Clinical Genomics Report

The Interplay Between Clinical Research and Clinical Diagnostics

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The Clinical Genomics Report – February 2021

Leading medical organizations have established precision medicine programs that support personalized patient treatment. ***Implementation of clinical genomics applications and enterprise-wide clinical data warehouses are considered the foundation for successful genomic medicine programs***. Innovative technological advancements have allowed us to sequence and uncover mutational events at unprecedented scale, while facilitating linking genomic data to high quality clinical data and diagnosis. Medical organizations understand the benefit of being empowered by data-driven approaches to reduce operational costs and time and to provide researchers and clinicians what is necessary to decipher critical research data and data for clinical-decision making. However, technical and scientific limitations still need to be addressed for optimized and universal use of various data sources for both clinical and research purposes.

While data production is no longer a challenge, and targeted panels – and to some extent whole exome sequencing - are well adopted, the expected dramatic rise in whole genome sequencing will result in unforeseeable quantities of data at the clinical level that need to be managed, understood, and communicated. ***Low-cost sequencing of whole genomes at population scale is already in existence, but not yet widespread in the clinic, as many observed changes at the genome level cannot yet be fully interpreted or explain an existing phenotype***. Scalable, fully automated analysis and knowledge extraction solutions incorporating rich annotation information are necessary to overcome these challenges. With massive quantities of NGS data (linked to different clinical and other types of data), artificial intelligence and machine learning are hailed as pivotal solutions to address the data interpretation and knowledge extraction challenges and to advance the clinical application of genomics.

Despite increasing efforts and investments in implementing clinical applications and building data solutions, ***many organizations are still challenged with the multi-faceted complexities in transforming to become data-driven***. Implementations are challenged by ineffective data sharing, scalability and automation issues, non-optimized data generation and data flow approaches, and non-standardized data from numerous sources. ***Implementing a complex clinical data warehouse*** presents many challenges starting with the various data sources it needs to support and the tools required to view the clinical information. Ingestion of data of different types and origins with relevant metadata; data transformation, standardization, and cleansing to support the needs of a diverse set of end users in both the clinical and research settings; and varied end users with individual needs and computational capabilities are all important considerations.

Data management, genomic analysis tools, and data warehouse solutions are rapidly developed and are essential in addressing the critical need to manage and interpret the data to benefit research, drug discovery, and, of course, the clinic. Adoption and implementation of NGS and genomics discovery technologies have advanced clinical assessment of genomic alterations associated with oncology, hereditary cancer, cardiology, pediatrics, rare disease, among others. The next logical goals for NGS solutions, besides risk detection and disease identification, are disease prevention and management.

In line with this demand, the genomics data analysis, knowledge extraction, clinical reporting space is rich with commercial cloud, platforms, and software solution providers trying to address this need. Some of these commercial offerings support or overlap in their genomics workflow capabilities, while others differ substantially focusing predominantly on one specific element. This can create a competitive environment, which presents challenges to the end users and different organizations seeking an appropriate product that addresses their needs. While commercial companies struggle with understanding the competitive landscape or how-to best partner for a successful product and business strategy, this qualitative report reviews similarly aligned solution providers and those providers whose technology may fill a current gap in a company's portfolio.

