Stanford MEDICINE | Center for Digital Health

DIGITAL HEALTH at STANFORD

Stanford Center for Digital Health Landscape Report

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STANFORD UNIVERSITY

Stanford University is an international center of learning, discovery and innovation, dedicated to advancing knowledge for the benefit of humanity. Stanford educates students for a life of purpose, creates knowledge, and responds to the urgent challenges of our times by accelerating solutions for human health, society, and our planet. Located in the San Francisco Bay Area within the traditional territory of the Muwekma Ohlone Tribe, Stanford welcomed its first students in 1891. Today, Stanford's areas of excellence span seven schools along with interdisciplinary research and policy institutes, athletics, and the arts. More than 7,000 undergraduate and 9,000 graduate students pursue studies at Stanford each year. Learn more at Stanford.edu. Across the university, there are 2,276 faculty members, 19 of whom are Nobel laureates. Stanford's dedication to research has translated into more than 6,800 externally sponsored projects and a budget for sponsored projects totaling approximately $1.63 billion for 2019-20.

Stanford Medicine Overview

Comprised of Stanford Health Care, Stanford Children's Health, and Stanford University School of Medicine, the oldest medical school in the western United States, Stanford Medicine is the home of leaders, innovators, and trailblazers. Stanford Medicine is driven to lead advances in biomedicine across its tripartite mission of research, education, and patient care. The academic medical center's leadership includes:

- Lloyd Minor, MD, Dean, Stanford University School of Medicine
- David Entwistle, President and CEO, Stanford Health Care
- Paul A. King, President and CEO, Stanford Children's Health

While digital health has risen in prominence in recent years, revolutionary breakthroughs in science and technology like MRIs, gene splicing, and stem cell medicine were born on Stanford Medicine's campus. As part of Stanford Medicine's central vision, precision health offers a high-tech and high-touch approach to predicting, preventing, and curing disease – precisely. This vision places specific emphasis on empowering the individual and uses proactive and personalized care to not only treat disease but to catch it before it strikes.

Stanford Medicine at a Glance

8

Nobel Prize winners over the past six decades

1,356

residents and clinical fellows

1,428

postdoctoral scholars

37

members of the National Academy of Sciences

47%

of the total university professoriate are in the School of Medicine

$728M

received by faculty in 2019 for sponsored research

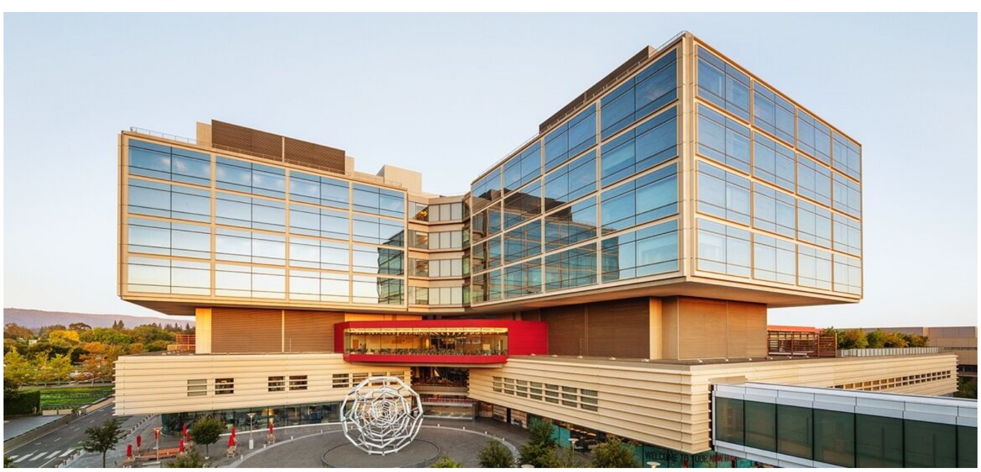
Stanford School of Medicine

Affiliated hospitals and clinics include Stanford Health Care, Lucile Packard Children's Hospital Stanford (LPCH), VA Palo Alto Health Care System, ValleyCare Health System, Santa Clara Valley Medical Center, and the University HealthCare Alliance. Stanford's robust research environment has translated into numerous NIH grants and the highest NIH funding per researcher ratio in the country. Faculty received over $728 million for sponsored research in 2019 and $458 million in NIH funding in 2018. The School of Medicine includes eight Nobel Prize winners, 37 members of the National Academy of Sciences, 49 members of the National Academy of Medicine, four MacArthur Foundation "geniuses", and 15 Howard Hughes Medical Institute investigators.

