United States Government Accountability Office

Report to Congressional Committees

March 2023

REGENERATIVE MEDICINE AND ADVANCED THERAPIES

Information on Workforce and Education

Accessible Version

GAO-23-106030

GAO Highlights

Highlights of GAO-23-106030, a report to congressional committees

March 2023

REGENERATIVE MEDICINE AND ADVANCED THERAPIES

Information on Workforce and Education

Why GAO Did This Study

The field of regenerative medicine and advanced therapies—including cell, gene, and tissue-based therapies—is evolving and interdisciplinary. Practitioners believe these therapies have the potential to revolutionize patient care and improve lives. The promise of such therapies to ameliorate, or cure, previously untreatable diseases and conditions depends, in part, on the existence of a robust, well-trained workforce.

The Timely ReAuthorization of Necessary Stem-cell Programs Lends Access to Needed Therapies (TRANSPLANT) Act of 2021 included a provision for GAO to study the regenerative medicine and advanced therapies workforce in the commercial and academic sectors. This report provides information on (1) the makeup of this workforce, (2) education and training for this workforce, and (3) current and future workforce and education and training needs.

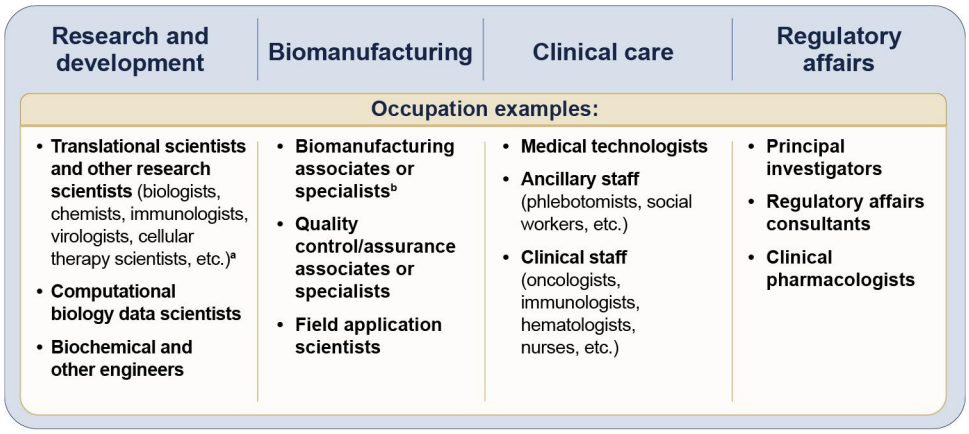
GAO interviewed officials from the Department of Health and Human Services (HHS), and eight stakeholder organizations selected for representation across the occupational areas GAO identified for this work, as well as other criteria. GAO also reviewed related reports and job postings. Existing workforce and education data do not contain information specific to the regenerative medicine workforce. To quantify the number of stakeholders who made certain statements, “some” means two to four stakeholders and “many” means five to seven stakeholders.

View GAO-23-106030. For more information, contact Leslie V. Gordon at (202) 512-7114 or GordonLV@gao.gov.

What GAO Found

The goal of regenerative medicine and advanced therapies is to repair or replace damaged human cells, tissues, or organs to supplement or restore function. The field is developing therapies that go beyond existing treatments to address underlying causes of disease or provide cures for previously untreatable diseases and conditions. The regenerative medicine and advanced therapies workforce is generally reflective of the larger life sciences workforce, with individuals occupying a wide range of jobs across research and development, biomanufacturing, clinical care, and regulatory affairs, as shown below.

Examples of Regenerative Medicine and Advanced Therapy Occupations



Source: GAO analysis of information from articles, industry reports, and interviews with selected stakeholders and federal officials. | GAO-23-106030

Accessible Data for Examples of Regenerative Medicine and Advanced Therapy Occupations

Activity	Occupation examples
Research and development	• Translational scientists and other research scientists (biologists, chemists, immunologists, virologists, cellular therapy scientists, etc.)[a] • Computational biology data scientists • Biochemical and other engineers
Biomanufacturing	• Biomanufacturing associates or specialists[b] • Quality control/assurance associates or specialists • Laboratory application scientists
Clinical care	• Medical technologists • Ancillary staff (phlebotomists, social workers, etc.) • Clinical staff (oncologists, immunologists, hematologists, nurses, etc.)
Regulatory affairs	• Principal investigators • Regulatory affairs consultants • Clinical pharmacologists

[a]Translational scientists take discoveries made in the laboratory, clinic, or field, and transform them into new treatments and approaches that help improve the health of the population.

[b]Biomanufacturing activities include the production of therapies using living cells.

Individuals working with regenerative medicine and advanced therapies would need postsecondary degrees appropriate to their area of work. For example, researchers would generally need science- and engineering-based degrees, and clinical occupations would generally need clinical and professional degrees. Further, stakeholders noted that many occupations would likely need additional specialized training, such as training in laboratory techniques, or medical fellowships in topics and practices specific to the field.

Many of the eight stakeholders GAO interviewed discussed shortages in the number of current and projected laboratory and biomanufacturing technicians to support the development of regenerative medicine and advanced therapies, as well as gaps in other positions, such as data scientists. Some stakeholders said that education for these technicians at the community and technical college level is insufficient to meet current and future workforce needs. In addition, many stakeholders noted that there is no nationally recognized education curriculum for the field. One of these stakeholders agreed that a core curriculum that reflects the diverse, interdisciplinary nature of regenerative medicine and advanced therapies would help support a competent, robust workforce.