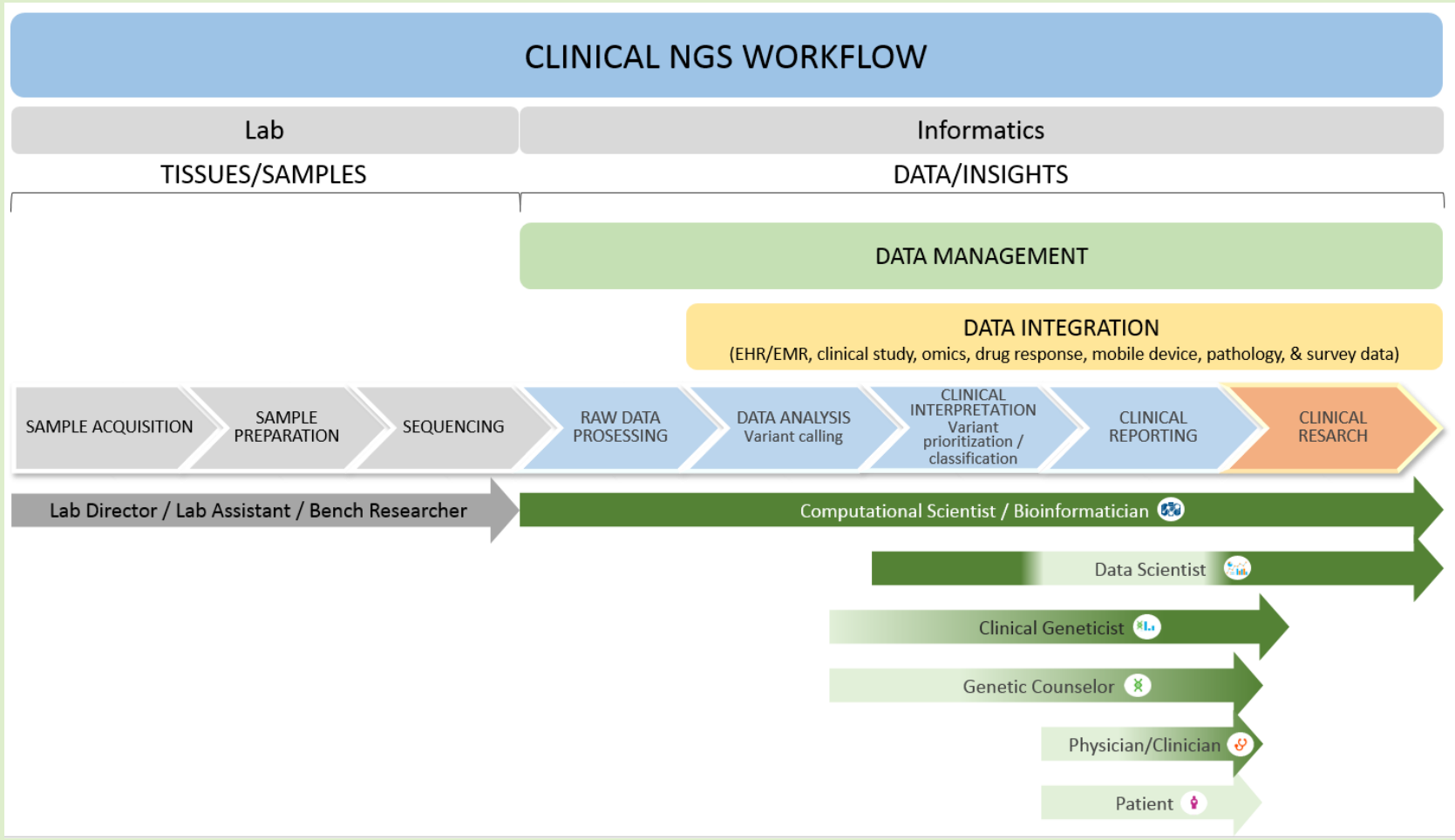
While this report does not intend to provide direct recommendations on commercial offerings, the deep-dive analysis is an insightful review to help clinicians, researchers, commercial entities, and investors choose the best partner for success.

Our "Clinical Genomics Report: The Interplay Between Clinical Research and Clinic Diagnostics" provides an in-depth analysis of differences in product characteristics related to data processing, analysis, knowledge extraction and reporting of findings, and compliance and security mechanisms. Both clinical end-users and commercial companies who require insight into this expanding industry and its providers and products will benefit from our critical, investigative, and qualitative report.

The 280-page ***Clinical Genomics Report - The Interplay between Clinical Research and Clinical Diagnostics*** consists of 13 Figures, 95 Tables, 14 comprehensive Medical Organization Profiles, and 20 comprehensive Company Profiles that includes company metrics, funding sources, product details, founder/executive and board information, additional notes, and company visions.

For more information contact info@enlightenbio.com or visit our website, enlightenbio.com.

