Chapter 14

An Update to Approved Cell, Gene, and Tissue Therapy Products

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Abstract

CGTPs[1] are distinct therapeutic products intended for human use to provide cures, prevention, palliative care, or diagnostic functions. Currently, these therapeutic approaches are revolutionizing medical science by targeting previously incurable diseases, including inherited genetic disorders, blood-related diseases, malignancies, and neurodegenerative disorders. Additionally, clinical practices have progressively shifted towards these products. The latest analysis by the Alliance for Regenerative Medicine reports 2,125 clinical trials for CGTPs up to November 2025. In this part of the book, based on available information from regulatory agencies and relevant companies' websites,

[1]. Cell, gene and tissue therapy products

articles, and other data sources, we provide an in-depth discussion of classified CGTPs, including the product's description, manufacturer, indications, approval dates, and the corresponding regulatory agency.
Keywords: Stem Cells; Cell Therapy; Products; Clinical Trials.

1. Introduction

With the advent of CGTPs, various regulatory bodies have defined and classified them in different ways to ensure their acceptable quality, safety, and effectiveness. The European Union designates them as ATMPs[1] and divides them into four distinct types: GTMPs[2], sCTMPs[3], TEPs[4], and cATMPs[5]. GTMPs are products based on recombinant nucleic acids that have direct therapeutic, prophylactic, or diagnostic effects. sCTMPs consist of cells or tissues that have been substantially manipulated or are not intended to perform the same function in the recipient as in the donor. TEPs are products that contain cells or tissues designed to repair, replace, or regenerate dysfunctional, damaged, or absent human tissue (**Tables 1**, **2**, and **3**) [1]. CGTPs are regulated as biological products by the FDA's[6] CBER[7] under 21 CFR Parts 1270/1271 as human cells or tissues that are introduced to a human recipient via implantation, transplantation, infusion, or transfer. This definition does not refer to cases where a medical doctor performs minimal manipulation for homologous use (e.g., cutting or sizing, grinding, shaping, centrifugation, soaking in an antibiotic or antimicrobial solution, sterilization or irradiation, cell separation, concentration or purification, filtration, lyophilization, freezing, cryopreservation, or

1. Advanced Therapy Medicinal Products
2. Gene therapy medicinal products
3. Somatic cell therapy medicinal products
4. Tissue-engineered products
5. Combined products
6. U.S. Food and Drug Administration
7. Center for Biologics Evaluation and Research

vitrification) that does not alter the cell's biological functions or traits, or the tissue's structural integrity. FDA classifies cell therapy products into cell-based immunotherapies, tumor vaccines, and other autologous and allogeneic cells for specific therapeutic applications, while gene therapy products are utilized to regulate or modify the expression of a gene and the biological features of living cells for medicinal purposes [2]. As of July 2025, the global total of approved CGTPs reaches 115, made up of approximately 43 CTMPs, 39 GTMPs, and 33 TEPs. The United States leads in this field by authorizing 47 CGTPs, followed by the European Union with 28 and South Korea with 16 products. The categorization of each CGTP highlights the significance of indications associated with skin and soft tissue disorders, oncology, and hematological related disorders [1-4].

2. CTMPs

CTMPs can be divided into nine distinct groups based on the condition for which they were developed: hematologic and oncologic disorders; skin and connective tissue disorders; immunological, cardiovascular, gastrointestinal, neurological, and ocular disorders.

2.1. Hematologic Disorders

Hemacord, Ducord, Allocord, Clevecord, OMISIRGE, Regenecyte, and four other HPC-based products are approved for hematopoietic stem cell transplantations. All these products are human allogeneic cord blood-derived HPCs [2].

2.2. Skin and Connective Tissue Disorders

For managing different types of acne scars and facial wrinkles, CureSkin [3] is approved for depressed acne scars, Queencell [3] is approved for subcutaneous tissue defects, Azficel-T [2], Rosmir, and

RenudermCell [5] are approved to treat moderate to severe nasolabial fold wrinkles and nasojugal groove. KeraHeal and KeraHeal-allo are approved for the treatment of deep partial-thickness or second-degree burns that cover more than 30 percent of TBSA[1] and third-degree burns that cover more than 10 percent of TBSA. Finally, RecolorCell [5] is indicated for various types of Vitiligo. CureSkin, Rosmir, Laviv, and RenudermCell are human autologous dermal fibroblasts; KeraHeal is human autologous dermal keratinocytes; KeraHeal-Allo is human autologous dermal keratinocytes suspended in a thermosensitive hydrogel; RecolorCell is human autologous keratinocytes and melanocytes suspension; and Queencell is human autologous adipose tissue-derived cells by minimal manipulation or SVF[2].

2.3. Orthopedic Disorders

For cartilage defects, Chondron [3], Cartistem [3], Chondrocytes-T Ortho-ACI [6], and Cartigrow [7] are approved to treat symptomatic articular cartilage lesions (ICRS grade III or IV)[3] in the knee, patella, and ankle associated with trauma, wear, degradation, chondromalacia patella, osteochondritis dissecans, or early osteoarthritis. For bone regeneration, RMS Ossron [3] is approved for focal bone formation in injury or defect scenarios, and Ossgrow is indicated for non-union fractures. Whartocell [5] is approved for knee osteoarthritis. Chondron is autologous cartilage cells cultured in fibrin gel, Cartistem is allogeneic UCB-MSCs [4], Chondrocytes-T Ortho-ACI is autologous chondrocytes cultured and transplanted into collagen scaffolds, Cartigrow is autologous BM-MSCs[5],

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1. Total body surface area
2. Stromal vascular fraction (SVF)
3. International Cartilage Repair Society
4. Umbilical cord blood-derived mesenchymal stem cells
5. Bone marrow derived mesenchymal stem cells

RMS Ossron is cultured autologous osteoblasts implanted with fibrin glue, Ossgrow is autologous cultured osteoblasts, and Whartocell is allogeneic cultured Wharton jelly-derived MSCs.

2.4. Immunological Disorders

Prochymal [8], Temcell HS [9], Ryoncil [2], and Destrocell [10] are approved for use in the management of aGvHD[1] for pediatric patients who are 2 months of age or older. For post-transplant lymphoproliferative disease, Ebvallo [1] is approved for use in adult and pediatric patients aged two years and older with relapsed or refractory EBV+ PTLD[2]. Finally, Lantidra [2] was indicated for the treatment of adults with type one diabetes who cannot achieve glycemic targets despite intensive diabetes management and education due to frequent severe hypoglycemia or experience severe hypoglycemia despite intensive diabetes management and education. Prochymal, Temcell HS, and Ryoncil are allogeneic human BM-MSCs; Destrocell is an allogeneic human decidua-derived MSCs; Ebvallo is an allogeneic EBV-specific cytotoxic T lymphocyte; and Lantidra is an allogeneic pancreatic islet cellular suspension of a single deceased donor.

2.5. Cardiovascular Disorders

For acute myocardial infarction, Cellgram-AMI [3] is approved for the treatment of AMI[3] to improve left ventricular ejection fraction and reduce major adverse cardiac events. For CLI[4], Stempeucel [7] is approved for the treatment of CLI due to thromboangiitis obliterans (Buerger's disease).