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Abbreviations

CAR	chimeric antigen receptor
FDA	Food and Drug Administration
HHS	Department of Health and Human Services
NIH	National Institutes of Health

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March 23, 2023

The Honorable Bernard Sanders
Chair
The Honorable Bill Cassidy
Ranking Member
Committee on Health, Education, Labor and Pensions
United States Senate

The Honorable Cathy McMorris Rodgers
Chair
The Honorable Frank Pallone, Jr.
Ranking Member
Committee on Energy and Commerce
House of Representatives

The field of regenerative medicine and advanced therapies is evolving and interdisciplinary. Practitioners believe these therapies have the potential to revolutionize patient care and improve lives. Regenerative medicine and other advanced therapies include cell, gene, and tissue-based therapies.[1] The goal of these therapies is to repair or replace damaged human cells, tissues, or organs to supplement or restore function, by going beyond existing medical treatments to address the underlying causes of disease or provide cures for previously untreatable diseases and conditions.

Over the years, technologies for the development of these therapies have advanced significantly. Research and development for such technologies includes, for example, new ways to engineer tissue-based therapies. As of December 2022, the Food and Drug Administration (FDA) has

[1]For the purposes of this report, we use "regenerative medicine and advanced therapies" to refer to cell, gene, and tissue-based therapies that are intended to repair damage or restore function. Individuals working in regenerative medicine may use different terminology to describe such therapies as the field continues to evolve.

approved 26 regenerative medicine and advanced therapies.[2] In 2019, a former FDA commissioner predicted FDA could approve 10 to 20 such therapies annually by 2025.[3] The promise of new, approved regenerative medicine and advanced therapies to ameliorate and cure previously untreatable diseases and conditions depends, in part, on the existence of a robust, well-trained workforce.

Within the Department of Health and Human Services (HHS), the National Institutes of Health (NIH) and FDA have responsibilities for regenerative medicine and advanced therapy development and oversight. NIH funds scientific regenerative medicine and advanced cell, gene, and tissue research, while FDA reviews, approves, and regulates the development and marketing of therapies for which research and development has been successful.[4] From fiscal year 2015 through fiscal year 2021 (the most recent complete fiscal year of data available), NIH provided close to $7 billion in funds for regenerative medicine research.[5] Neither FDA nor NIH has responsibility for ensuring the sufficiency of this workforce.

The Timely ReAuthorization of Necessary Stem-cell Programs Lends Access to Needed Therapies (TRANSPLANT) Act of 2021 included a

[2]Physicians have been conducting stem cell bone marrow transplants since the late 1950s. FDA approved the first tissue-engineered product in 1998, a skin graft for the treatment of a specific form of ulcers. Most recently, in November 2022, FDA approved a viral vector-based gene therapy for the treatment of adults with hemophilia B who meet certain conditions.

[3]Food and Drug Administration, "Statement from FDA Commissioner Scott Gottlieb, M.D. and Peter Marks, M.D., Ph.D, Director of the Center for Biologics Evaluation and Research on new policies to advance development of safe and effective cell and gene therapies," https://www.fda.gov/news-events/press-announcements/statement-fda-commissioner-scott-gottlieb-md-and-peter-marks-md-phd-director-center-biologics, accessed November 8, 2022. According to the statement, this predication was based on an assessment of the current therapies in the development pipeline and their clinical success rates.

[4]In addition, HHS's Health Resources and Services Administration contracts with The National Bone Marrow Donation/Be the Match and cord blood banks to administer the C. W. Bill Young Cell Transplantation Program to provide support to patients who need bone marrow or umbilical cord blood transplants to treat leukemia, lymphoma, sickle cell anemia, or other inherited metabolic or immune system disorders.

[5]We previously reported on NIH funding amounts for regenerative medicine research from fiscal year 2012 through fiscal year 2014. See, GAO, *Regenerative Medicine: Federal Investment, Information Sharing, and Challenges in an Evolving Field*, GAO-15-553 (Washington, D.C.: June 23, 2015).

provision for GAO to study the regenerative medicine and advanced therapies workforce in the commercial and academic sectors.[6] This report provides information on

1. the makeup of the regenerative medicine and advanced therapies workforce;
2. education and training for this workforce; and
3. current and future workforce and education and training needs for this evolving field.

To provide information on the makeup of the regenerative medicine and advanced therapies workforce, we interviewed federal officials from FDA and NIH, as well as representatives from eight stakeholder organizations. We selected these organizations based on several criteria, including that they represent individuals across four broad occupational categories for this workforce, which we identified for the purposes of this report—research and development, biomanufacturing, clinical care, and regulatory affairs.[7] We also reviewed reports related to the science and technology workforce, such as the National Institute for Innovation in Manufacturing Biopharmaceuticals July 2021 report on the cell and gene therapy technician workforce, and others.[8] We relied on information from these interviews and reports because, based on consultation with officials from the Department of Labor and the Association of American Medical Colleges, we determined that existing federal and national data is not

[6]Pub. L. No. 117-15, § 5, 135 Stat. 277. This act also directs HHS to review the state of the science of adult stem cell therapies and directs NIH to "further the field" of regenerative medicine using adult stem cells.

[7]We selected and interviewed representatives from the following organizations: Alliance for Regenerative Medicine; Advanced Regenerative Manufacturing Institute; American Academy and Board of Regenerative Medicine; National Academies of Science, Engineering, and Medicine Forum on Regenerative Medicine; American Society for Transplantation and Cellular Therapy; Association of American Medical Colleges; Mayo Clinic Center for Regenerative Biotherapeutics; and Wake Forest Institute for Regenerative Medicine. For the purposes of quantifying the number of stakeholder organizations who made certain statements for this report, "some" means two to four stakeholders and "many" means five to seven stakeholders. We also interviewed officials from HHS's Health Resources and Services Administration.

[8]See, National Institute for Innovation in Manufacturing Biopharmaceuticals, *Labor Market Analysis for Cell and Gene Therapy Technician Workforce* (Newark, Del: July 2021), and National Science Board, National Science Foundation, *The State of U.S. Science and Engineering 2022*, NSB-2022-1 (Alexandria, Va.: January 2022).

specific to this workforce.[9] We also conducted a simple key word search on a national online job search site to corroborate and expand on workforce information provided by our eight stakeholders.