The Clinical Genomics Process



Objectives

Our “Clinical Genomics Report - The Interplay Between Clinical Research and Clinic Diagnostics” details the observations and learnings across the complex, multi-step clinical genomics data process following clinical genomics data generation, which includes data processing, analysis, knowledge extraction, clinical reporting of actionable findings, and the clinical research side that employs large scale clinical genomics data to further clinical applications via population studies, data querying, and validation of research findings.

Market trends, including mergers and acquisitions, implemented genomics workflows at leading medical organizations with solution provider and testing lab preferences, innovations and technologies impacting the implementation of clinical genomics and molecular profiling applications, and COVID-19 disruption on our current healthcare system are detailed within the report. The medical industry/end users’ unmet clinical genomics data needs and challenges, and data solution provider and genetic testing lab preferences are also highlighted. Finally, an extensive comparison of scalable cloud solutions and solution providers in the SaaS and PaaS sector for the management, analysis and interpretation of clinical genomics data is included.

To create our robust, qualitative report, we researched these questions:

- What are the current implementation choices of data solutions and testing services at leading medical organizations;
- What are the unmet needs and challenges of medical organizations/clinical end users in relation to clinical genomics implementation;
- What are current clinical genomics market trends, and what innovations/technologies impact the adoption of clinical genomics applications;
- Who are the key commercial data solution providers and what solutions/products do they offer;
- Who are the genetic testing service providers and what specific services do they provide; and
- What needs do the genomics data management, process, analysis and interpretation commercial companies address with what product capabilities, and how do they compare across the ecosystem of solution providers?