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[1]. Acute Graft versus Host Disease
[2]. Epstein-Barr virus-positive post-transplant lymphoproliferative disease
[3] Acute myocardial infarction
[4] Critical limb ischemia

Cellgram-AMI is autologous BM-MSCs, and Stempeucel is allogeneic BM-MSCs.

2.6. Neurological Disorders

For amyotrophic lateral sclerosis, Neuronata-R [3] is approved for use in patients suffering from ALS[1], and Stemirac [9] is approved as a treatment option for traumatic spinal cord injury. Both Neuronata-R and Stemirac are composed of autologous BM-MSCs.

2.7. Gastrointestinal Disorders

Two MSCs based product, Cupistem [3] and Alofisel [1], are approved for the management of complex perianal fistulas in patients with CD[2]. Cupistem is autologous AT-MSCs[3], and Alofisel is allogeneic AT-MSCs.

2.8. Ocular Disorders

For limbal stem cell deficiency, Holoclar [1] is approved for use in adult patients with moderate to severe LSCD[4] due to ocular burns. Holoclar is a circular sheet made up of autologous human corneal epithelial cells that contain limbal stem cells.

3. GTMPs

There are seven distinct groups of GTMPs, which are divided based on the indication for which they have been developed: oncology, hematological, neurological, immunological, cardiovascular, ocular-related disorders, and skin and connective tissue disorders.

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[1]. Amyotrophic lateral sclerosis
[2] Crohn's disease
[3]. Adipose tissue derived mesenchymal stem cells
[4] limbal stem cell deficiency

3.1. Oncology

Gendicine [11], a recombinant Type 5 Adenovirus consisting of the human wild-type p53 gene, is approved for administration in patients with head and neck squamous cell carcinoma. Oncolytic adenovirus products consist of Oncorine [11] a recombinant human AV[1] type 5 with E1B-55kD and E3 region deletion which is approved for treatment nasopharyngeal, head and neck, lung, liver and pancreatic cancers, Imlygic [2] an attenuated HSV1[2] genetically modified to express hGM-CSF[3] is approved as a treatment option in adults with unresectable melanoma and Delytact [9] a third-generation recombinant oncolytic HSV1 is approved for management of malignant glioma. For malignancies affecting B cells, Yescarta [2] and Breyanzi [2] are approved for the treatment of adult patients with DLBCL[4] and HGBL[5]. Kymriah, Tecartus [2], and Carteyva [2] are indicated in adults with relapsed or refractory B-ALL [6] or relapsed/refractory MCL[7]. Abecma, Carvykti, Fucaso, and Zevor-cel are approved for controlling relapsed or refractory multiple myeloma. Finally, Inaticabtagene autoleucel and Aucatzyl are approved for use in adults with relapsed or refractory ALL[8]. Among these products, Fucaso and Zevor-cel are BCMA[9]-targeting CAR[10]-T cells, while all the others are CD19-directed genetically modified T cells. Finally, Adstiladrin, a recombinant adenovirus serotype 5 vector delivering the human INF-a2b[11] gene, is approved to

[1] Adenovirus
[2]. Herpes simplex virus type 1
[3]. Human granulocyte-macrophage colony-stimulating factor
[4]. Diffuse large B cell lymphoma
[5] . High-grade B-cell lymphoma
[6] . B-cell precursor acute lymphoblastic leukemia
[7]. Mantle cell lymphoma
[8]. Acute lymphoblastic leukemia
[9] . B cell maturation antigen-specific
[10] . Chimeric antigen receptor
[11] . Interferon alfa-2b

treat high-risk non-muscle-invasive bladder cancer in patients who do not respond to BCG[1], and Tecelra, an autologous TCR[2] targeting MAGE-A4[3], is approved as a therapeutic for advanced synovial sarcoma.

3.2. Hematological Disorders

Three hemophilia therapies have received regulatory approval. [2] is approved to treat patients with severe hemophilia A. Hemgenix and Beqvez have received regulatory approval for the management of hemophilia B. Casgevy, and Lyfgenia are approved for the treatment of sickle cell disease in patients with recurrent vaso-occlusive crises or history of vaso-occlusive events. Zynteglo is approved for use in patients diagnosed with transfusion-dependent beta-thalassemia. Roctavian is a recombinant AAV5[4] carrying a β-domain deleted human coagulation factor VIII gene, Hemgenix and Beqvez are AAV5 carrying the human coagulation factor IX (FIX) variant Padua, Casgevy is autologous CRISPR-Cas9 gene-edited HSCs disrupting the BCL11A erythroid enhancer, Lyfgenia is autologous HSCs transduced with a LVV[5] carrying a modified β-globin gene (HBB T87Q), and Zynteglo is autologous HSCs transduced with a LVV encoding the βA–T87Q–globin gene.

3.3. Neurodegenerative Diseases

Zolgensma [2] is approved for use in children under 2 years of age with SMA [6] and confirmed bi-allelic mutations in the SMN1 [7] gene, while ITVISMA has received approval for treating adult patients and children

[1] Bacillus Calmette–Guérin
[2] . T-cell receptor
[3]. Melanoma-Associated Antigen-A4
[4]. Adeno-associated virus serotype 5
[5] Lentiviral vector
[6]. Spinal muscular atrophy
[7]. Survival of motor neuron 1

aged ≥2 years, with the same genetic abnormality. Upstaza [1] and Kebilidi are approved for use in adults and pediatric patients ≥18 months with severe AADC[1] deficiency. Skysona is approved for the treatment of boys with early, active CALD[2]. Elevidys is approved for use in pediatric patients between 4 and 5 years old with DMD[3], and Lenmeldy is approved for the treatment of children with PSLI[4], PSEJ[5] , or ESEJ[6], MLD[7]. Zolgensma and ITVISMA are AAV9 delivering a functional SMN1 gene, Kebilidi and Upstaza are AAV2 delivering a functional human AADC gene, and Skysona is a genetically modified autologous CD34+ cell genetically modified *ex vivo* with LVV encoding the ABCD1[8] gene. Elevidys is an AAVrh74 [9] delivering a micro-dystrophin transgene, and Lenmeldy is genetically engineered autologous CD34+ HSCs that have been transduced *ex vivo* with a lentiviral vector encoding the human ARSA[10] gene.

3.4. Immunological Disorders

Strimvelis is approved for the treatment of ADA-SCID[11] in patients who do not have a suitable HLA-matched related stem cell donor. It is an autologous gene therapy product that consists of CD34+ HSCs transduced *ex vivo* with an RVV[12] carrying the functional ADA gene. Zalmoxis was previously approved as an adjunctive treatment in patients

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1. Aromatic L-amino acid decarboxylase
2. Cerebral adrenoleukodystrophy
3. Duchenne muscular dystrophy
4. Pre-symptomatic late infantile
5. Pre-symptomatic early juvenile
6. Early symptomatic early juvenile
7. Metachromatic leukodystrophy
8. ABCD1 ATP binding cassette subfamily D member 1
9. Adeno-associated virus serotype rh74
10. Arylsulfatase A
11. Adenosine deaminase deficiency
12. Retroviral vector

with high-risk hematological malignancies after haploidentical HSC transplantation. It consists of donor-derived T lymphocytes genetically engineered with an RVV encoding the HSV-TK Mut2[1] suicide gene. This gene serves as a safety measure, allowing for the selective deletion of the T lymphocytes in case of GVHD.