To provide information on education and training for the regenerative medicine and advanced therapies workforce, we interviewed FDA and NIH officials, as well as representatives from the eight selected stakeholder organizations, and reviewed related science and technology reports as cited above. Similar to workforce data, based on consultation with the Department of Education and the Association of American Medical Colleges, we determined that existing federal and national education data are not specific to regenerative medicine and advanced therapies.[10]

To provide information on current and future workforce and education and training needs, we interviewed the same federal officials and eight stakeholder organizations. Information obtained from stakeholder organizations is intended to be illustrative and does not represent the perspectives of all individuals and organizations in this field.

We conducted this performance audit from May 2022 to March 2023 in accordance with generally accepted government auditing standards. Those standards require that we plan and perform the audit to obtain sufficient, appropriate evidence to provide a reasonable basis for our

[9]The Department of Labor's Bureau of Labor Statistics collects data on the more general life sciences occupations in biological science and technology, such as biochemists, biological technicians, chemical technicians, material scientists, and microbiologists. However, it does not include more granular categories specific to regenerative medicine and advanced therapies or other biological science and technology fields. The Association of American Medical Colleges collects data on medical residents in the U.S. and projected physician workforce by medical specialties, but it does not include data specific to those working with regenerative medicine and other advanced therapies. Regenerative medicine and advanced therapies are not medical specialties recognized by the American Board of Medical Specialties, which provides independent evaluation, verification, and certification of physician and medical specialist skills and expertise and grants certificates to physicians who complete certain requirements.

[10]The Department of Education collects data on postsecondary degrees conferred in various fields, including biological sciences. However, these data do not necessarily reflect the number of individuals who may go on to work in regenerative medicine and advanced therapies research or clinical care. The Association of American Medical Colleges collects data on students entering and graduating from medical school, in addition to physician workforce data. However, similar to workforce data, because regenerative medicine and advanced therapies are not medical specialties recognized by the American Board of Medical Specialties, the Association of American Medical Colleges does not have any data on medical education in this field.

findings and conclusions based on our audit objectives. We believe that the evidence obtained provides a reasonable basis for our findings and conclusions based on our audit objectives.

Background

Regenerative medicine and advanced therapies are used to treat patients with a wide range of diseases and conditions across numerous fields. Current FDA-approved therapies are for the treatment or correction of certain hematological, oncological, dermatological, ophthalmological, dental, immunological, orthopedic, and neurological diseases and conditions. For example, patients with certain types of leukemia, lymphoma, and other types of cancer may undergo chemotherapy to kill the cancerous cells in their bone marrow and then receive healthy, blood-forming cells through one of FDA's approved bone marrow transplant therapies. Other types of approved therapies aim to provoke an immune response, such as gene-edited cellular therapies that modulate patients' immune systems to attack cancerous tumors, or help rebuild tissues, such as a tissue-engineered therapy to repair knee cartilage. As such, the regenerative medicine and advanced therapies workforce encompasses individuals responsible for the research, development, and biomanufacturing of such therapies for eventual marketing approval by FDA, as well as the clinicians and technicians responsible for administering these therapies to patients across these varied medical fields.

Advanced Therapies and Biomanufacturing

Cell and gene therapies use cells either from a patient's own body or from a donor to treat disease. These therapies use naturally occurring, reprogrammed, or genetically modified cells, including stem cells, immune system cells, and other types of cells, to grow, replace, or repair diseased or damaged ones to help treat or cure disease. Gene therapies also include therapies that deliver genetic material to cells using viral or other vectors, to change how proteins are used by cells.

Tissue-based therapies combine cells and biologically compatible materials from natural or artificial sources (e.g., animal tissues or polyethylene plastic) that serve as structural scaffolds into a single product to restore or strengthen damaged tissue.

Biomanufacturing for regenerative medicine and advanced therapies requires: collecting biological materials, such as cells or tissues from patients or donors; altering and testing such materials for safety, sterility, and efficacy; and packaging and delivering the therapies to clinical care sites for patient administration. Currently, biomanufacturing is primarily conducted manually in small batches in laboratories. In the longer term, biomanufacturers aim to produce versions of existing and developing cell and tissue therapies in larger quantities, which may significantly increase accessibility and reduce the cost of such therapies. This future state necessitates the development of standards, equipment, and automated processes to make biomanufacturing scalable, consistent, and stable.

Source: GAO. | GAO-23-106030

The process for bringing new regenerative medicine and advanced therapies to the market generally takes years. For a therapy to be considered for marketing approval by FDA, commercial and academic developers of such therapies must carry out numerous activities across research and development, biomanufacturing, clinical care, and regulatory affairs.

- Research and development activities include preclinical testing for safety and effectiveness.
- Biomanufacturing activities include the production of therapies using living cells and testing these therapies on human subjects.[11]
- Clinical care activities include assessing patients for suitability of treatment with such therapies, administering the therapies, and assessing patient outcomes.
- Regulatory affairs activities include navigating the federal regulatory process and submitting the necessary applications, results of toxicity and safety testing, and other required information and data, to FDA.

The Regenerative Medicine and Advanced Therapies Workforce Is Wide-Ranging and Interdisciplinary

The regenerative medicine and advanced therapies workforce is generally reflective of the larger life sciences workforce. As such, individuals working in the regenerative medicine and advanced therapies field occupy a wide range of jobs across research and development,

[11]Before testing therapies in human subjects may occur, manufacturers must submit an investigational new drug application to FDA.

biomanufacturing, clinical care, and regulatory affairs activities. For example,

- Research and development occupations may include research physicians, cell therapy scientists (including biologists, chemists, and immunologists), data scientists, and laboratory technicians, among others.[12] These individuals may work in academic medical centers or in commercial companies, such as pharmaceutical or biotechnology companies.
- Biomanufacturing occupations may include manufacturing associates, cell therapy process development engineers, quality control associates, and technical sales specialists, among others.[13]
- Clinical care occupations may include physicians, advanced practitioners, nurses, phlebotomists, and transplantation surgeons, among others.[14]
- Regulatory occupations may include regulatory consultants, clinical pharmacologists, and others who are responsible for ensuring that manufacturers meet FDA's regulatory requirements for new therapies. These occupations may be the same as or similar to those in research and development and biomanufacturing.