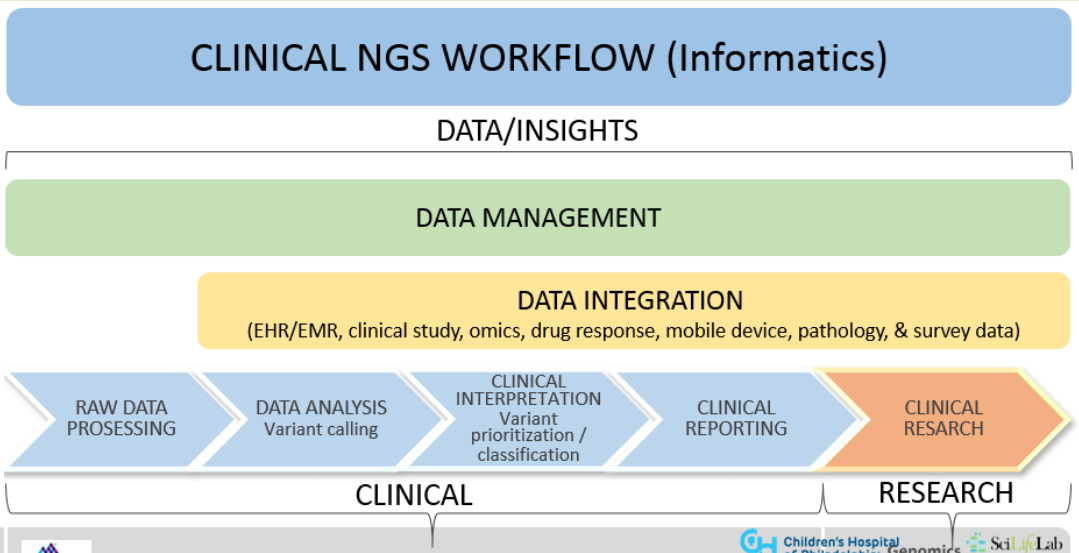
Approach

1) ***End-user interviews:*** Conducted to understand medical industry and clinical end user's needs and challenges, commercial solution preferences, and challenges with clinical data and integrating and communicating findings via an electronic healthcare system with the physician and the patient.
2) ***Meta-Data analysis:*** Performed a deep-dive interrogation of individual software, platform solutions, and genetic testing providers with publicly available information on the WWW [scientific publications, presentations, annual reports, white papers, and use cases].
3) ***Deep level analysis:***
    a. ***Researched implemented clinical genomics workflows at leading medical organizations*** (N=14) to support their internal precision medicine efforts.
    b. ***Evaluated key commercial software and platform providers*** (N=18) of clinical genomics solutions, such as scaled data storage and computing solutions, and data analysis and interpretation to understand product focus, capabilities, and the strategy to address end user needs.
    c. ***Researched optimal genomic data generation, data flow, and intelligence data platform requirements*** that support the interplay between clinical research and clinical genomics.
        i. ***Researched the challenges and requirements of scalable data warehouse infrastructure.***
    d. ***Evaluated commercial players*** (N=8) ***implementing artificial intelligence/machine learning or real-world evidence/real-world data*** applications for clinical genomics.
4) ***Medical organizations profiles:*** Reviewed leading medical organizations (N=14) and their implemented internal clinical genomics workflows and specific applications in support of their precision medicine efforts, including precision medicine initiatives initiated, sequencing services offered, warehouse solutions implemented, and more.
5) ***Company/product profiles:*** Reviewed key companies with comprehensive solutions across the entire Clinical Genomics Workflow, including genetic testing/diagnostics service providers (N=20), their product focus, offered capabilities, and their strategy to address end user needs, and more.
6) ***Key representative input*:** Interviewed company representatives of established software suppliers to learn about current and future product solutions.

Twenty-one (21) Clinical End-User Interviews

Twenty-one (21) individuals from across eighteen (18) medical and clinical research organizations, including two individuals from academic organizations who provide via their role and responsibility internal/external clinical research, were interviewed.

Clinical interviews detailed challenges associated with creating a workflow that incorporates a clinical data warehouse connecting clinical research with clinical diagnostics and vice versa. This important workflow leads to efficient clinical decision-making and reporting findings between clinical research and the clinic, which can optimize clinical outcome and patient treatment.



Computational scientist / bioinformatician Data scientist	Icahn School of Medicine at Mount Sinai; sema4; CHEO	Children's Hospital of Philadelphia; Genomics England; SciLifeLab; Nationwide Children's; Geisinger; Baylor College of Medicine; Stanford Health Care; University of Colorado Anschutz Medical Campus; Stanford Medicine
Clinical geneticist Genetic counselor	St. Jude Children's Research Hospital	
Physician / clinician	School of Medicine Vanderbilt University; Kaiser Permanente	Kaiser Permanente
Strategist / task force member	Providence St. Joseph Health; UCSF; Kaiser Permanente	Cincinnati Children's; Johns Hopkins School of Medicine

Interviews Revealed Medical Industry Unmet Needs & Challenges

The needs and challenges analysis conducted with various end users across the dry lab/informatics portion of the Clinical Genomics Workflow uncovered answers to the questions below.

	Focus
Status quo	What genetic testing and molecular profiling processes are currently established at various medical organizations?
Status quo	What platforms and infrastructures are currently implemented in support of clinical genomics applications at various medical organizations?
Challenges	What are the challenges with scaling genomics applications in the clinical setting?
Challenges	What are the challenges with selecting a test, testing lab, and when clinical findings are returned to the test requestor (clinical geneticists, genetic counselors, and patients)?
Needs	What are current critical needs to scale clinical genomics data analysis and interpretation for successful and efficient diagnosis?
Needs	How is clinical data (ideally) reported to physicians, patients, and health care organizations?
Needs	What is required for successful integration of clinical research with clinical diagnostics?
Outlook	What innovations of emerging technologies are required for successful adoption and acceleration of clinical genomics applications?
Outlook	What clinical areas will see the fastest widespread adoption over the coming years?
Outlook	What collaborations are created to accelerate growth of existing and new emerging markets?

The challenges and needs identified can be divided into two major categories, the technical/infrastructure challenges and the scientific data challenges, which are discussed in detail within this report.

Fourteen (14) Profiles of Leading Medical Organizations

Numerous healthcare organizations are leading the way in implementing clinical genomics workflows to support their internal precision medicine efforts. We selected fourteen (14) medical organizations for deep dive research, plus detailed organization profiles.

The end users interviewed provided information on platforms and infrastructures currently implemented across their affiliations, which was enriched with details learned from the top research medical organizations researched. The solutions implemented often include adopted open-source solutions packaged into in-house developed workflows, but also complete commercial offerings adapted to their internal needs.