Within the School of Medicine, the Division of Cardiovascular Medicine is one of the largest academic and clinical units and is home to over 80 faculty, clinician educators, and instructors who provide clinical services to more than 250,000 patients annually. The division's outstanding achievements in basic, clinical and translational research rank it among the top ten clinical cardiology programs in the nation.

- **1,096 faculty**
- **8 Nobel laureates**
- **1,428 postdoctoral scholars**
- **489 MD students**
- **1,172 PhD and MS candidates**
- **1,356 residents and clinical fellows**

Stanford Health Care



- **2,300 faculty physicians**
- **1,400 residents and fellows**

Stanford Health Care is consistently ranked among the top hospitals in the nation for innovative programs in cancer treatment, cardiac care, neurology, orthopedic surgery, and organ transplantation. Recently, Stanford Health Care was named on the 2020-21 U.S. News & World Report's Best Hospitals Honor Roll for the sixth time. As a leading academic health system, Stanford Health Care delivers clinical innovation across a variety of care settings, including inpatient services, specialty health centers, physician offices, virtual care offerings, and health plan programs. With 368 private patient rooms beds and 28 state-of-the-art operating rooms, the recently opened 824,000-square-foot Stanford Hospital is evidence of the commitment towards a digitally driven future.

Stanford Children's Health
Lucile Packard Children's Hospital Stanford

- **1,058 medical staff**
- **5,005 employees**
- **575 volunteers**

At the center of Stanford Children's Health is Lucile Packard Children's Hospital Stanford, the largest healthcare system in the Bay Area exclusively dedicated to children and expectant mothers. It was recently named on the 2020-21 U.S. News & World Report Honor Roll for Best Children's Hospitals and serves patients at more than 65 locations throughout the region. With 1,058 medical staff, 5,005 employees and 575 volunteers, Stanford Children's Health provides world-class pediatric and obstetric specialty care for more than 500,000 patient visits every year.

Value Focused, Digitally Driven, Uniquely Stanford

Stanford Medicine is a leader in the field of digital health and has a long history of discovering new clinical therapies and developing cutting-edge technologies. Because of Stanford's location at the center of the Silicon Valley biotech, medical device, technology, and entrepreneurial ecosystem, Stanford Medicine is uniquely positioned to accelerate the pace at which new knowledge is translated into tangible clinical progress. The Stanford environment fosters innovation, promotes collaboration, and is a place where the future of digital health can flourish. Stanford Medicine contributes to the national and global expansion of scientific knowledge in healthcare and the atmosphere of interdisciplinary collaboration continues to fuel a legacy of innovation in medicine.

CENTER FOR DIGITAL HEALTH

Stanford MEDICINE | Center for Digital Health

Housed within the School of Medicine, the Stanford Center for Digital Health leverages Stanford's collective resources to innovate, enable, and collaborate with industry and academia to accelerate digital health initiatives. As Stanford's collaborative digital health hub, we are focused on three core principles:

Leadership: leading our partners through the digital health life cycle – strategy, ideation, product iteration, validation, and implementation at scale.

Research: conducting novel research as part of a robust infrastructure with interdisciplinary collaborators, ranging from pilot projects to real-world evidence generation to large scale, multi-center trials.

Education: Educating and training the next generation of health technology leaders by sharing knowledge and insights from our community and creating a forum for collaboration.