According to some of our stakeholders, many of these occupations—such as data scientists, various technicians, physicians, and regulatory consultants—may be needed across the product development and clinical care activities.

See figure 1 for an illustrative example of the activities and occupations that correspond to the four broad occupational categories for one FDA-

[12]Data scientists collect and analyze data, conduct experimental measurements, capture digital images and analyses, and maintain cybersecurity standards and practices throughout the development and biomanufacturing process.

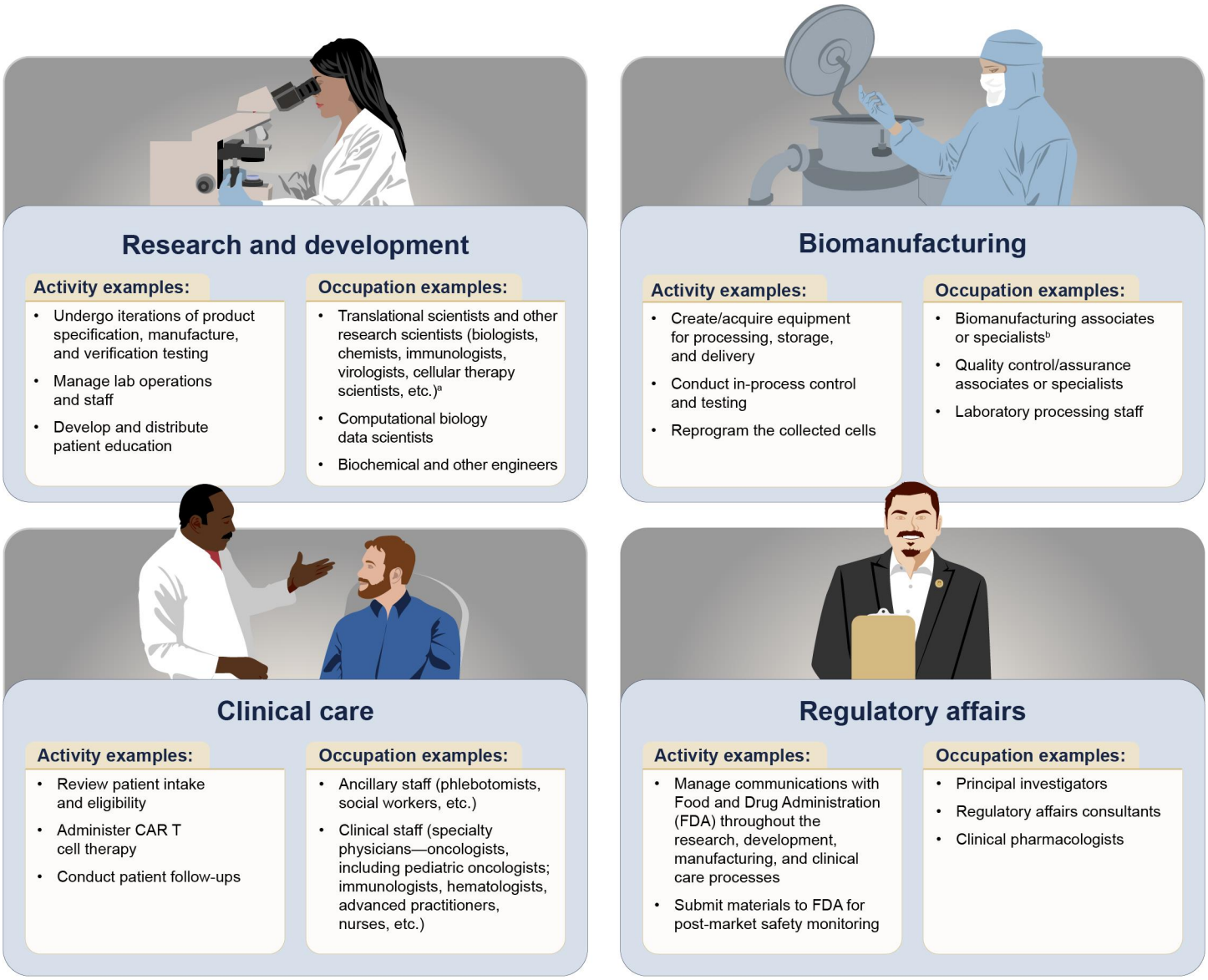
[13]Quality control and assurance associates create standard operating procedures, develop training, and test products and samples, among other duties.

[14]Some stakeholders said other health care-related occupations needed in this field include social workers, patient advocates, patient educators, and clinical trial diversity coordinators.

approved advanced therapy.[15] See appendix I for more detailed information on activities and occupations for this cell therapy.

[15]The FDA-approved chimeric antigen receptor (CAR) T cell therapy used for this example is designed to treat multiple myeloma, or cancer of the plasma cells, and relapsed large B cell lymphoma, a type of non-Hodgkin lymphoma. Patients whose disease has relapsed or is not responding to prior treatments are eligible for this CAR T cell therapy. FDA has approved multiple CAR T cell therapies.