Medical organization profiles	Website
Cedars-Sinai	https://www.cedars-sinai.org/
Emory Healthcare	https://www.med.emory.edu/
Geisinger Health Systems	https://www.geisinger.org/
Intermountain Healthcare	https://intermountainhealthcare.org/
Kaiser Permanente	https://thrive.kaiserpermanente.org/
Mayo Clinic	https://www.mayoclinic.org/
MD Anderson Cancer Center	https://www.mdanderson.org/
Moffitt Cancer Center	https://moffitt.org/
Mount Sinai Health System	https://icahn.mssm.edu/
Nationwide Children's Hospital	https://www.nationwidechildrens.org/
Partners Healthcare System	https://www.partners.org/
Sanford Health	https://www.sanfordhealth.org/
St. Jude Children's Hospital	https://www.stjude.org/
Vanderbilt University Medical Center	https://medschool.vanderbilt.edu/

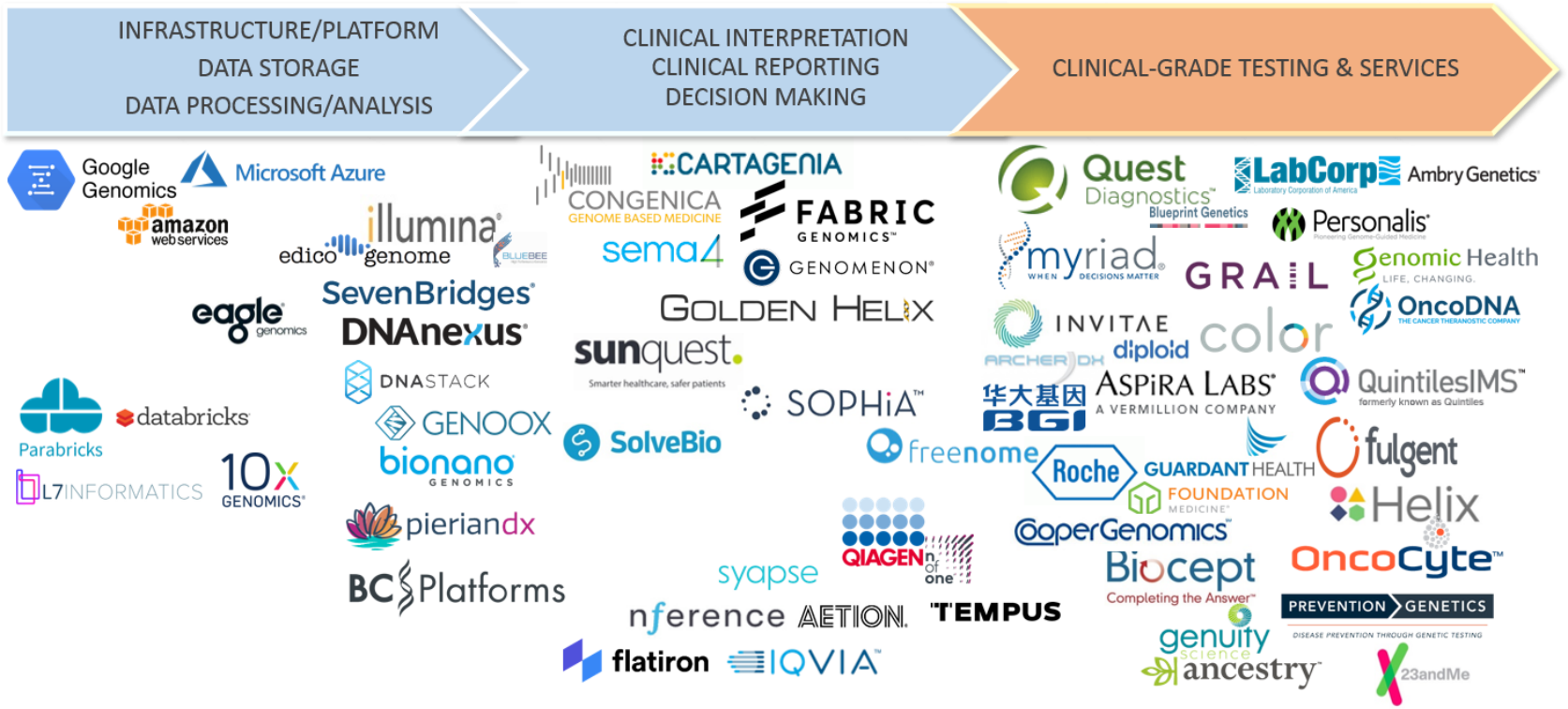
A Comparative Analysis of Different Clinical Genomics Solution Providers