3.5. Ocular Disorders

Luxturna, an AAV2 delivering the RPE65 gene, is approved for the treatment of vision impairment caused by an inherited retinal dystrophy in patients with confirmed biallelic mutations in the RPE65 gene. Encelto allogeneic encapsulated retinal pigment epithelial cell genetically modified to secrete rhCNTF,[2] is approved for use in adult patients with idiopathic MacTel type 2[3].

3.6. Skin and Connective Tissue Disorders

For RDEB [4] with a mutation in the COL7A1 [5] gene, Vyjuvek, a recombinant, replication-deficient, non-integrating HSV-1-based gene therapy vector engineered to express full-length, functional human COL7A1, is approved for the treatment of wounds in patients 6 months of age and older, and Zevaskyn, an autologous keratinocyte sheet transduced with RVV[6] carrying a transgene encoding human COL7A1, is approved for the treatment of wounds in adult and pediatric patients.

3.7. Cardiovascular Disorders

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1. Herpes simplex virus thymidine kinase mutant 2
2. Recombinant human ciliary neurotrophic factor
3. Macular telangiectasia type 2
4. Recessive dystrophic epidermolysis bullosa
5. Collagen type VII alpha one chain
6. Retroviral vector

Neovasculgen [12] is approved for the treatment of PAD[1], a condition characterized by the narrowing or blockage of arteries that leads to reduced blood flow, particularly in the lower limbs. It is a non-viral gene therapy using a plasmid DNA vector that encodes the VEGF165[2] protein. On the other hand, Collategene [9] is approved for the treatment of CLI[3], which is caused by atherosclerosis and occlusions in peripheral arteries, leading to a severe reduction in blood flow and tissue ischemia. It involves the delivery of a non-viral plasmid DNA vector that encodes the HGF[4] protein.

4. TEPs[5]

TEPs have been developed for four distinct types of indications: skin and connective tissue disorders, oncology, ocular, orthopedic, and cardiovascular disorders.

4.1. Skin and Connective Tissue Disorders

For the management of different types of ulcers, Apligraf [2] is approved for the indication in VLU[6] and DFU[7]. It is a bi-layered skin substitute composed of human keratinocytes and fibroblasts obtained from neonatal foreskin cultured on a bovine collagen matrix. Dermagraft is approved for treating DFU involving subcutaneous tissue or deeper structures. It is composed of neonatal human fibroblasts cultured on a biodegradable polyglactin mesh scaffold. Aurix is approved for treating chronic non-healing wounds such as DFU, VLU, and pressure injuries. It is a

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[1]. Peripheral arterial disease
[2]. Vascular endothelial growth factor isoform 165
[3]. Critical limb ischemia
[4]. Hepatocyte growth factor
[5]. Tissue engineering products
[6] Venous leg ulcers
[7] Diabetic foot ulcers

biodynamic hematogel created at the point of care from the patient's own blood to produce a PRP[1] gel that releases growth factors and cytokines to stimulate tissue regeneration. Hyalograft 3D[2] [3] is also designed for treating DFU and VLU. It involves cultivating autologous dermal fibroblasts in a 3D scaffold made from hyaluronic acid to support cell growth and mimic the extracellular matrix for neodermis formation. Omnigraft is approved for the treatment of neuropathic DFU that has persisted for more than six weeks, as well as for treating deep partial-thickness and full-thickness burns and reconstructive burn-scar surgery. It is a bilayer dermal regeneration matrix with a porous dermal replacement scaffold of cross-linked bovine collagen and chondroitin-6-sulfate, topped with a removable silicone epidermal layer. ReGenerCell [1] is approved for use in chronic wounds such as VLU and DFU. It uses a small patient skin sample to produce an autologous regenerative epithelial suspension containing keratinocytes, fibroblasts, and melanocytes, applied to promote healing. Vergenix FG is approved for the treatment of acute and chronic DFU and VLU. It is a flowable gel wound filler composed of recombinant human collagen combined with the patient's PRP to form a bioactive scaffold for tissue regeneration. ReNovaCell is designed for treating skin pigmentation defects and improving scar appearance. It uses autologous skin cell suspension, including melanocytes, keratinocytes, and fibroblasts, sprayed onto depigmented or scarred areas to restore natural pigmentation and texture. Vergenix STR is approved for the treatment of tendinopathy, including lateral epicondylitis, rotator cuff injuries, patellar and Achilles' tendinopathy, and hand tendon repairs. It is a soft tissue repair matrix composed of cross-linked recombinant human collagen

[1]Platelet-rich plasma
[2]Three-dimensional

combined with the patient's PRP, injected to form a gel-like scaffold for controlled release of growth factors. For mucogingival conditions, Gintuit is approved for topical application in vascular wound beds surgically established in adult patients with mucogingival deformities. It is composed of allogeneic cultured keratinocytes and fibroblasts in bovine collagen, secreting growth factors, cytokines, and extracellular matrix proteins to promote oral soft tissue regeneration. Cell-Amniosin [13] is manufactured for treating chronic wounds such as DFU, bedsores, and severe burns. It is a biological wound dressing derived from human amniotic membrane retaining stem cells that release growth factors continuously. Amniosin [13] is used for chronic wounds, DFU, bedsores, and burns. It is an acellular, cryopreserved amniotic membrane enriched with extracellular matrix components such as collagen, fibronectin, and laminin, providing a scaffold for cell migration and helping to reduce inflammation. Amniodisk [13] has received approval for managing corneal ulcers, conjunctival and epithelial damage, chronic wounds, general wound care, and gynecological conditions, including cervicitis. It is a dehydrated human amniotic membrane-derived dressing that promotes repair through growth factors, cytokines, and structural proteins. Finally, RoyinGraf [14] is approved as an allogeneic therapy for skin regeneration and wound healing in chronic diabetic foot ulcer, based on cultured foreskin derived keratinocytes and fibroblasts on bovine collagen.