Figure 1: Sample Activities and Occupations for Chimeric Antigen Receptor (CAR) T Cell Therapy by Occupation Category



Source: GAO analysis of information from articles, industry reports, and interviews with selected stakeholders and federal officials; GAO (illustrations). | GAO-23-106030

Accessible Data for Figure 1: Sample Activities and Occupations for Chimeric Antigen Receptor (CAR) T Cell Therapy by Occupation Category

Activity	Activity examples	Occupation examples
Research and development	• Undergo iterations of product specification, manufacture, and verification testing • Manage lab operations and staff • Develop and distribute patient education	• Translational scientists and other research scientists (biologists, chemists, immunologists, virologists, cellular therapy scientists, etc.)[a] • Computational biology data scientist • Biochemical and other engineers
Biomanufacturing	• Create/acquire equipment for processing, storage, and delivery • Conduct in-process control and testing • Reprogram the collected cells	• Biomanufacturing associates or specialists[b] • Quality control/assurance associates or specialists • Laboratory processing staff
Clinical care	• Review patient intake and eligibility • Administer CAR T cell therapy • Conduct patient follow-ups	• Ancillary staff (phlebotomists, social workers, etc.) • Clinical staff (specialty physicians—oncologists, including pediatric oncologists; immunologists, hematologists, advanced practitioners, nurses, etc.)
Regulatory affairs	• Manage communications with Food and Drug Administration (FDA) throughout the research, development, manufacturing, and clinical care processes • Submit materials to FDA for post-market safety monitoring	• Principal investigators • Regulatory affairs consultants • Clinical pharmacologists

Note: This CAR T cell workforce figure is intended to serve as an illustrative example of the range of activities and occupations across the four categories of therapy development we use for this report. As an illustrative example, this figure may not be a complete rendering of all activities and occupations that are involved. The occupation examples are not intended to align with the order of activity examples.

[a]Translational scientists take discoveries made in the laboratory, clinic, or field and transform them into new treatments and approaches that help improve the health of the population.

[b]Biomanufacturing activities include the production of therapies using living cells.

Occupations Require Postsecondary Biological Science or Clinical Degrees and Additional Specialized Training

Individuals working with regenerative medicine and advanced therapies would need postsecondary education and degrees appropriate to their area of work.[16] That is, researchers and related occupations would need

[16]Postsecondary education includes technical certifications and associate, bachelor, master, doctoral, and professional degrees.

science- and engineering-based degrees, and clinical occupations would need clinical and professional degrees. Specifically,

- Research and development and biomanufacturing occupations generally require certificates or associate, undergraduate, or postgraduate degrees in biological sciences and biological engineering, among others.
- Clinical care occupations generally require medical, nursing, or related clinical or professional degrees.
- Regulatory affairs occupations require either life sciences degrees like those working in research and development and biomanufacturing, or clinical or professional degrees like those in clinical care, including pharmacology, in order to navigate the FDA approval process.

Further, according to many of our eight selected stakeholders, workers in many regenerative medicine and advanced therapy occupations would likely need additional specialized training, such as on-the-job training in laboratory techniques, or medical fellowships in topics and practices specific to the field. For example, laboratory technicians assisting with research and development of stem cell cancer therapies would need training on how to conduct human leukocyte antigen typing to match bone marrow donors and recipients. For CAR T cell cancer therapies, laboratory technicians assisting with research and development would need additional specialized knowledge and training on editing the genes of the cells.

Regenerative medicine biomanufacturing technicians would need training in current good manufacturing practices, and additional training may be needed for technicians working on specific types of therapies. For example, biomanufacturing technicians would need additional specialized knowledge and training on maintaining current good manufacturing and tissue practices for growing tissue using scaffolds.[17] There may be other

[17]Regulations for current good manufacturing practices for medical products provide minimum requirements for the design, monitoring, and controls used in manufacturing, processing, and packing. See 21 C.F.R. Parts 210, 211, 212 (2022). These regulations help ensure that a medical product is safe for use and it has the ingredients and intended effects it claims to have. Biologics manufacturers and products must also satisfy detailed standards set forth in regulations to help ensure product safety, identity, quality, purity, potency, and stability. See 21 C.F.R. Parts 600 and 610. Current good tissue practice requirements pertain to the methods used in, and the facilities and controls used for, the manufacture of human cells, tissues, and cellular and tissue-based products in a way that prevents the introduction, transmission, and spread of communicable diseases. See 21 C.F.R. Part 1271, Subparts D and E (2022).

nuanced differences in education and training for similarly titled occupations in the field depending on research, manufacturing, and clinical care needs of each therapy.

Various entities, such as academic medical centers, industry associations, and the federal government offer internships or continuing professional education for this workforce. For example, workers may participate in continuing professional education opportunities, such as conferences and webinars, to maintain proficiency and keep current on advances in the field. Other opportunities, such as internships and fellowships, may provide more intensive training, such as for individuals in their early careers. See Table 1 for examples of internships and fellowships for which agency officials and stakeholders provided information.[18]

[18]In addition, one of our stakeholders, The American Academy and Board of Regenerative Medicine, currently offers its own certification in regenerative medicine for physicians practicing musculoskeletal or plastic and cosmetic regenerative medicine. However, this organization is not affiliated with or a member of the American Board of Medical Specialties.

Table 1: Examples of Regenerative Medicine and Advanced Therapies Internships and Fellowships

Provider/sponsor	Description
FDA Regenerative Medicine Fellowship	This fellowship aims to enhance the agency's ability to regulate regenerative medicine products and support the development of highly trained scientists and engineers through experience working with FDA's Office of Tissues and Advanced Therapies within the Center for Biologics Evaluation and Research and the Center for Devices and Radiological Health. FDA will sponsor fellows who are within 5 years of obtaining a doctoral degree for 2-3 years and provide a stipend commensurate with their experience.
FDA-NIH Interagency Oncology Task Force Fellowship	This fellowship trains scientists to build awareness of regulatory requirements into early stages of medical product development, and develop strategies to improve planning throughout research and regulatory review. This fellowship has four tracks: three oncology product research and review tracks for (1) concurrent NIH hematology/oncology fellows, (2) physicians board-certified in oncology, and (3) postdoctoral research fellows; and a fourth cancer prevention product and review track for doctoral-level individuals.
Alliance for Regenerative Medicine GROW Internship	The GROW (GeneRating Diversity and Opportunity Within Regenerative Medicine) internship is a summer program that provides early career paid opportunities in the regenerative medicine sector to Black or African American undergraduates, graduating seniors, and graduate students.