A set of 20 leading commercial companies was analyzed revealing top players across the entire Workflow: BC Platforms, Bluebee, Color, Congenica, DNAnexus, Fabric Genomics, Foundation Medicine, Freenome, Genoox, Genuity Sciences, Google Life Sciences, GRAIL, Helix, Illumina (with BaseSpace Sequence Hub), Invitae, PierianDx, QIAGEN, Seven Bridges Genomics, SOPHiA Genetics, and Tempus.

- Cloud providers mentioned throughout the discussions included Microsoft (Azure), Amazon (AWS), and Google (Google Cloud);
- BC Platforms, BlueBee (now Illumina), DNAnexus, Google Life Sciences, Illumina, and Seven Bridges were among the most widely implemented data platforms;
- While in the context of data interpretation and clinical reporting Congenica, Fabric Genomics, QIAGEN, and PierianDx were predominantly mentioned;
- And clinical end users primarily chose Color, Foundation Medicine, Invitae, and Tempus for genetic testing.

Within this report we will focus predominantly on the different players and their products within those sectors, as they have funding power, a well-received customer perception, are strategically well connected with relevant partner companies, or enjoy generally high visibility in the sector.

The Clinical Genomics Solution Ecosystem



A ***comparative analysis*** of different solution providers in support of clinical genomics applications in research and the clinical setting which includes:

- Scaled data storage and computing solutions - cloud infrastructure providers
- Clinical genomics data platforms
- Clinical data management, analysis, and knowledge extraction solutions

Clinical Genomics Market Trends

Market trends, including mergers and acquisitions, implemented genomics workflows at leading medical organizations with solutions provider and testing lab preferences, innovations and technologies impacting the implementation of clinical genomics and molecular profiling applications, and COVID-19 disruption on our current healthcare system are detailed within the report.

Covers important clinical genomics market trends and adoption challenges, including a comparison of key players across high-level capabilities and offerings for specific segments.

- Factors impacting clinical sequencing adoption
- Genetic testing and molecular profiling trends
- Clinical genomics applications to be established in the clinic as a routine
- Mergers, acquisitions, and partnerships that accelerate adoption of clinical genomics
- Technologies impacting the implementation of clinical genomics & molecular profiling applications
    - 3rd and 4th generation sequencing technologies and long-read sequencing
    - Liquid biopsy in clinical diagnostics
    - Real World Data / Real World Evidence
- Clinical genomics adoption challenges
- COVID-19 and its impact on clinical genomics

Twenty (20) Company/Product Profiles

- BC Platforms – CGDP, RWE/AI
- Bluebee (now part of Illumina) - CGDP
- Color - Dx
- Congenica – DMR
- DNAnexus - CGDP
- Fabric Genomic - DMR
- Foundation Medicine (a Roche company) – Dx, LB
- Freenome – Dx, RWE/AI, LB
- Genoox - DMR
- Genuity Science – Dx, RWE/AI
- Google Life Sciences
- GRAIL - LB
- Helix - Dx
- Illumina (with BaseSpace Sequence Hub & DRAGEN Bio-IT Platform) - CGDP
- Invitae - Dx
- PierianDx – Dx, DMR
- QIAGEN (with QCI Interpret One & CLC) Genomics Workbench) – DMR, LB
- Seven Bridges- CGDP
- Sophia Genetics – DMR, RWE/AI
- Tempus – Dx, RWE/AI

Company/product profiles of clinical genomics solution providers.

