Solid Organ Donation and Transplantation
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Medical imaging plays a key role in solid organ donation and transplantation. In addition to confirming the clinical diagnosis of brain death, imaging examinations are used to assess potential organ donors and recipients, evaluate donated organs, and monitor transplantation outcomes. This article introduces the history, biology, ethics, and institutions of organ donation and transplantation medicine. The article also discusses current and emerging imaging applications in the transplantation field and the controversial role of neuroimaging to confirm clinically diagnosed brain death.

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After completing this article, the reader should be able to:
- Describe the evolution of solid organ transplant medicine over the past century.
- Explain the solid organ donation and transplantation process and eligibility criteria for donors and recipients.
- Discuss the clinical diagnosis of brain death and imaging criteria for confirmation of brain death diagnoses.
- Discuss the roles and applications of medical imaging in solid organ transplant medicine.
- Summarize potential adverse events following transplantation.

Thousands of Americans die each year awaiting donated hearts, lungs, kidneys, and pancreata—victims of shortages in donated organs. Because organ degradation begins soon after brain death, even in the presence of a heartbeat, the central paradox of organ transplantation medicine has been described as “the need for both a living body and a dead donor.”

In the 1970s, the legal definition of death was expanded to include the irreversible cessation of all cerebral and brainstem function including an absence of electrical activity and blood flow in the brain, and an absence of brain function as determined by clinical assessment and imaging data. Thus, imaging techniques were adopted during this time to confirm clinical diagnoses of brain death. These examinations have become widely used, but the evidence for their accuracy is not conclusive, and brain death imaging remains a controversial practice.

Nevertheless, medical imaging has important roles in organ donation and transplantation. In addition to confirming a clinical diagnosis of brain death in the donor, imaging also is used to assess organ condition, potential organ donors and transplant recipients, the success of transplantation, and any signs of organ rejection or infection.

This article reviews the many roles of medical imaging in organ donation and transplantation. Bone marrow, pancreatic islet and cornea transplantation, coronary arterial grafts, and blood transfusion are not described.

Solid Organ Transplantation

On any given day in the United States, approximately 120,000 people await life-saving organ donations (see Table). A new candidate is added to the national transplant waiting list every 10 minutes. According to the Organ Procurement and Transplantation Network (OPTN), on average 22 people die each day waiting for a transplant. However, the total number of candidates who die before
receiving a donated organ might be underestimated because individuals who become too ill to benefit from transplantation are removed from waiting lists.

Even as transplantation success rates improve, growing numbers of patients die while awaiting organs from genetically matched donors. Demand for donated organs increasingly outpaces supply. For example, OPTN reported that in 2015 only 30,975 transplants were performed while there were 122,071 transplantation candidates waiting at year end.3

The shortage in organ donations has led to the use of donor and transplantation methods that can help potential recipients who might otherwise die waiting. For example, living donors are supplying more kidneys; however, it is important to note that only 5,628 of the 17,878 kidney transplants performed in the United States in 2015 came from living donors.3 The use of marginal-quality kidneys from “riskier” donors increased in the decade from 2000 to 2010, thereby helping to meet the need.5

The development of split-liver transplantation allows a donor’s liver tissue to be transplanted into 2 recipients, and damaged but repaired hearts from deceased donors have been used as temporary “bridge” transplants to prolong recipients’ life spans as they await more viable donor hearts.6 However, even these trends combined have not closed the gap between supply and demand.

In the United States, the disparity between organ supply and demand, particularly for kidneys, has been most acute among African-, Asian-, and Native Americans.7 African-Americans are about 3.5 times more likely to develop end-stage renal disease compared with white Americans.4 Although researchers have reported racial disparities in the care of African-American patients including longer wait times for transplantation, later evaluation referrals, and fewer donor matches,7 the gap in kidney transplants appears to have closed.3 Rates of such transplants among white and black patients were at equal levels at the end of 2011.6 Kidney donation rates have improved among African-Americans since 2005, but donation rates remain low among Asian-Americans and Native Americans.3

Tragically, organ shortages are completely preventable.2,31 Shortages are caused by a failure to systematically secure organs from eligible potential donors. Lack of efficient donor detection systems and inter-institutional coordination play a role, but perhaps more important is the widespread reluctance of potential living donors and family members of deceased donors to consent to donation. In the face of scarcity, emerging organ black markets pose significant policy and ethical challenges.