For burn injuries, Transcyte consists of human foreskin derived fibroblast cells cultured on a porcine collagen-coated nylon scaffold, which is intended for second and third-degree burns. Holoderm, a cultured autograft keratinocyte sheet, is approved for the management of large deep second-degree burns (over 30% TBSA) and third-degree burns (over 10% TBSA). Kaloderm, a cultured allogenic keratinocyte sheet, is approved for treating

deep second-degree burns and non-infected diabetic foot ulcers. Epicel is approved for treating adults and pediatric patients with deep dermal or full-thick burns involving 30% or more of the TBSA. It consists of cultured epidermal autografts made from the patient's own keratinocytes expanded *ex vivo* into sheets using proliferation-arrested murine fibroblast feeder cells. JACE is approved for management scars, vitiligo, nevi (birthmarks), ulcers, skin-graft donor sites, and severe burns ≥30%. It is an autologous cultured epidermis-derived cell sheet produced from the patient's keratinocytes and a mouse fibroblast feeder layer. Bilayer artificial skin is designed to replicate the structure and function of natural skin for deep second-degree burn wounds (up to third-degree, ≤20 cm^2, diameter <5 cm). It consists of a bilayer construct with a layer of human epidermal cells and a layer of human fibroblasts supported by bovine collagen, providing enhanced angiogenesis, hemostatic function, antibacterial activity, and exudate absorption. Artificial transfected pigskin is developed as a tissue-engineered skin product involving gene transfection into pigskin using hexadimethrine bromide to enhance adenoviral vector efficiency, expressing therapeutic genes to promote healing and graft integration in burns and trauma wounds. Stratagraft is approved for promoting durable wound closure in adult patients with debrided thermal burns that retain intact dermal tissue. It is a bioengineered, living skin substitute composed of allogeneic cultured keratinocytes and fibroblasts seeded onto a murine collagen scaffold. RoyinSheet is an allogenic cultured keratinocyte sheet on a removable silicone layer for supporting skin regeneration in deep second-degree and third-degree burns.

4.2. Orthopedic Disorders

JACC (Japan PMDA.,2013), Novocart 3D, MACI, and Spherox have received approval for treating full-thickness cartilage defects in the knee joint, including those caused by trauma or osteochondritis dissecans.

JACC is an autologous chondrocyte cultured in atelocollagen gel; Novocart 3D is comprised of patient-derived chondrocytes cultured on a type I/III collagen matrix, and MACI is an autologous chondrocyte cultured on a porcine collagen membrane; Spherox contains 3D spheroids made of the patient's own chondrocytes and their self-produced extracellular matrix.

4.3. Cardiovascular Disorders

CardioCel [15] is an acellular bovine pericardium patch (pure collagen scaffold) processed with anti-calcification technology that is approved for cardiovascular repairs, including pericardial closure, intracardiac defect repair, valve repair, vascular reconstruction, and suture line buttressing. On the other hand, HeartSheet consists of autologous skeletal myoblast sheets derived from thigh muscle and has received approval for treating severe heart failure caused by chronic ischemic heart disease. Finally, SYMVESS is a tissue-engineered, acellular vascular conduit derived from vascular smooth muscle cells that is approved for use in extremity arterial injuries requiring immediate revascularization to avoid limb loss.

4.4. Immunological Disorders

Rethymic is the first and only FDA-approved tissue-based product for immune reconstitution in pediatric patients with congenital athymia, an ultra-rare disorder in which children are born without a thymus, resulting in severe immunodeficiency and immune dysregulation. It is an allogeneic processed thymus tissue implanted into the thigh muscle in a single surgical procedure.

4.5. Oncology

Neskeep, an innovative bioabsorbable spacer made from polyglycolic acid, is approved for protecting healthy organs from radiation exposure during radiotherapy treatments, particularly particle therapy such as proton or carbon-ion radiation for malignant abdominal, pelvic, bone, or soft tissue tumors. Neskeep is a non-woven fabric spacer that physically separates tumors from adjacent critical organs like the intestines or bladder to reduce radiation exposure and complications, and it disintegrates and is absorbed by the body after treatment without needing surgical removal.

Table 1. Cell therapy products

TRADE NAME/PROPER NAME	MANUFACTURER	INDICATION	APPROVED BY/DATE	PRODUCT DESCRIPTION	AT/AL
HEMACORD HPC, CORD BLOOD	New York Blood Center, Inc. (USA)	HSCT	USA FDA 2011 Nov.	CB-HPCs	AL
HPC, CORD BLOOD	Clinimmune Labs, UCCBB (USA)	HSCT	USA FDA 2012 May.	CB-HPCs	AL
DUCORD HPC, CORD BLOOD	Duke University School of Medicine (USA)	HSCT	USA FDA 2012 Oct.	CB-HPCs	AL
ALLOCORD HPC, CORD BLOOD	SSM Health Cardinal Glennon Children's Hospital (USA)	HSCT	USA FDA 2013 May.	CB-HPCs	AL
HPC, CORD BLOOD	LifeSouth Community Blood Centers, Inc. (USA)	HSCT	USA FDA 2013 Jun.	CB-HPCs	AL
HPC, CORD BLOOD	Bloodworks (USA)	HSCT	USA FDA 2016 Jan.	CB-HPCs	AL
CELEVECORD HPC, CORD BLOOD	Cleveland Cord Blood Center (USA)	HSCT	USA FDA 2016 Sep.	CB-HPCs	AL
HPC, CORD BLOOD	MD Anderson Cord Blood Bank (USA)	HSCT	USA FDA 2018 Jun.	CB-HPCs	AL
OMIDUBICEL-ONLV (OMISIRGE)	Gamida Cell Ltd. (Israel)	HSCT	USA FDA 2023 April.	CB-HPCs	AL
REGENECYTE	StemCyte, Inc. (USA)	HSCT	USA FDA 2024 Nov.	CB-HPCs	AL

PROVENGE SIPULEUCEL-T	Dendreon Corp. (USA)	mCRCP	USA FDA 2010 Apr. EMA 2010 Sept.	$CD54^{+}$ Cells activated with PAP-GM-CSF	AT
AZFICEL-T LAVIV	Fibrocell Technologies, Inc. (USA)	Moderate to severe NLF wrinkles	USA FDA 2011 Jun.	fibroblasts	AT
PROCHYMAL BM-MSCS	Mesoblast Ltd., International (Australia)	Acute and refractory GVHD	USA FDA 2015 June. Health Canada 2012 May.	BM-MSCs	AL
DONISLECEL-JUJN (LANTIDRA)	CellTrans Inc. (USA)	T1D	USA FDA 2023 Jun.	Deceased donor pancreatic islets of Langerhans cells	AL
LIFILEUCEL (AMTAGVI)	Iovance Biotherapeutics, Inc. (USA)	Unresectable or metastatic melanoma	USA FDA 2024 Feb.	ex vivo expanded T cells obtained from the resected tumor	AT
REMESTEMCEL-L-RKND (RYONCIL)	Mesoblast, Inc. (USA)	SR-aGvHD	USA FDA 2024 Dec.	BM-MSCs	AL
ALOFISELL(CX601) DARVADSTROCEL	TiGenix (USA) & Takeda (UK)	Complex Perianal Fistulas in CD	EMA 2018 Mar.	AT-MSC	AL
TABELECLEUCEL (EBVALO)	Atara Biotherapeutics, Inc (USA)	EBV+ PTLD	EMA 2022 Dec.	Human EBV-specific T-cell	AL
KERAHEAL	Biosolution Co., Ltd. (South Korea)	Deep 2^{nd} degree burn (>30% of the TBSA) and 3^{rd} degree burn (>10% of the TBSA)	South Korea MFDS 2006 May.	Keratinocytes	AT