Numerous commercial companies support the clinical genomics sector by providing infrastructure, data platforms, solutions, or services to advance clinical genomics applications. Within this report, a selected set of key players (N=20), across various components of the clinical genomics workflow have been chosen, for a deep-dive analysis and for the generation of a detailed company/products profile. Five types of companies have been profiled and they include:

Clinical genomics data platform providers (CGDP), clinical-grade genetic/diagnostic testing service providers (Dx), genomics data interpretation, decision-making, and reporting solution providers (DMR), Real World Evidence/Real World Data and/or AI solution providers (RWE/AI), and liquid biopsy-based testing service providers (LB).

Company profiles highlight company metrics (funding, number of employees, etc.), product details, data security and privacy guarantees, founder/executive and board information, strategic collaborations, and notes/company vision.

Key Data from Secondary Sources

Clinical genomics workflow end user challenges, & unmet needs	• End user interviews	Clinical genomics market trends	• End user interviews • Company representatives • Press releases • Public databases • Peer review publications • World Wide Web
Product details	• Company websites • Press releases • Public reports • User interviews • Company representatives • World Wide Web	Clinical genomics solution provider details	• Company websites • Press releases • Public reports • User interviews • Company representatives
Medical organization profiles	• Organization websites • End user interviews • Press releases • World Wide Web	Company/ product profiles	• Company websites • Annual reports • Press releases • Public databases • Use cases/white papers • World Wide Web
Data warehouse research & unmet needs	• End user		

Companies & Products Mentioned in Report

A number of companies have been researched and discussed thoroughly within this report and have either been integrated into a comparative analysis, researched via a company profile, or analyzed within the context of clinical genomics workflow solution providers.

Aetion, Agilent Technologies, Amazon (AWS), Ambry Genetics, BC Platforms, BioDiscovery (NxClinical), Bluebee (now Illumina), Color, Congenica, Cota Healthcare, DNAnexus, DNASTAR, Fabric Genomics, Flatiron Health, Foundation Medicine, Freenome, Fulgent Genetics, Genapsys, GeneDx, Genuity Science, Genestack, Genoox, Golden Helix (VarSeq), Google Life Sciences/Google Cloud, GRAIL, Helix, Illumina (with BaseSpace Sequence Hub & DRAGEN Bio-IT Platform), Invitae, IQVIA, L7 Informatics, MGI Tech, Microsoft (Azure), Myriad Genetics, NABsys, Oxford Nanopore Technologies, Ontera, Pacific Biosciences, PierianDx, Prevention Genetics, QIAGEN (with QCI Interpret One & CLC Genomics Workbench), Quest Diagnostics, Roche, Sema4, Seven Bridges, SOPHiA Genetics, Stratos Genomics, Sunquest, Syapse, Thermo Fisher Scientific, and Tempus.

About enlightenbio LLC

enlightenbio was founded in 2013 in the San Francisco Bay Area to provide a conduit between research and related technical and analytical resources. Our company consists of PhD level research scientists who bring decades of industry experience and expertise in the biotechnology, molecular diagnostics, pharma, and life science research markets. We are dedicated to communicating in the researcher's language, identifying unmet needs, and understanding product development. Our goals are aligned to researchers' needs to increase experiment productivity and to make sense of the resulting biological data.

In addition to our varied industry experiences - Applied Biosystems (now Thermo Fisher Scientific), DNAnexus. Iconix Biosciences, Incyte, Ingenuity Systems (now a Qiagen company), and Pfizer – we have built and maintained content curation services, defined product strategy, managed tactical product projects, performed extensive ecosystem analyses, and defined go-to-market plans.

Building on our initial success and previous experiences - microarray and next-generation sequence data analysis, toxicogenomics, solutions for sequence data management, analysis, and interpretation, drug discovery, and biochemistry - we continuously monitor worldwide market trends in healthcare information technology, life sciences, genomics, clinical diagnostics, and the medical devices space to expand our critical service offerings. Combined with our extensive global network, we can identify market pain points and unmet needs, perform detailed market and product research, and undertake horizontal and vertical ecosystem or competitive analyses, and more.

This background with our future-focus makes us a resourceful and agile alternative to traditional market research companies. Our comprehensive knowledge of the market in which we live and breathe is invaluable to our partnerships and potential.

enlightenbio, along with market research reports is managed by Brigitte Ganter, PhD, Founder & Managing Director of enlightenbio LLC.