic somatic *CDH1* variant and *MET* amplification and the absence of a *KRAS* variant, characteristic of a gastric rather than a pancreatic primary. Notably, it was determined that the donor did not have hereditary diffuse gastric cancer, given the absence of a germline *CDH1* variant. Tumors from the liver and the right kidney/pancreas recipients were nearly identical based on pathogenic variants, allele frequency, and copy number variation (Figure 3B, Table 1). Insufficient tumor cellularity in all specimens from the left kidney recipient precluded UCSF500 profiling; however, clinical immunohistochemistry testing found that the cancer was mismatch-repair–proficient, HER2-equivocal, and PD-L1–positive. The left kidney and right kidney/pancreas recipients had blood samples sent for ctDNA testing at PTD 680 and PTD 684, respectively.[16,17] Interestingly, although *CDH1* and *MET* were both assessed and the left kidney recipient had known active cancer, neither ctDNA test uncovered any genomic alterations. *MET* amplification was subsequently shown in the tumor of the left kidney recipient using fluorescence in situ hybridization probes (Figure 3C).

## Discussion

Donor-transmitted cancer has been identified when not suspected due to long latency[13,14] or, in our series, a young, medically complicated donor and an older heart transplant recipient, underscoring the need to adhere to centralized reporting guidelines when cancer is diagnosed in an organ transplant recipient (supplemental eAppendix 1). In addition, we recommend universal testing for a donor-derived malignancy because early recognition has treatment implications. This parallels guidelines for universal mismatch repair/microsatellite instability