QUEENCELL	Anterogen (South Korea)	Subcutaneous tissue defects	South Korea MFDS 2010 Mar.	Human AT derived cells	AT
CURESKIN	S. Biomedics (South Korea)	Depressed acne scars	South Korea MFDS 2010 May.	HDF	AT
KERAHEAL-ALLO	Biosolution Co., Ltd. (South Korea)	Deep 2nd degree burns	South Korea MFDS 2015 Oct.	Keratinocytes suspended in a thermosensitive hydrogel.	AL
ROSMIR	Tego Sciences (South Korea)	Nasojugal groove	South Korea MFDS 2017 Dec.	Fibroblasts	AT
CHONDRON	Sewon Cellontech Corp. (South Korea)	Focal knee cartilage defect	South Korea MFDS 2001 Jan.	Chondrocytes	AT
RMS- OSSRON	Sewon Cellontech Co., Ltd. (South Korea)	Bone defects	South Korea MFDS 2009 Aug.	Osteoblasts	AT
CARTISTEM	Medipost (South Korea)	Knee OA (ICRS grade IV)	South Korea MFDS 2012 Jan.	UC-MSCs	AL
CREAVAX-RCC	JW CreaGene (South Korea)	Advanced RCC	South Korea MFDS 2007 May.	DCs	AT
IMMUNCELL-LC	Green Cross Cell Corp. (South Korea)	Postsurgical recurrence of HCC	South Korea MFDS 2007 Aug.	CIK cells	AT
CUPISTEM	Anterogen (South Korea)	CD	South Korea MFDS	AT-MSCs	AT

			2012 Jan.		
CELLGRAM-AMI	FCB Pharmicell (South Korea)	AMI	South Korea MFDS 2011 July.	BM-MSCs	AT
NEURONATA-R	Corestem (South Korea)	ALS (Lou Gehrig's Disease)	South Korea MFDS 2014 July.	BM-MSCs	AT
CARTIGROW	Regrow Biosciences Pvt. Ltd. (India)	Knee/ankle cartilage loss	India DCGI 2017 Apr.	Chondrocytes	AT
OSSGROW	Regrow Biosciences Pvt. Ltd. (India)	Early-stage hip osteonecrosis	India DCGI 2017 Apr.	Osteoblasts	AT
APCEDEN AMDDC	APAC Biotech (India)	Prostate, ovarian, colorectal, and NSCLC	India DCGI 2017 Mar.	Monocyte-derived mature DCs	AT
STEMPEUCEL	Stempeutics Research (India)	CLI due to TAO (Buerger's disease)	India DCGI 2016 May.	BM-MSCs	AL
CHONDROCYTES-T-ORTHO-ACI CARTOGEN	Orthocell (Australia)	Patients aged 18–55 years with chondromalacia patella or OCD	Australia TGA 2017 Mar.	Chondrocytes	AT
TEMCELL HS	JCR Pharmaceuticals (Japan)	Acute and refractory GVHD	Japan PMDA 2015 Sep.	BM-MSCs	AL
STEMIRAC	NIPRO CORP. (Japan)	TSCI	Japan PMDA 2019 Nov.	BM-MSCs	AT
RENUDERMCELL	Cell Tech Pharmed (Iran)	Facial wrinkles, acne scarring, and post-traumatic atrophic skin lesions	Iran FDA 2018 Jan.	HDFs	AT
MESESTROCELL	Cell Tech Pharmed (Iran)	OA and knee joint arthritis	Iran FDA 2018 Jan.	BM-MSCs	AT
RECOLORCELL	Cell Tech Pharmed (Iran)	Different forms of vitiligo: focal, segmental, and generalized	Iran FDA 2019 Feb.	Keratinocytes and melanocytes	AT

DESTROCELL	Taskin (Iran)	Acute and refractory GvHD	Iran FDA 2024 Agu.	D-MSCs	AL
WHARTOCELL	Cell Tech Pharmed (Iran)	Knee OA	Iran FDA 2025 Nov.	WJ-MSCs	AL

Abbreviations: HSCT: Hematopoietic stem cell transplantation, CB-HPCs: Cord Blood-Hematopoietic stem cell, PAP: Prostatic acid phosphatase, GM-CSF: Granulocyte-macrophage colony-stimulating factor BM-MSCs: Bone marrow-derived mesenchymal stem cell, UC-MSCs: Umbilical cord-derived mesenchymal stem cells, AT-MSCs: adipose tissue-derived MSCs, D-MSCs: Decidua-derived MSCs, RCC: Renal cell carcinoma, WJ-MSCs: Wharton jelly-derived MSCs, mCRPC: Metastatic castration-resistant prostate cancer, NLF: Nasolabial fold, SR-aGvHD: Steroid-refractory acute graft versus host disease, EBV+ PTLD: Epstein-Barr virus-positive post-transplant lymphoproliferative disease, TAO: Thromboangiitis obliterans, CIK: Human cytokine-induced killer, AMI: Acute Myocardial Infraction, T1D: Type 1 diabetes, CD: Crohn disease, EBV+ PTLD: Epstein-Barr virus-associated post-transplant lymphoproliferative disorders, TBSA: total body surface area, HCC: Hepatocellular carcinoma, ALS: Amyotrophic lateral sclerosis, AVN: Avascular necrosis, NSCLC: Non-small cell lung cancer, HDF: Human dermal fibroblasts, TSCI: Traumatic spinal cord injury, CLI: Critical limb ischemia, OCD: Osteochondritis dissecans, OA: Osteoarthritis.

Table 2. Gene therapy products

TRADE NAME/ PROPER NAME	MANUFACTURER	INDICATIONS	APPROVED BY/DATE	DESCRIPTION	AT/AL
IMLYGIC TALIMOGENE LAHERPAREPVEC	Amgen, Inc. (USA)	Unresectable cutaneous, subcutaneous, and nodal lesions in recurrent melanoma after initial surgery	USA FDA 2015 Oct. EMA 2015 Dec.	Live, attenuated HSV-1 genetically modified to express hGM-CSF.	-
KYMRIAH TISAGENLECLEUCEL	Novartis Pharmaceuticals Corp. (USA)	Patients ≤25 years with r/r B-ALL and adult patients with r/r large B-cell lymphoma	USA FDA 2017 Aug. EMA 2018 Aug.	CAR-engineered T cells targeting CD19	AT
YESCARTA AXICABTAGENECILOLEUCEL	Kite Pharma, Inc. (USA)	Adult patients with r/r large B-lymphoma	USA FDA 2017 Oct.	CAR-engineered T cells targeting CD19	AT