Source: GAO analysis of information from Food and Drug Administration (FDA), National Institutes of Health (NIH), and our selected stakeholders. | GAO-23-106030

Stakeholders Noted Current Shortages of Skilled Technicians and a Need for Additional Education for the Future Workforce

Stakeholders Identified Current Shortages of Skilled Laboratory and Manufacturing Technicians and Others

Many of the stakeholders we interviewed discussed shortages in either the number of current and projected laboratory technicians or the number of biomanufacturing technicians needed to support the development of regenerative medicine and advanced therapies. For example, some stakeholders cited a lack of technicians with the specialized skills and experience to conduct laboratory research activities, such as developing assays and conducting flow cytometry and mass spectrometry.[19] These stakeholders noted that the small number of 2-year biotechnology degree or certificate programs contributes to this shortage. Because of the lack of

[19]Assays are test systems that evaluate the effects of chemical compounds on cellular, molecular, or biochemical processes of interest. Flow cytometry is a technique that allows for the analyses of multiple characteristics of thousands of individual cells in a short period of time. Mass spectrometry is a tool used for measuring the mass-to-charge ratio of one or more molecules in a sample, to identify known and unknown compounds via molecular weight determination, and to determine structure and chemical properties of molecules.

individuals with this educational background, some stakeholders said individuals with higher levels of education than may be necessary—such as bachelor's or master's degrees–were working in these roles, which tend to require repetitive manual work. This practice leads to high turnover, as staff with more advanced degrees seek to further their research and development careers. Academic medical institutions' inability to compete with salaries and benefit packages offered by commercial companies that conduct similar research is a contributing factor to technician shortages and high turnover, according to one stakeholder.

Stakeholders also identified workforce shortages and gaps in other specialized positions. For example, many stakeholders noted that there is a lack of quality control or quality assurance associates and data scientists who can work with large data sets. In addition, stakeholders noted shortages of individuals who have knowledge of and experience with FDA regulations, individuals with master's degrees who can manage both the scientific and operational/managerial sides of biomanufacturing, technicians with education or experience in clean room manufacturing and good manufacturing practices, and nurses and medical technologists who provide post-transplant care with education and training in assessing cell viability.[20] However, the lack of federal or national data specific to the regenerative medicine and advanced therapies workforce limits comprehensive analyses of workforce capacity and identification of potential gaps specific to this field.

Representatives from two stakeholder groups we spoke with said their organizations have conducted regenerative medicine and advanced therapies workforce assessments. For example, the Alliance for Regenerative Medicine published a workforce assessment in March 2023.[21] The Forum on Regenerative Medicine—a forum of the National Academies of Science, Engineering, and Medicine (National Academies)—convened a public workshop to discuss workforce issues in November 2022, and is expected release a report of the proceedings in spring 2023.

[20]In addition to individuals in the commercial and academic sectors with FDA regulatory experience, one stakeholder also mentioned a shortage of FDA employees to review regenerative medicine biologics licensing applications.

[21]Alliance for Regenerative Medicine, *Workforce Report: Gap Analysis for the Cell and Gene Therapy Sector* (Washington, D.C.: March 2023), accessed March 16, 2023, https://alliancerm.org/sector-report/workforce/.

Stakeholders Identified the Need for Additional Education to Help Ensure a Sufficient Workforce for the Future

Some stakeholders noted that vocational education for skilled laboratory and manufacturing technicians at the community and technical college level is insufficient to meet current and future workforce needs. In addition, many stakeholders noted that no nationally recognized regenerative medicine and advanced therapies education curriculum currently exists for either scientific or clinical and professional degrees.[22] For example, a representative from one stakeholder group told us that, of the approximately 200 community and technical colleges in Georgia, only four offer certificate programs or associate's degrees in biotechnology. In addition, a search of the Department of Education's College Navigator shows that only 73 institutions offer certificate programs or associate degrees in biotechnology, which is about 7 percent of the 1,043 public, tribal, and independent community colleges in the U.S. in 2022, according to the American Association of Community Colleges.

Some stakeholders we spoke with suggested the need to establish additional technical and other education programs to meet future workforce needs. They identified particular subjects a regenerative medicine-based curriculum should include for such programs, primarily in two of the four broad categories we identified—research and development and biomanufacturing. For example, one stakeholder group emphasized that education for this field needs to include active practice with laboratory and manufacturing equipment and in such environments, in addition to classroom learning.

Some stakeholders noted that additional education programs should include subjects consistent with technologies and processes for therapies that are FDA-approved or on a path toward regulatory approval, so that such programs are developed in line with industry needs. Such programs should also include education on good manufacturing practices, quality assurance, and regulatory requirements. Many stakeholders also noted such programs should include education on data science, especially as the field anticipates moving toward larger-scale, more automated

[22]Regenerative medicine and advanced therapies are not medical specialties recognized by the American Board of Medical Specialties; therefore, specific medical education or coursework may not exist in these areas. However, medical schools integrate regenerative medicine topics into foundational coursework as part of regular updates to the curricula, according to officials from the Association of American Medical Colleges.

manufacturing.[23] One stakeholder group suggested that certificate programs could also provide the education individuals would need to carry out laboratory techniques, especially for individuals who may be changing careers.[24]

One stakeholder group noted that some organizations were working to develop curricula for regenerative medicine and advanced therapies education. This stakeholder group suggested that such a curriculum could be franchised across colleges as well as industry, which might minimize the need for on-the-job training. In addition, this group noted establishing additional 2-year certificate or degree programs based on such a curriculum would also make such programs available to more diverse communities, thereby increasing workforce diversity. This stakeholder group agreed that consensus on a core curriculum that reflects the diverse, interdisciplinary nature of regenerative medicine and advanced therapies would help clarify the education and training needs for a competent, robust workforce.