Mintu Turakhia, MD, MAS
Executive Director,
Center for Digital Health

Robert Harrington, MD
Chair, Department of
Medicine

Euan Ashley, MD
Associate Dean,
Precision Medicine

Avani Gupta, MPH
Director of Strategy
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Clark Seninger
Program Manager

Marius Mainz
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Aparna Suresh
Project Coordinator
(Intern)

Ashish Sarraju, MD
Heart Health
Technology Center
(H2T) Fellow

Bryant Lin, MD
Head of Education

Alexander C. Perino, MD
Head of Real-World
Evidence

Stanford MEDICINE | Center for Digital Health

Center for Digital Health: Heart Health Technology Center (H2T)

American Heart Association (AHA): Strategically Focused Research Network (SFRN)

The Stanford Center for Digital Health was chosen in early 2020 as one of five multidisciplinary teams to help create the American Heart Association's new Strategically Focused Research Network (SFRN) on Health Technologies and Innovation. This nationwide collaborative effort is focused on identifying, creating, testing, and bringing to scale future innovative health technologies and assisting the American Heart Association (AHA) as a research network and think tank. As part of the Center for Digital Health, the newly formed Heart Health Technology Center (H2T) brings together a core team of experienced Stanford faculty and leverages the many resources, centers, programs, and faculty that have allowed Stanford to excel across the entire health technology life cycle, from ideation to implementation.

> "As the peer review team moved forward with their selection of the centers for our latest Strategically Focused Research Network right at the break of the COVID-19 pandemic in the U.S., the Association felt this was an incredible opportunity for us to provide additional support in harnessing new innovations to tackle the challenges that are crippling the nation, and frankly the globe."

Robert Harrington, MD, Arthur L. Bloomfield Professor of Medicine and Chair of the Department of Medicine at Stanford University, Immediate Past President, American Heart Association

CDH Heart Health Technology Center (H2T): Our Vision

- **Develop technology using a proven needs-finding approach**
- **Quickly and inexpensively test early viable products**
- **Implement at scale using pragmatic approaches for evidence generation**
- **Train and develop cardiovascular health tech leaders of tomorrow**

Four Core Principles

1	2	3	4
Address large, fundamental problems	**Evaluate minimum viable products early**	**Design for diversity**	**Create a training program that will endure**
More impactful than pursuing a niche technology or disease	Iterate and retest as you go	Address, not exacerbate, disparities	Don't recapitulate existing programs; new content for health tech leaders of tomorrow

H2T Project: Technology-Enabled Management of Hypertension in Underrepresented Communities and in the Gig Economy

H2T is dedicated to enabling technology development related to heart health through disciplined needs-finding approaches, quick and inexpensive testing of solutions, pragmatic approaches to evidence generation with large-scale deployment, and training the cardiovascular health technology leaders of tomorrow. The team will first address the issue of hypertension in a project titled "Technology-Enabled Management of Hypertension in Underrepresented Communities and in the Gig Economy," by developing a clinician- and patient-facing platform for semi-automated management and evidence-based titration of blood pressure medications; such technology may lead to efficiency and scale.

The app will be tested in a randomized trial conducted in Northern California and New Jersey that will include a diverse patient population of different races and ethnicities, education levels, and backgrounds, and, to our knowledge, is the first cardiovascular intervention study to include a gig economy (rideshare driver) population. H2T is led by Mintu Turakhia, MD, MAS and a core team of Stanford faculty including Paul Wang, MD, FAHA (Project PI), Vivek Bhalla, MD, FAHA (Project Co-I), Tara Chang, MD, MS, FAHA, and Fatima Rodriguez, MD, MPH. As part of the training mission of the center, the CDH has launched a new Health Technology Fellowship within H2T. We are proud to have Ashish Sarraju, MD, currently a Chief Fellow for the Stanford Cardiovascular Medicine Fellowship, as the first H2T Fellow.

EXECUTIVE SUMMARY

The global challenges of 2020 have triggered a renewed focus on public health and social welfare. An important aspect of this changing paradigm has been the shift towards digital services and their role in addressing important global issues of health, the safe restarting of economies, and the reopening of society.