LUXTURNA VORETIGENEPARVOVEC-RZYL	Spark Therapeutics, Inc. (USA)	Biallelic RPE65 mutation-associated retinal dystrophy	EMA 2018 Aug. USA FDA 2017 Dec. EMA 2018 Sep.	Live, non-replicating AAV2 genetically modified to express the hRPE65 gene.	-
ZOLGENSMA ONASEMNOGENE ABEPARVOVEC-XIOI	AveXis (USA)	Pediatric patients <2 years of age with SMA and bi-allelic mutations in the SMN1 gene	USA FDA 2019 May. EMA 2020 May.	AAV9 vector containing a functional copy of the SMN1 gene	-
BREXUCABTAGENE AUTOLEUCEL (TECARTUS)	Kite Pharmaceuticals, Inc. (USA)	Adult patients with r/r B-ALL or r/r MCL	USA FDA 2021 Oct. EMA 2020 Dec.	CAR-engineered T cells targeting CD19	AT
IDECABTAGENE VICLEUCEL (ABECMA)	Celgene Corporation, a Bristol-Myers Squibb Company (USA)	r/r MM	USA FDA 2021 March. EMA 2021 Agu.	CAR-engineered T cells targeting BCMA	AT
NADOFARAGENE FIRADENOVEC-VNCG (ADSTILADRIN)	Ferring Pharmaceuticals A/S (USA)	High-risk BCG-unresponsive NMIBC	USA FDA 2022 Dec.	Recombinant AV5 vector carrying the human IFNα2b gene	-
CILTACABTAGENE AUTOLEUCEL (CARVYKTI)	Janssen Biotech, Inc. (USA)	r/r MM	USA FDA 2022 Feb. EMA 2022 May.	CAR-engineered T cells targeting BCMA	AT
LISOCABTAGENE MARALEUCEL (BREYANZI)	Juno Therapeutics, Inc., a Bristol-Myers Squibb (USA)	Adult patients with LBCL	USA FDA 2022 Jun. EMA 2022 Apr.	CAR-engineered T cells targeting CD19	AT
BETIBEGLOGENE AUTOTEMCEL (ZYNTEGLO)	bluebird bio-Inc. (USA)	Adult and pediatric patients with ß-thalassemia	USA FDA 2022 Aug. EMA 2019 May.	CD34+ cell-enriched population transduced ex vivo with the BB305 LVV encoding βA-T87Q-globin	AT

ETRANACOGENE DEZAPARVOVEC-DRLB (HEMGENIX)	CSL Behring LLC (USA)	Adults with Hemophilia B (missing or defective factor IX)	USA FDA 2022 Nov.	AAV5 carrying a genome that encodes the human coagulation FIX R338L variant	-
ELIVALDOGENE AUTOTEMCEL (SKYSONA)	bluebird bio-Inc. (USA)	Boys 4- 17 years of age with early CALD	USA FDA 2022 Sep. EMA 2021 Jul.	CD34+ cell that transduced ex vivo with LVV encoding ABCD1 cDNA	AT
VALOCTOCOGENE ROXAPARVOVEC-RVOX (ROCTAVIAN)	BioMarin Pharmaceutical Inc. (USA)	Adults with severe hemophilia A (deficiency or inactivation of factor VIII)	USA FDA 2023 Jun. EMA 2022 Aug.	Recombinant AAV5 vector encoding a human β-domain deleted FVIII gene	-
LOVOTIBEGLOGENE AUTOTEMCEL (LOVO-CEL) (LYFGENIA)	bluebird bio-Inc. (USA)	Patients ≥12 years old with SCD	USA FDA 2023 Dec.	Autologous CD34+ cells transduced with the BB305 LVV-5 encoding human βA-T87Q-globin	AT
EXAGAMGLOGENE AUTOTEMCEL (EXA-CEL) (CASGEVY)	Vertex Pharmaceuticals Incorporated (USA)	Patients ≥12 years old with SCD	USA FDA 2023 Dec. EMA 2024 Feb.	CD34+ cells genetically modified with CRISPR/Cas9 (SPY101) to disrupt BCL11A expression in erythroid cells	AT
BEREMAGENE GEPERPAVEC-SVDT (VYJUVEK)	Krystal Biotech, Inc. (USA)	Pediatric and adult patients with COL7A1 mutation-associated DEB	USA FDA 2023 May. EMA 2025 Apr.	Non-integrating HSV-1-based gene therapy vector engineered to express full-length, functional human COL7	-
DELANDISTROGENE MOXEPARVOVEC-ROKL (ELEVIDYS)	Sarepta Therapeutics, Inc. (USA)	DMD	USA FDA 2024 Jan.	AAVrh74 carries a functional version of the dystrophin gene.	-
ATIDARSAGENE AUTOTEMCEL (LENMELDY)	Orchard Therapeutics (Europe) Limited (UK)	Children with PSLI, PSEJ, or ESEJ, MLD	USA FDA 2024 March. EMA 2020 Dec.	CD34+ cells transduced ex vivo with an LVV carrying the human ARSA gene	AT
FIDANACOGENE ELAPARVOVEC-DZKT (BEQVEZ)	Pfizer, Inc. (USA)	Adults with moderate to severe hemophilia B	USA FDA 2024 Apl. EMA 2024 Jul.	AAV5 carrying the human coagulation FIX R338L variant	-

AFAMITRESGENE AUTOLEUCEL (TECELRA)	Adaptimmune LLC (USA)	Advanced unresectable and metastatic SS	USA FDA 2024 Aug.	MAGE-A4 TCR-positive T cells	AT
OBECABTAGENE AUTOLEUCEL (AUCATZYL)	Autolus Limited (UK)	Adults with relapsed or refractory B- ALL	USA FDA 2024 Nov.	CAR-engineered T cells targeting CD19	AT
ELADOCAGENE EXUPARVOVEC-TNEQ (KEBILIDI)	PTC Therapeutics (USA)	Pediatric and adult patients with AADC deficiency	USA FDA 2024 Nov.	Non-replicating AAV2 vector containing human DDC cDNA	-
REVAKINAGENE TARORETCEL-LWEY (ENCELTO)	Neurotech Pharmaceuticals, Inc. (USA)	adults with idiopathic MacTel type 2	USA FDA 2025 March.	Retinal pigment epithelial cells expressing rhCNTF	AL
PRADEMAGENE ZAMIKERACEL (ZEVASKYN)	Abeona Therapeutics, Inc. (USA)	Adult and pediatric patients with RDEB	USA FDA 2025 Apl.	keratinocyte cell sheet-based that are transduced with RVV carrying a transgene encoding human COL7A1	AT
ZOPAPOGENE IMADENOVEC-DRBA (PAPZIMEOS)	Precigen, Inc. (USA)	Adults with RRP	USA FDA 2025 Aug.	Non-replicating adenoviral vector encoding HPV 6 and 11 antigens	-
ONASEMNOGENE ABEPARVOVEC-BRVE (ITVISMA)	Novartis Gene Therapies, Inc.	Adult and pediatric patients <2 years of age with SMA caused by bi-allelic mutations in the SMN1 gene	USA FDA 2025 Nov.	A recombinant AAV9 vector encoding the functional SMN1 gene	-
ZALMOXIS	Molmed S.p.A. (Italy)	Adults with high-risk hematologic cancers treated with haploidentical HSCT	EMA 2016 Aug. Withdrawn 2019 Oct.	T-lymphocytes genetically modified with an RVV encoding ΔLNGFR and HSV-TK	AL
STRIMVELIS	GlaxoSmithKline (GSK, UK)	ADA-SCID	EMA 2016 May.	Transduced CD34+ cells with an RVV to express human ADA	AT
UPSTAZA	PTC Therapeutics International Limited (Ireland)	Adults and children ≥18 months of age with severe AADC deficiency	EMA 2022 Jul.	Recombinant AAV2 vector encoding the human DDC gene.	-
GENDICINE	Shenzhen SiBiono Gene Tech Co., Ltd. (China)	Late-stage HNSCC linked to mutations in the TP53 gene	CFDA 2003 Oct.	Recombinant AV expressing human p53	-