### History

Archeological evidence suggests surgical bone grafts were attempted thousands of years ago.11 Although almost certainly mythological, 5,000-year-old Hindu texts describe the use of skin autografts (ie, tissue or organ grafts transplanted into a recipient from the same donor or a genetically identical donor) from patients’ buttocks and chins to reconstruct their noses cut off as punishment.11,12

Experimental xenotransplantation (ie, tissue or organ transplantation from a nonhuman animal to a human recipient) of animal kidneys to human recipients was tried in the early 20th century and again in the 1960s, with dismal outcomes. In retrospect, these failures are not surprising, given the genetic dissimilarities of different species; recipient immune systems recognize foreign proteins as a threat and attack them. Nevertheless, the potential for xenotransplantation has
received renewed interest and international preclinical research in recent years.

French surgeon Alexis Carrel developed vascular sutting methods and cold organ preservation in the early 1900s, during the course of his kidney transplant research with dogs, establishing the importance of slowing metabolic activity and the resulting degradation of organs through cold storage between surgical removal and reimplantation. Carrel noted that kidney auto-allografts (ie, organ grafts reimplanted back into the individual from which they were removed) can function normally, but that transplantation into another individual caused physiological disturbances and graft failure. Carrel attributed these graft failures not to transplanted organ damage but to recipients’ “biological factors,” anticipating the discovery decades later of immunogenetic incompatibility, the basis of organ rejection.  

Attempts at skin grafts during World War I largely failed because of rejection by the recipients’ bodies. During World War II, however, British surgeon Peter Medawar, working in a hospital burn unit, discovered that skin grafts between identical twins (isografts) were tolerated, establishing immunogenetic incompatibility as one of Carrel’s “biological factors” underlying organ rejection. In 1954, a successful human kidney transplantation was reported between identical twins. Blood type matching was soon found to reduce the severity of organ rejection among unrelated donors and recipients, ushering in the modern era of organ transplantation medicine. Improvements during the 1960s in tissue typing, supportive care (such as dialysis), and immune system-suppressing drug therapies set the stage for solid organ transplantation becoming a routine surgical procedure. The first successful heart and liver transplants were performed in 1967 and 1968, respectively.

The federal Uniform Anatomic Gift Act of 1968 legalized organ donation and was quickly adopted by all 50 states. This law allows people older than 18 years of age to donate specified organs or their entire bodies on death for transplantation or medical training and research. Donor status frequently is noted on drivers’ licenses. The Uniform Anatomic Gift Act also permits related survivors (family members or those with power of attorney for the patient) to consent to organ donation. Even when organ donor status is confirmed on a driver’s license, in clinical practice, clinicians typically seek consent from next of kin. State laws frequently prioritize next of kin consent. New Mexico, for example, allows the deceased patient’s guardian or individual with power of attorney to consent to organ donation; next, the patient’s spouse can grant or deny consent (unless a divorce is pending or the couple is legally separated), followed by the patient’s adult child, sibling, parent, or grandparent. In New Mexico, the individual granting consent also can specify to which recipient the organ is to be donated. Kidney transplants remain the most common and successful form of solid organ transplantation today, and the refinement of storage technologies has allowed successful grafting (ie, tissue or organ removal from a human donor for transplantation into that of another individual) with organs from deceased donors.

In 1977, the use of cyclosporine for recipient immune system suppression was found to be superior to other available drugs to inhibit acute organ rejection and improve short-term transplantation success rates. Cyclosporine was approved for transplant surgery by the U.S. Food and Drug Administration in 1983. However, serious adverse effects soon were noted, including opportunistic infections, neurotoxicity, nephrotoxicity, diabetes, and even lymphoma. Subsequently developed immunosuppressive drugs were shown to match or exceed cyclosporine’s efficacy, in many cases with greater safety for the patient. These included FK-506, antilymphocytic drugs, mycophenolate mofetil, interleukin-2 receptor antagonists, and sirolimus.

Chronic rejection of transplanted organs remains the central challenge of transplantation medicine, with more than half of kidney transplants failing within a decade of surgery. Patients facing chronic rejection must be matched to another donor organ and undergo a new transplant surgery, or die.

ABO blood-type matching between donors and organ transplant recipients has been a mainstay of transplantation medicine since the late 1950s. Blood-type compatibility reduces the probability and severity of recipient immune system attacks on donated tissues and organs. In the 1970s, human leucocyte antigen (HLA) cross-match assays were developed to allow more precise matching of donors and recipients and to determine the likelihood of organ rejection.