As a result of the COVID-19 pandemic, demand for technology-enabled services has been especially pronounced across a variety of industries and has provided a unique counterbalance to various "lockdown" experiences. During these challenging times, this new wave of virtual adoption may ultimately support a more permanent shift towards a new normal. The demand for digital adoption has been especially pronounced in healthcare as telemedicine and remote patient monitoring have expanded the capacities of health systems globally.

Digital health is a rapidly evolving field and new technologies are being developed each day. This growth has been accompanied by increasing consumer adoption and heightened awareness of digital health tools. Throughout healthcare, we are also seeing the rise of the "Data-Driven" physician and the expansion of technology-based skill sets of next-generation physicians. As a world-class research institution with close ties to Silicon Valley, Stanford University's position at the intersection of medicine and technology provides a unique opportunity to observe and shape the expanding landscape of digital health.

The Stanford Center for Digital Health (CDH) has built a strong network of researchers, faculty, and other experts from across the Stanford ecosystem to advance digital health and promote collaboration. To describe the magnitude of interdisciplinary research in our community, we have created a comprehensive overview of the efforts and achievements of Stanford University in the field of digital health.

Our report focuses on four core elements:

1. Literature review of Stanford's digital health publications
2. Survey data describing the expertise of Stanford Faculty in the digital health space
3. Interviews and statements from Stanford's key opinion leaders
4. Overview of the Stanford ecosystem and the groups involved in digital health work

The Stanford Center for Digital Health Landscape Report serves as a central resource for promoting collaboration and aims to leverage Stanford's collective power to help shape the future of digital health.

Scope of the Stanford Center for Digital Health Landscape Report

The Stanford Center for Digital Health Landscape Report provides a comprehensive overview of digital health efforts across the Stanford ecosystem to illustrate Stanford's impact in the space. By publishing this report, we aim to:

- **Aggregate and catalog Stanford's digital health efforts into one source**
- **Quantify the impact of Stanford's contribution to the field of digital health**
- **Examine digital health trends at Stanford through an in-depth literature review**
- **Provide a detailed index of organizations, faculty, and staff to promote internal and external collaboration**
- **Characterize the relationships between key stakeholders in digital health across the Stanford ecosystem**

Definition of Digital Health

The boundaries of the term "digital health" seem to be constantly shifting. We define digital health broadly, using it to describe digital information or data and communications technologies to collect, share, and manipulate health information to improve patient health and healthcare delivery (Turakhia, Desai, & Harrington, 2016).

This definition therefore encompasses a wide variety of software and data technologies (e.g., data science, advanced analytics, artificial intelligence, electronic health records (EHRs), virtual and augmented reality), hardware (e.g., smartphones, tablets, computers, health trackers, wearable technologies, sensors, medical devices), and services or solutions (e.g., video conferencing, mHealth apps, remote monitoring). For the purposes of this report, the terms digital health and "healthcare technology" will be used interchangeably. We recognize the difficulty in establishing one all-encompassing definition for digital health but feel that this broad definition best represents the field. We also considered regional interpretations, the influence of regulatory bodies, and existing guidelines from large health organizations, such as the World Health Organization and National Institutes of Health.

A WORD FROM STANFORD MEDICINE LEADERSHIP

Mintu Turakhia, MD, MAS

Executive Director, Stanford Center for Digital Health; Associate Professor of Medicine (Cardiovascular Medicine); Director of Cardiac Electrophysiology and Cath Labs, VA Palo Alto Health Care System

Mintu Turakhia, MD, MAS

"The Stanford Center for Digital Health Landscape Report is a comprehensive look at the most impactful developments at the intersection of healthcare and technology and an overview of the technologies that are shaping the healthcare sector. Across the world and in our local Stanford Community, enormous transformations are taking place that present a number of opportunities for students, staff, and faculty to come together to help heal and innovate as we tackle some of the most significant health challenges in 2020 and beyond.