ONCORINE	Shanghai Sunway Biotech (China)	Nasopharyngeal carcinoma	CFDA 2005 Nov.	Recombinant human adenovirus type 5 with E1B-55kD and E3 region deletion	-
CARTEYVA (RELMA-CEL)	JW Therapeutics (China)	Adult patients with r/r B-ALL or r/r MCL	CFDA 2021 Feb.	CAR-engineered T cells targeting CD19	AT
INATICABTAGENE AUTOLEUCEL (INATI-CEL)	Juventas (China)	adult r/r B-ALL	CFDA 2023 Oct.	CAR-engineered T cells targeting CD19	AT
FUCASO	IASO BIO (China)	r/r MM	CFDA 2023 Nov.	CAR-engineered T cells targeting BCMA	AT
ZEVORCABTAGENE AUTOLEUCEL	SparkCures (China)	r/r MM	CFDA 2024 Sep.	CAR-engineered T cells targeting BCMA	AT
NEOVASCULGEN CAMBIOGENEPLASMID	Human Stem Cells Institute (Russia)	PAD & CLI	MOH of the Russia Federation 2011 Dec.	Non-viral plasmid carrying the CMV-VEGF gene	-
COLLATEGENE	AnGes Inc. (Japan)	CLI	PMDA Japan 2019 Sep.	Non-viral plasmid DNA vector encoding HGF protein	-
DELYTACT	Daiichi Sankyo (Japan)	Malignant glioma	PMDA Japan 2021 Oct.	Genetically engineered oncolytic HSV-1	-

Abbreviations: hGM-CSF: Human granulocyte-macrophage colony-stimulating factor, AADC : Aromatic L-Amino acid decarboxylas, aGvHD: acute Graft versus Host Disease, ALS: Amyotrophic lateral sclerosis, RDEB: Recessive dystrophic epidermolysis bullosa, RRP: Recurrent respiratory papillomatosis, B-ALL: B-cell precursor acute lymphoblastic leukemia, MCL: Mantle cell lymphoma, r/r: Relapsed or refractory,RPE65: Retinal pigment epithelium-specific 65 kDa protein, SMA: Spinal muscular atrophy, SMN1: Survival motor neuron gene 1, MM: Multiple myeloma, CLI: Critical limb ischemia, MacTel: macular telangiectasia, HNSCC: Head and neck squamous cell carcinoma, HSV1: herpes simplex virus type 1, NMIBC: non-muscle invasive bladder cancer, BCG: Bacillus Calmette-Guérin, IFNα2b: interferon-alfa 2b, LBCL: Large B-cell lymphoma, SS: Synovial Sarcoma, AV: Adenoviruses, RVV: Retroviral vector, LVV: Lentiviral vector, ADA-SCID: adenosine deaminase- severe combined immune deficiency, PSLI: pre-symptomatic late infantile, PSEJ: pre-symptomatic early juvenile, ESEJ: early symptomatic early juvenile, ARSA: Arylsulfatase A, FIX: Human coagulation factor IX, TCR: T cell receptor, CALD: active cerebral adrenoleukodystrophy, cDNA: complementary deoxyribonucleic acid, SCD: sickle cell disease, DEB: dystrophic epidermolysis bullosa, COL7A1: collagen type VII alpha 1 chain, AAV: adeno-associated virus, DMD: Duchenne muscular dystrophy, PSLI: Children with pre-symptomatic late infantile, PSEJ: pre-symptomatic early juvenile, ESEJ: Early symptomatic early juvenile, MLD: metachromatic leukodystrophy Disease, ARSA: arylsulfatase A, MAGE-A4 :Melanoma-associated antigen 4, DDC: Dopa decarboxylase, HPV: human papillomavirus, BCMA: B cell maturation antigen, PAD: peripheral arterial disease, CLI: Critical limb ischemia, HGF: Hepatocyte growth factor, CMV-VEGF: Cytomegalovirus-vascular endothelial growth factor, HSV-TK: Herpes

simplex thymidine kinase, ΔLNGFR: Low affinity nerve growth factor receptor, rhCNTF: recombinant human ciliary neurotrophic factor, ABCD1: ATP binding cassette subfamily D member 1.

Table 3. Tissue engineering products

TRADE NAME/ PROPER NAME	MANUFACTURER	INDICATIONS	APPROVED BY/DATE	DESCRIPTION	AT/AL
TRANSCYTE	Advanced Biohealing, Inc. (USA)	2nd and 3rd degree burns	USA FDA 1997 Feb.	Newborn HDF cultured on a nylon mesh coated with porcine collagen	AL
APLIGRAF	Organogenesi, Inc. and Novartis AG (USA)	Chronic VLU, DFU	USA FDA 1998 Jun.	Bi-layered tissue-engineered skin containing an inner HDF layer and an outer HEK layer	AL
DERMAGRAFT	Organogenesis, Inc. (USA)	Full-thickness DFU >6 weeks extended through the dermis without tendon, muscle, joint capsule, or bone exposure	USA FDA 2001 Sep.	HDF on a piece of bioabsorbable scaffold	AL
AURIX	Nuo Therapeutics, Inc. (USA)	All types of ulcers (DFU, pressure, VLU, etc.)	USA FDA 2007 Sep.	PRP hematogel	AL
EPICEL CULTURED EPIDERMAL AUTOGRAFTS	Vericel Corp. (USA)	Deep dermal or full-thickness burns	USA FDA 2007 Oct.	HEK cultured on murine 3T3 fibroblasts, with grafts attached to petrolatum-impregnated gauze and fixed with titanium clips	AT
GINTUIT ACKFBC	Organogenesis, Inc. (USA)	Surgically created vascular wound bed in the treatment of mucogingival conditions	USA FDA 2012 Mar.	Neonatal HEK and HDF cultured on bovine COL matrix	AL

OMNIGRAFT DERMAL REGENERATION MATRIX	Integra LifeSciences Corp. (USA)	DFU	USA FDA 2016 Jan.	Bi-layered bioengineered scaffold comprising an inner layer of bovine COL and chondroitin and an outer layer of thin silicone	Xn
ALLOGENEIC CULTURED KERATINOCYTES AND DERMAL FIBROBLASTS IN MURINE COLLAGEN-DSAT (STRATAGRAFT)	Stratatech Corporation (USA)	DPT	USA FDA 2021 Jun.	A sheet of approximately 100 cm2 consisting of keratinocytes grown on gelled COL containing HDF	AL
ALLOGENEIC PROCESSED THYMUS TISSUE–AGDC (RETHYMIC)	Enzyvant Therapeutics GmbH (Switzerland)	Pediatric patients with congenital athymia	USA FDA 2021 Oct.	Thymus tissue that is collected from donors <9 months of age	AL
ACELLULAR TISSUE-ENGINEERED VESSEL-TYPE (SYMVESS)	Humacyte Global, Inc. (USA)	Extremity arterial trauma requiring immediate revascularization	USA FDA 2024 Dec.	Acellular tissue-engineered vessel as a vascular conduit	-
MACI	Vericel Corp. (USA)	Single or multiple symptomatic full-thickness cartilage defects of the knee, with or without subchondral bone involvement	USA FDA 2016 Dec. EMA. 2013 June.	Cultured chondrocytes on a porcine COLI/II membrane	AT
RECELL	AVITA Medical Americas, Inc. (USA)	Acute PTB Surgical excursion or resection	USA FDA 2023 Jun.	The device prepares a suspension of a mixed population of HEK, HDF, and melanocytes.	AT
NOVOCART 3D	Octane Biotherapeutics Inc. (Canada)	Knee joint cartilage defects	EMA 2003 Aug.	3D-chondrocyte-loaded COL scaffold	AT