Agency Comments

We provided a copy of the draft report to HHS for review and comment. HHS provided technical comments, which we incorporated as appropriate.

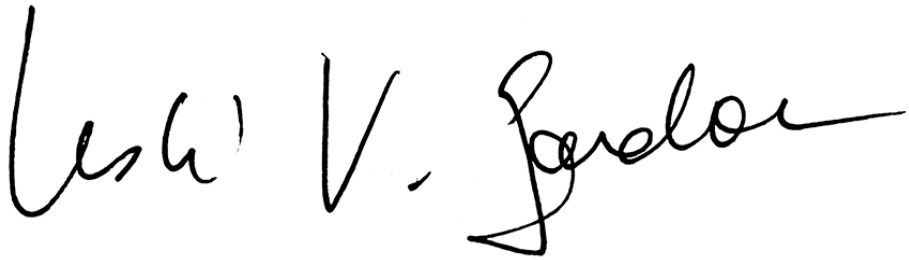
We are sending copies of this report to appropriate congressional committees and the Department of Health and Human Services. In addition, the report is available at no charge on the GAO website at https://www.gao.gov.

[23]Certain regenerative medicine and advanced therapies, such as CAR T cell therapy, are currently manufactured in clinical laboratories on an individual patient basis, according to one stakeholder. Developers are working toward a future state where therapies may be manufactured on a larger scale and with some automation. However, because these therapies are made with living cells that may be more sensitive to their environments and microenvironments than other drugs and biologics, such a future state would require a workforce that can implement manufacturing processes and analytics to ensure their consistency, efficacy, and safety.

[24]One stakeholder noted that additional professional training, such as in data science, would also help individuals in the current workforce advance their careers.

If you or your staff have any questions about this report, please contact me at (202) 512-7114 or GordonLV@gao.gov. Contact points for our Offices of Congressional Relations and Public Affairs may be found on

the last page of this report. GAO staff who made key contributions to this report are listed in appendix II.



Leslie V. Gordon
Director, Health Care

Appendix I: Activities and Occupations for Chimeric Antigen Receptor (CAR) T Cell Therapy by Category

Figure 2: Activities and Occupations for Chimeric Antigen Receptor (CAR) T Cell Therapy by Occupation Category

Research and development

Activity examples	*Occupation examples (not intended to align directly with activity examples)*

Early research and development

- Define the clinical need for CAR T cell therapy
- Identify target market(s) and product classification
- Form concept design with patients with cancer
- Select cells, materials, biochemical factors, and manufacturing methods
- Establish commercial strategy
- Manage lab operations and staff
- Execute defined project protocols
- Develop and assess animal models

- **Principal investigators**
- **Translational scientists and other research scientists** (biologists, chemists, immunologists, virologists, cellular therapy scientists, etc.)[a]
- **Public health experts**
- **Physicians**
- **Project scientists**
- **Process analytics research associates**
- **Regulatory affairs consultants**
- **Product analytical strategy leads**
- **Computational biology data scientists**
- **Laboratory technicians or managers**
- **Quality control/assurance associates or specialists**

Pre-clinical development

- Compile applicable standards
- Evaluate regulatory options
- Compile product requirements, such as patient needs, performance, regulation
- Undergo iterations of product specification, manufacture, and verification testing, with maintained traceability over the materials, processes, inspection methods, and results
- Validate sterile product and environment
- Identify optimal cell type/source for CAR T cell therapy
- Identify and collaborate with relevant clinical partner
- Conduct safety assessment to check for contaminants
- Determine requirements for cell and modified T cell stability, packaging, transport, delivery, and administration
- Prepare clinical evaluation, clinical protocols, and technical files for ethics and regulatory submissions, including defined CAR T cell metrics

- **Principal investigators**
- **Laboratory technicians** (animal science, physiology, pharmacology)
- **Engineers** (cell therapy process development engineers, biochemical engineers, etc.)
- **Laboratory processing staff**
- **Quality control/assurance associates or specialists**
- **Ancillary staff** (phlebotomists, social workers, etc.)
- **Clinical staff** (specialty physicians—oncologists, including pediatric oncologists; immunologists, hematologists, advanced practitioners, nurses, etc.)
- **Regulatory affairs consultants**

Clinical trials

- Apply quality control and quality assurance systems for design, manufacturing, and testing processes
- Implement infrastructure, work environment, and training controls
- Implement control of changes in production, suppliers, and design
- Conduct clinical investigation and follow up using defined CAR T cell metrics to establish the safety and efficacy of the product
- Evaluate clinical trial data
- Develop and distribute patient education

- **Principal investigators**
- **Engineers** (cell therapy process development engineers, biochemical engineers, etc.)
- **Laboratory processing staff**
- **Quality control/assurance associates or specialists**
- **Ancillary staff** (phlebotomists, social workers, etc.)
- **Clinical staff** (specialty physicians—oncologists, including pediatric oncologists; immunologists, hematologists, advanced practitioners, nurses, etc.)