Stanford has a rich history of innovation in medicine and has long been a pioneer at the health-tech intersection in the field of healthcare technology. The diversity of our community, culture of collaboration, and our forward-thinking, get-it-done mentality all contribute to make Stanford a place where a thousand flowers bloom. At Stanford Medicine, we strongly believe in the approach of precision health: predicting, preventing, and curing disease precisely. This means using high-tech and high-touch approaches to improve the quality of care and outcomes for our patients. The digital health technologies listed in this report demonstrate a shifting tide in the world of healthcare delivery. Physicians are now leveraging big data and cutting-edge scientific advancements to help patients live healthier lives.

While technology has the potential to improve quality of life for many patients around the world, the challenges faced by scientists, physicians, and patients with respect to the health of humanity are complex, complicated, and formidable. The rising cost of health care, increasing rates of noncommunicable diseases, environmental health issues like air pollution, and most pressing, the lightning-fast spread of highly consequential infectious diseases, are forcing us to reevaluate our roles and responsibilities as we work towards improving health on a local, national, and global stage. The pandemic has shown just how fast a virus can cause global contagion, while also showing how difficult it is to scale health care in times of surge. At the same time, we have seen rapid adaptation, with uptake in technologies such as telehealth, remote patient monitoring, and rapid implementation of pragmatic clinical trials using sophisticated electronic data capture approaches.

Given these challenges, the field of digital health is poised to be a key player in the future of global health care development as we continue to search for scalable, cost-effective, user-friendly, and "sticky" solutions in an industry where stakeholders must navigate a complex-system of trade-offs and incentives.

How is Stanford using digital health to address these problems? Over the past decade, Stanford has helped push the boundaries of technology in health care and has made a significant impact in the field of digital health. As 2020 ushers in a new decade of hope, Stanford will continue to develop disruptive technologies with the promise of improving outcomes for patients everywhere.

The goal of this report is to paint the picture of what digital health means at Stanford. This includes a deep dive into historical research trends, modern-day care delivery methods, and unique perspectives from a variety of stakeholders throughout the Stanford ecosystem. Ultimately, we hope that this report can inform and educate patients, physicians, industry partners, policymakers, and other members of the medical community that are interested in understanding what digital health means at Stanford. In this report, we will sift through the hype, misconceptions, and marketing in digital health today, and uncover how Stanford is pushing the field forward in tangible and compelling ways. "

The field of digital health is poised to be a key player in the future of global healthcare development as we continue to search for scalable, cost-effective, user-friendly, and "sticky" solutions in an industry where stakeholders must navigate a complex-system of trade-offs and incentives.

Lloyd B. Minor, MD

Lloyd B. Minor, MD

Dean
Stanford University School of Medicine

"Through digital health, Stanford Medicine researchers are redefining the future of biomedicine. Not only do these technologies advance our Precision Health vision to predict, prevent, and cure disease precisely, they promise to enhance health care locally – and globally.

Consumer-facing technologies, such as wearables, have shown the potential to mitigate the impact of intractable diseases. In the largest virtual clinical study to date, Stanford researchers demonstrated that an Apple Watch can help detect atrial fibrillation, a condition with elusive and sporadic symptoms. Another ongoing study involving wearables aims to use heart rate, skin temperature, and other data that could lead to quicker diagnosis of viral illnesses, such as COVID-19, and better inform public policy responses to reduce viral spread.

Artificial intelligence and advanced analytics are also having transformative impacts in clinics and labs. CheXNeXt, a first-of-its-kind algorithm developed at Stanford, can accurately read chest X-rays for 14 pathologies in just seconds. This has application in patient diagnosis but also in expanding access to vital services around the world. In research, Stanford scientists have deployed artificial intelligence to identify drugs that could inhibit a key protein in SARS-CoV-2 infections – potentially reducing the time for developing a more effective treatment for the millions of people with this disease."

Through digital health, Stanford Medicine researchers are redefining the future of biomedicine. Not only do these technologies advance our Precision Health vision to predict, prevent, and cure disease precisely, they promise to enhance health care locally – and globally.