REGENERCELL	Avita Medical Ltd (UK)	DFU& VLU	EMA 2015 Jan.	The device produces a skin epithelial cell suspension	AT
HOLOCLAR	Chiesi Farmaceutici S.p.A (Italy)	Severe LSCD	EMA 2015 Feb.	HCEpC containing stem cells	AT
VERGENIX STR	CollPlant (Israel)	connective tissue disorders (tendinopathy)	EMA 2016 Oct.	Recombinant human type I collagen combined with autologous PRP	AT
RENOVACELL	Avita Medical Ltd (UK)	Repigmentation of hypopigmented burn scars	EMA 2016 Sep.	The combination of medical needling with a suspension of epithelial cells	AT
SPHEROX	CO.DON AG (Germany)	Symptomatic cartilage defects on the femoral condyle and/or patella, with defect areas ≤10 cm^2	EMA 2017 July.	Spheroids consist of autologous chondrocytes and extracellular matrix	AT
VERGENIX FG	CollPlant (Israel)	Surgical wounds and chronic wounds, DFU	EMA 2020 Oct.	Type I rhCOL and HPMC	-
HOLODERM	Tego Science (South Korea)	Deep 2^{nd} and 3^{rd} degree burns	South Korea MFDS 2002 Dec.	Cultured HEK sheet	AT
KALODERM	Tego Science (South Korea)	Deep 2^{nd} degree burns and DFU	South Korea MFDS 2005 Mar. (for burns) 2010 Jan. (for DFU)	Cultured HEK sheet	AL
HYALOGRAFT 3D™	CHA Bio&Diostech Co Ltd (South Korea)	DFU	South Korea MFDS 2007 Sep.	Cultured HDF on Hyaluronic derivative scaffold	AT
CARDIOCEL	Admedus (Singapore)	ASD & VSD	Australia HAS	Tissue-engineered bovine pericardium	Xn

PURE COLLAGEN SCAFFOLD			2014 Nov.		
JACE EPIDERMIS-DERIVED CELL SHEET	J-TEC (Japan)	Scars, vitiligo, birthmarks, ulcers, donor sites, or severe burns involving ≥30% total DDB + DB	Japan PMDA 2007 Oct.	HEK sheets cultured on 3T3-J2 cells	AT
JACC AT CHONDROCYTE	J-TEC (Japan)	Cartilage defects >2–4 cm^2 with no other viable treatment option	Japan PMDA 2012 July.	Cultured chondrocytes in atelocollagen gel	AT
HEARTSHEET SDCS	Terumo Corp. (Japan)	Severe heart failure due to ischemic heart disease	Japan PMDA 2015 Sep.	Skeletal myoblast sheet	AT
NESKEEP	Alfresa Pharma (Japan)	Spacer placement surgery	Japan PMDA 2018 Oct.	Absorbable polyglycolic acid spacer	-
ARTIFICIAL TRANSPLANTED PIGSKIN	Chongqing Zongshen Junhui Biotechnology (China)	Burn wounds and other types of traumatic injuries	China CFDA 2007	Fresh skin from Bama miniature pigs transfected with CTLA4Ig	Xn
BILAYER ARTIFICIAL SKIN	Shaanxi Eyre skin Biological Engineering (China)	Deep burn wound ranging between 2^{nd} degree and 3^{rd} degree, with an area up to 20 cm^2 (diameter <5 cm)	China CFDA 2007	Bilayer tissue-engineered skin comprising an outer layer of human epidermal cells and an inner layer of HDF on bovine COL matrix.	AL
AMNIOSIN	SinaCell (Iran)	Corneal ulcer and chronic full-thickness DFU (>6 weeks) involving the dermis without underlying tendon, muscle, joint capsule, or bone	Iran FDA 2017 Mar.	A dressing derived from acellular human amniotic membrane	AL

CELL-AMNIOSIN	SinaCell (Iran)	Chronic full-thickness DFU (>6 weeks) penetrating the dermis without underlying tendon, muscle, joint, or bone exposure	Iran FDA 2017 Mar.	Cellular dressing formed from human amniotic membrane	AL
ROOINSHEET	Royan AtiTech Pharmed (Iran)	Deep 2nd degree and 3rd degree burn wounds	Iran FDA 2024 Sep.	Cultured HEK sheet	AL
ROOINGRAF	Royan AtiTech Pharmed (Iran)	Deep 2nd degree burns and DFU	Iran FDA 2024 Sep.	Neonatal HEK and HDF on bovine COL matrix	AL

Abbreviations: HDF: Human dermal fibroblast, HEK: Human epidermal keratinocytes, PRP: platelet-rich plasma, rhCollagen: recombinant human collagen, HPMC: hydroxypropyl methyl cellulose, COL: collagen, DFU: Diabetic foot ulcers, DDB: Deep dermal burn, ASD: Atrial septal defect, VSD: Ventricular septal defect, VLS: venous leg ulcers, PTB: partial-thickness thermal burn, LSCD: limbal stem cell deficiency, DPT: deep partial thickness.

5. Conclusion

The global trend in CGTPs demonstrates particularly strong growth in the development of gene therapy and immune cell-based therapies for the treatment or functional management of life-threatening and previously incurable diseases, such as cancers and rare genetic disorders. TEPs are also expanding, but with slightly more moderate growth compared with gene and cell therapies. According to the most recent report from the Alliance for Regenerative Medicine, the total number of clinical trials involving CGTPs reached 2,125 by the third quarter of 2025. Notably, the Asia-Pacific region has surpassed North America in the number of active trials, highlighting growing global competition to drive CGTPs innovation. Within this landscape, gene therapies and immune cell–based therapies constitute the largest and most rapidly expanding categories in the fields of oncology and inherited diseases [4]. Despite the remarkable progress and great interest in CGTPs, as evidenced by the rising investments by leading pharmaceutical companies over the last decade, developing these innovative products faces many challenges, including requirements for advanced technological equipment, difficulties in processes involved in manufacturing, such as scaling up or scaling out, ensuring product efficacy, and managing packaging, storage, and stability. The complexity of clinical trial design is due to the rarity of target diseases, the limited number of patients, a lack of comprehensive knowledge about disease pathophysiology, problems in interpreting endpoints for new indications, and concerns about long-term adverse events. Additionally, regulatory considerations related to limited appropriate standards and reference materials, inadequate guidelines, high costs, and lengthy approval processes further complicated efforts to ensure these products' safety and efficacy [16, 17]. To address these challenges, emerging technologies like

dynamic culture systems, process analytical monitoring, continuous production, artificial intelligence, and the development of human biobanks are under development to improve process control, consistency, automation, and scalability [18, 19].

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