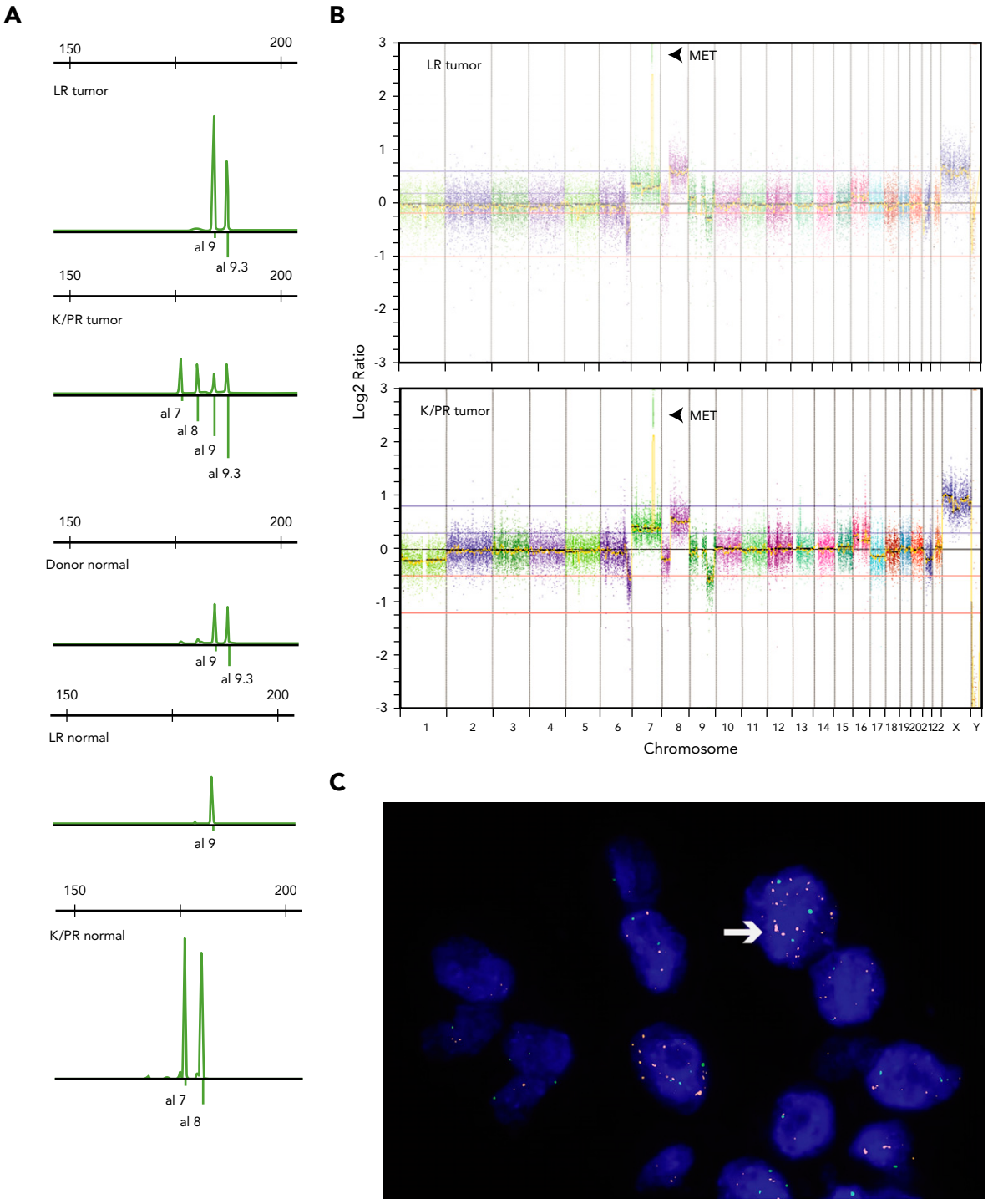


**Figure 3.** Comparative molecular profiling. (A) STR analysis of the TH01 marker (chromosome 11), indicating the STR alleles and fragment sizes in LR tumor specimen, K/PR tumor specimen, donor normal tissue, LR normal specimen, and K/PR normal specimen. (B) Copy number changes identified by NGS in tumors from the LR and the K/PR. (C) *MET* amplification on the left kidney recipients' tumor specimen, detected by fluorescence in situ hybridization. A probe at 7q11.1 (green) and a *MET* probe at 7q31.2 (orange) were used (original magnification ×100). The normal chromosome number is indicated by the green dots, and the *MET* amplification is identified by more orange dots (arrow). The nuclei are stained with 4′,6-diamidino-2-phenylindole.

Abbreviations: al, alleles; K/PR, right kidney/pancreas recipient; LR, liver recipient; NGS, next-generation sequencing; STR, short-tandem repeat.

**Table 1. Comparative Genomic Profiling**

| | Liver | Kidney/Pancreas |
|---|---|---|
| **Organ Recipient** | **Allele Frequency (%)** | |
| Pathogenic variants | | |
| *CDH1* p.Q23* | 29 | 25 |
| *CDH1* p.[W156L; N166K] | 40 | 39 |
| *RHOA* p.R5L | 34 | 29 |
| *ARID1A* p.G2087R | 60 | 56 |
| | **Copy Number Changes** | |
| *MET* amplification | Present | Present |
| Chromosomal copy number gains | 7, 8q, 16 | 7, 8q, 16 |
| Chromosomal copy number losses | 6q, 9q | 1, 6q, 8p, 9q, 17, 21, Y |

testing in several tumor types: although a minority of tumors are affected, the importance of a positive test result for patient management justifies routine testing. Although other methods can be used for molecular identity testing (eg, HLA typing and NGS as described herein), STR analysis is cost-efficient and time-efficient and produces easily interpretable results (supplemental eAppendix 2).[15]

With a donor-transmitted malignancy, the tissue type that gave rise to cancer, which is used to assign therapy, may be difficult to determine given the lack of a primary tumor and an atypical pattern of metastatic spread. Diagnostic clues may emerge from histopathology, serum tumor markers, and molecular profiling. For some patients, such as the heart and liver recipients, prognosis will remain poor due to the inability to remove the graft and cease immunosuppression. Nonetheless, prompt STR analysis (or a comparable assay) and reporting are crucial for notifying medical teams caring for other organ recipients with the same donor. Whenever feasible, immunosuppression should be reduced and organ explant considered. In some patients, as with the right kidney/pancreas recipient, this protocol is sufficient for immune clearance of the cancer.[13,18,19] Ability to reject the cancer correlates in part with the degree of HLA mismatch between the donor and the recipient.[14] In this case series, however, both the left kidney and right kidney/pancreas recipients were mismatched with the deceased donor on 6/6 HLAs, so the extent of the HLA mismatch does not explain the difference in outcomes between the 2 kidney recipients. If cancer persists, checkpoint inhibitor immunotherapy can be attempted, preferably after organ explant to prevent fulminant allograft rejection.[20,21] There is an increasing number of reports of favorable response to checkpoint inhibition.[21–25] We hypothesize that older age and delaying explant by >2 years may have impaired the ability of the left kidney recipient to respond to pembrolizumab.

