TABLE 92e-1 ENGINEERED TISSUES IN PATIENTS

Engineered Tissues in Patients	Year	Clinical Indication	Cell Source
Skin	1989	Burns	Autologous cultured epithelial cells
Cartilage	1997	Knee articular cartilage injuries	Autologous cultured chondrocytes
Skin	1998	Venous leg ulcers	Allogeneic neonatal dermal keratinocytes and fibroblasts
Bladder	1998	Myelomeningocele with poorly compliant bladders	Autologous smooth-muscle and urothelial cells on biodegradable scaffolds
Blood vessel	2001	Single ventricle physiology (pulmonary artery)	Autologous mixed population of endothelial, muscle, and fibroblast cells on biodegradable scaffolds
Blood vessel	2001	Single ventricle physiology (pulmonary artery)	Autologous bone marrow mononuclear cells on biodegradable scaffolds
Skin	2003	Diabetic foot ulcers	Allogeneic neonatal dermal fibroblasts on biodegradable scaffolds
Urethra	2004	Urethral strictures	Autologous smooth-muscle and epithelial cells seeded on biodegradable scaffolds
Skin	2004	Deep partial-thickness burns	Autologous keratinocytes, melanocytes, Langerhans cells, and fibroblasts
Blood vessel	2004	Kidney dialysis arteriovenous shunts	Autologous tubularized fibroblasts
Trachea	2008	End-stage airway disease	Autologous epithelial cells and mesenchymal stem cell–derived chondrocytes seeded on biodegradable scaffolds
Skin	2013	Acute and chronic wound repair	Allogeneic mesenchymal stem cells, fibroblasts, and epithelial cells from placental membrane
Blood vessel	2013	Kidney dialysis arteriovenous shunts	Acellular collagenous extracellular matrix secreted by smooth muscle

have been implanted in patients dating back to the 1990s. These include bladders, blood vessels, urethras, vaginal organs, tracheas, and skin for permanent replacement (Table 92e-1). Various types of skin substitutes, which were used as temporary "living wound dressings" to cover burn areas until skin grafts could be obtained from the same patient, were implanted starting in the 1990s. However, the use of engineered skin as a permanent replacement occurred only recently. Many engineered tissues are still being used in patients under regulatory guidelines for clinical trials. To date, solid organs have not yet been engineered for clinical use.

Tissue engineering is a rapidly evolving field where new technologies are continuously being applied to achieve success. The field still has many challenges ahead, including the long regulatory timelines required for the approval of widespread use, the need for improved scale-up production technologies, and the cost of the technologies, which include multiple processes involving biologics. Nonetheless, the list of tissues and organs being implanted in patients keeps growing, and the ability of these technologies to improve health has been demonstrated. More patients should be able to benefit from these technologies in the coming years.

VIDEO 92e-1 **Engineered heart valve in a pulsatile bioreactor** showing the valves opening and closing.

VIDEO 92e-2 **A dye is injected through the portal artery** of a decellularized liver showing an intact vascular tree.

VIDEO 92e-3 **A modified inkjet printer shows the three-dimensional construction of a two-chambered heart** and how the structure beats with the cardiomyocytes in synchrony.