Appendix I: Activities and Occupations for Chimeric Antigen Receptor (CAR) T Cell Therapy by Category

Biomanufacturing

Activity examples	*Occupation examples (not intended to align directly with activity examples)*
• Create/acquire equipment for processing, storage, and delivery • Test starting material for contamination • Conduct in-process control and testing • Reprogram collected cells • Perform cryopreservation	◦ **Principal investigators** ◦ **Biomanufacturing associates and specialists**[b] ◦ **Engineers** (cell therapy process development engineers, biochemical engineers, etc.) ◦ **Good manufacturing practices quality control analysts** ◦ **Laboratory processing staff** ◦ **Quality control/assurance associates or specialists** ◦ **Technical specialists** ◦ **Field application scientists** ◦ **Technical sales specialists**

Clinical care

• Review patient intake and eligibility • Perform leukapheresis (removal of the blood to collect specific blood cells) • Administer chemotherapy • Administer CAR T cell therapy • Evaluate clinical trial data • Conduct post-market reviews for safety and efficacy • Conduct patient follow-ups	• **Medical Technologists** • **Ancillary staff** (phlebotomists, social workers, etc.) • **Clinical staff** (specialty physicians—oncologists, including pediatric oncologists; immunologists, hematologists, advanced practitioners, nurses, etc.) • **Clinical pharmacologists** • **Principal investigators**

Regulatory affairs

• Manage communications with Food and Drug Administration (FDA) throughout the research, development, manufacturing, and clinical care processes • Submit materials to FDA for post-market safety monitoring	◦ **Principal investigators** ◦ **Regulatory affairs consultants** ◦ **Clinical pharmacologists**

Source: GAO analysis of information from articles, industry reports, and interviews with selected stakeholders and federal officials; GAO (icons). | GAO-23-106030

Accessible Data for Figure 2: Activities and Occupations for Chimeric Antigen Receptor (CAR) T Cell Therapy by Occupation Category

Activity	Activity examples	Occupation examples (not intended to align directly with activity examples)
Research and development: Early research and development	• Define the clinical need for CAR T cell therapy • Identify target market(s) and product classification • Form concept design with patients with cancer • Select cells, materials, biochemical factors, and manufacturing methods • Establish commercial strategy • Manage lab operations and staff • Execute defined project protocols • Develop and assess animal models	• Principal investigators • Translational scientists and other research scientists (biologists, chemists, immunologists, virologists, cellular therapy scientists, etc.)[a] • Public health experts • Physicians • Project scientists • Process analytics research associates • Regulatory affairs consultants • Product analytical strategy leads • Computational biology data scientists • Laboratory technicians or managers • Quality control/assurance associates or specialists
Research and development: Pre-clinical development	• Compile applicable standards • Evaluate regulatory options • Compile product requirements, such as patient needs, performance, regulation • Undergo iterations of product specification, manufacture, and verification testing, with maintained traceability over the materials, processes, inspection methods, and results • Validate sterile product and environment • Identify optimal cell type/source for CAR T cell therapy • Identify and collaborate with relevant clinical partner • Conduct safety assessment to check for contaminants • Determine requirements for cell and modified T cell stability, packaging, transport, delivery, and administration • Prepare clinical evaluation, clinical protocols, and technical files for ethics and regulatory submissions, including defined CAR T cell metrics	• Principal investigators • Laboratory technicians (animal science, physiology, pharmacology) • Engineers (cell therapy process development engineer, biochemical engineer, etc.) • Laboratory processing staff • Quality control/assurance associates or specialists • Ancillary staff (phlebotomists, social workers, etc.) • Clinical staff (specialty physicians—oncologists, including pediatric oncologists; immunologists, hematologists, advanced practitioners, nurses, etc.) • Regulatory affairs consultants

Activity	Activity examples	Occupation examples (not intended to align directly with activity examples)
Research and development: Clinical trials	• Apply quality control and quality assurance systems for design, manufacturing, and testing processes • Implement infrastructure, work environment, and training controls • Implement control of changes in production, suppliers, and design • Conduct clinical investigation and follow up using defined CAR T cell metrics to establish the safety and efficacy of the product • Evaluate clinical trial data • Develop and distribute patient education	• Principal investigators • Engineers (cell therapy process development engineers, biochemical engineers, etc.) • Laboratory processing staff • Quality control/assurance associates or specialists • Ancillary staff (phlebotomists, social workers, etc.) • Clinical staff (specialty physicians—oncologists, including pediatric oncologists; immunologists, hematologists, advanced practitioners, nurses, etc.)
Biomanufacturing	• Create/acquire equipment for processing, storage, and delivery • Test starting material for contamination • Conduct in-process control and testing • Reprogram collected cells • Perform cryopreservation	• Principal investigators • Biomanufacturing associates and specialists[b] • Engineers (cell therapy process development engineers, biochemical engineers, etc.) • Good manufacturing practices quality control analysts • Laboratory processing staff • Quality control/assurance associates or specialists • Technical specialists • Field application scientists • Technical sales specialists
Clinical care	• Review patient intake and eligibility • Perform leukapheresis (removal of the blood to collect specific blood cells) • Administer chemotherapy • Administer CAR T cell therapy • Evaluate clinical trial data • Conduct post-market reviews for safety and efficacy • Conduct patient follow-ups	• Medical Technologists • Ancillary staff (phlebotomists, social workers, etc.) • Clinical staff (specialty physicians—oncologists, including pediatric oncologists; immunologists, hematologists, advanced practitioners, nurses, etc.) • Clinical pharmacologists • Principal investigators
Regulatory affairs	• Manage communications with Food and Drug Administration (FDA) throughout the research, development, manufacturing, and clinical care processes • Submit materials to FDA for post-market safety monitoring	• Principal investigators • Regulatory affairs consultants • Clinical pharmacologists

Note: This CAR T cell workforce figure is intended to serve as an illustrative example of the range of activities and occupations across the four categories of therapy development we use for this report. As an illustrative example, this figure may not be a complete rendering of all activities and occupations that are involved. The occupation examples are not intended to align with the order of activity examples.

[a]Translational scientists work to turn observations in the laboratory, clinic, or community into interventions that improve the health of individuals and the public, from diagnostics and therapeutics to medical procedures and behavioral changes.

[b]Biomanufacturing activities include the production of therapies using living cells.

Appendix II: GAO Contact and Staff Acknowledgments

GAO Contact

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Staff Acknowledgments

In addition to the contact named above, Gerardine Brennan (Assistant Director), Shana R. Deitch (Analyst in Charge), Manuel Buentello, and Ling Guo made key contributions to this report. Also contributing were Sam Amrhein and Ethiene Salgado-Rodriguez.

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