## Conclusions

In an effort to improve patient safety, any diagnosis of malignancy in an organ transplant recipient should be centrally reported. Furthermore, STR analysis (or a comparable assay) should be standard immediately after cancer diagnosis to ascertain donor origin. Health policy implications of universal molecular identity testing are numerous. Enforcement of standardized testing and reporting will define the true incidence of donor-transmitted malignancies. This in turn will inform the need for prevention measures, which could include donor prescreening with more extensive imaging and/or ctDNA testing as the technology evolves to increase the rapidity and predictive value of results.[26] Protocols are warranted to ethically address the detection of a germline cancer–associated variant in donor tissues. Finally, systematically following patient outcomes is essential to define criteria for retransplant when a complete radiographic response is achieved.

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**Disclaimer:** This study used data from the Organ Procurement and Transplantation Network (OPTN). The OPTN data system includes data on all donor, waitlisted candidates, and transplant recipients in the United States, submitted by OPTN members. The Health Resources & Services Administration of the US Department of Health & Human Services provides oversight to the activities of the OPTN contractor.

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**eTable 1:** Organ Donor Evaluation
**eTable 2:** Laboratory Studies
**eAppendix 1:** Reporting a Cancer Diagnosed in an Organ Transplant Recipient
**eAppendix 2:** Ordering Short Tandem Repeat Testing

## eTable 1. Organ Donor Evaluation

| Evaluation | Finding |
|---|---|
| Body mass index | 38.1 kg/m$^2$ |
| Kidney donor profile index | 26% |
| Imaging | |
| EKG | Sinus rhythm with short PR; incomplete right bundle branch block; nonspecific T-wave abnormality. |
| Echocardiogram | Study is technically limited. Mild concentric LV hypertrophy is observed. There is normal LV systolic function (LV ejection fraction: 56%). Abnormal LV diastolic filling is observed, consistent with impaired relaxation. The right ventricular global systolic function is normal. There is mild tricuspid regurgitation. The inferior vena cava seems normal in size. |
| Chest radiograph | Low lung volumes. Basilar atelectasis, mild vascular congestion, and mild interstitial edema. Moderate pleural effusions bilaterally. Cardiac silhouette is normal. No mediastinal widening. No free air. Chest wall is normal. |
| Abdominal ultrasound | Liver enlarged, measuring 18 cm. Nonspecific heterogeneous echogenicity within it. Gallbladder shows no cholelithiasis. No evidence for pericholecystic fluid. Gallbladder wall thickness is 2.9 mm, which is within normal limits. Common duct measures 7.2 mm in diameter, which is mildly dilated. Pancreas is not well seen because of obscuration by overlying bowel gas. Right kidney measures 10.7 cm in length. No evidence for hydronephrosis. Left kidney is poorly visualized and not adequately evaluated because patient was intubated and could not be repositioned. Spleen has an obscured IVC and aorta is incompletely imaged and partially obscured. No aneurysmal dilatation of the visualized aorta shown. Impression is no cholelithiasis. Hepatomegaly with nonspecific heterogeneous echogenicity. |
| CT of brain without contrast | No intracranial hemorrhage or midline shift. Questionable subtle loss of gray-white matter differentiation. Findings may represent subtle anoxic brain injury. |
| Electroencephalogram | Unreactive suppressed background rhythm with no significant epileptogenic potentials or electrographic seizures noted. Photic stimulation performed because activating procedures not associated with any significant abnormalities. Abnormal-electrocerebral silence, consistent with brain death. |
| MRI of brain without contrast | Diffuse cerebral edema most consistent with hypoxic ischemic encephalopathy. Effacement of basilar cisterns concerning for descending transtentorial herniation. Additional cerebellar tonsillar herniation. |

Abbreviations: EKG, electrocardiogram; IVC, inferior vena cava; LV, left ventricular.

## eTable 2. Laboratory Studies

| | |
|---|---|
| Sodium (mEq/L): 148 | Total bilirubin (mg/dL): 0.6 |
| Potassium (mmol/L): 3.3 | Alanine aminotransferase (U/L): 31 |
| Chloride (mmol/L): 115 | Aspartate aminotransferase (U/L): 23 |
| $CO_2$ (mmol/L): 25 | Alkaline phosphatase (U/L): 354 |
| Blood urea nitrogen (mg/dL): 20 | Albumin (g/dL): 2.3 |
| Creatinine (mg/dL): 1.24 | Total protein (g/dL): 6.5 |
| Glucose (mg/dL): 238 | Lactate dehydrogenase (U/L): 375 |
| Hemoglobin A1c (%): 5.8% | International normalized ratio: 1.2 |
| Creatine kinase (U/L): 513 | Prothrombin (sec): 15.6 |
| Creatine kinase MB (ng/mL): 6.7 | Partial thromboplastin time (sec): 40.5 |
| Troponin I (ng/mL): 0.57 | Serum amylase (U/L): 21 |
| HLA: Class I, Bw6 positive | Serum lipase (U/L): 10 |
| Toxicology screen negative for amphetamines, barbiturates, benzodiazepines, cocaine, methadone, opiates, PCP; positive for cannabinoid | Urinalysis: pH 5.5, SG 1.03, protein trace, negative glucose, negative blood, negative leukocyte esterase |
| Infectious diseases: negative for anti-HBcAb, hepatitis B virus NAT, HBsAg, anti–hepatitis C virus, hepatitis C virus NAT, anti–HIV I/II, HIV NAT, anti–human T-lymphotropic virus 1/2, anti-cytomegalovirus, syphilis, Epstein-Barr virus (VCA) IgM; positive for Epstein-Barr virus (VCA) IgG | Microbiology: blood cultures negative; bronchoscopy with many budding yeast; urine culture pending |

Abbreviations: Bw6, HLA epitope Bw6; HBcAb, hepatitis B core antibody; HBsAg, hepatitis B surface antigen; NAT, nucleic acid testing; SG, specific gravity; VCA, viral capsid antigen.

## eAppendix 1. Reporting a Cancer Diagnosed in an Organ Transplant Recipient

Promptly communicate the finding to the transplant center patient safety contact and/or your local organ procurement organization (OPO).[1] The OPO representative will record any reported cancer diagnosis on the transplant recipient follow-up form. Transplant recipient follow-up forms from other organ recipients with the same donor may be reviewed. Potential donor-derived disease transmission event (PDDTE) reports are entered into the Organ Procurement and Transplantation Network (OPTN) Improving Patient Safety portal. Reporting is recommended even if one is unsure whether a specific situation constitutes a PDDTE, in an effort to promote patient safety. It is the OPO's responsibility to notify recipient transplant programs of a suspected PDDTE. Additional guidance related to reporting a PDDTE is provided by the OPTN Disease Transmission Advisory Committee.[2]

## eAppendix 2. Ordering Short Tandem Repeat Testing

Information on ordering specimen identity testing, as assessed by genotyping STRs, can be found on the University of California, San Francisco Health Center for Clinical Genetics and Genomics website.[3] This specimen identity test uses a DNA identification kit called the AmpFlSTR Identifiler kit (Applied Biosystems) that genotypes 15 different STR loci. Regarding tissue requirements, if slide macrodissection is required, then the tissues of interest should be a minimum of 0.3 cm in diameter. If tissue can be removed directly from a tissue block, or if no macrodissection is needed, then it may be possible to test smaller areas. Comparison of the alleles at each STR locus between $\geq$2 samples is used to determine if the samples come from genetically identical or different individuals. To use STR testing for ascertainment of tumor origin in an organ transplant recipient, the following specimens should be analyzed: tumor, donor normal tissue, and recipient normal tissue.

### References

1. Health Resources & Services Administration, U.S. Government Information on Organ Donation and Transplantation. Find your Local Organ Procurement Organization. Accessed July 29, 2020. Available at: https://www.organdonor.gov/awareness/organizations/local-opo.html
2. Organ Procurement and Transplantation Network and United Network for Organ Sharing. Guidance for Reporting Potential Donor-Derived Disease Transmission Events (PDDTE). Accessed July 29, 2020. Available at: https://unos.org/wp-content/uploads/unos/Guidance_DTAC_PDDTE_06-2011.pdf
3. UCSF Health Center for Clinical Genetics and Genomics. Specimen Identity. Accessed July 29, 2020. Available at: https://genomics.ucsf.edu/content/specimen-identity