Paul A. King

President and CEO
Stanford Children's Health

Paul A. King

"Stanford Children's Health is a national and regional referral center for children and expectant mothers with the most severe health care needs. Traditional healthcare delivery for these complicated patients is associated with significant disruption in the lives of children and families; with resulting developmental delays for the child and significant family stress. For years, we have understood that the expansion of digital health at Stanford Children's is critical to transforming the model of pediatric and maternal health care delivery from disruptive, episodic, and reactive to continuous, supportive, and proactive in pursuit of the highest quality of health for children and families. In support of this goal, Stanford Children's Health accelerated the use of video visits in the last year, and deployed mobile apps and remote patient monitoring to support our most complicated patients. Stanford Children's Health has also been recognized by numerous industry awards for leading the use of digital technology and analytics to transform health care, notably the highest HIMSS Level 7 Inpatient and Outpatient EMR and Analytics, CHIME Most Wired, and the HIMSS Davies Award for innovating sustained improvements in patient outcomes.

This foundation of technology infrastructure was critical for enabling our response to the COVID-19 pandemic, where we rapidly saw a greater than 35X growth of telehealth visits in just a few weeks. During the pandemic, telehealth became a lifesaving tool that enabled thousands of patients, families, and providers to ensure appropriate health care was delivered, while minimizing the spread of disease and conserving personal protective equipment. The experience has taught us many invaluable lessons, and now that our patients, families, and providers have all experienced the substantial benefits of telehealth, they are eager to stick with us on our continued digital health journey to a more proactive, efficient, and effective model of care delivery that achieves our Digital Health goal of patients "In Our Care Anywhere."

Additionally, our overall digital transformation initiatives expand beyond our focused digital health efforts to broader business and health care delivery innovation. Novel business models include virtual asynchronous consults with specialists and digital second opinions. With a focus on patient and family experience and enhanced access, we have recently deployed self-scheduling and virtual waitlists to streamline and expedite patient appointments. To assist our support staff and improve operational efficiency, we are deploying robotic process automation (RPA) tools such as artificial intelligence (AI) guided eligibility checking and billing. We continue to improve our clinician's EHR experience through advances in speech recognition and clinical decision support integrated within their normal day-to-day workflow. To further support our clinicians, we are collaborating with our partners across Stanford School of Medicine to enable an industry leading and thoughtful translation of AI and machine learning into the clinical setting. All of these innovations advance our mission as a learning health system, and advance exemplary and precise access and care for children and mothers worldwide."

Robert Harrington, MD

Robert Harrington, MD

Arthur L. Bloomfield Professor of Medicine and Chairman of the Department of Medicine at Stanford University

"When the Center for Digital Health launched over three years ago, we aimed for it to cultivate a community around digital technology, help connect and enable our faculty to continue pursuing cutting-edge research, and form relationships and collaborations with industry here in Silicon Valley and beyond. I am proud to say it has delivered on those promises and continues to create new models for advancing digital health initiatives here at the School of Medicine.

As Chair of the Department of Medicine, I am continuously proud of the Stanford community's ability to push the boundaries in healthcare through scientific breakthroughs, new product development, and unique educational initiatives.

Our faculty and staff work tirelessly to advance digital technologies and tools so that they can have a significant impact on the healthcare system. With recent challenges brought on by managing a global pandemic and addressing societal and systemic issues of race, equity, and justice, Stanford's role as a vehicle for reimagining education, healthcare delivery, and rigorous research has proven critical. Our ability to respond to an ever-changing and complex world has never been more important; digital health is and will continue to be an important tool that the public will increasingly rely on to understand and manage the difficult issues facing our society.

As I look towards the future, my hope is that our work in digital health at Stanford can first be better understood by those in the external community and then amplified to better the health and wellbeing of the world for many years to come. Our dozens of teams, centers, labs, and initiatives have been working for years on solving some of healthcare's biggest problems and we are proud to showcase their work in this report. Our digital health community has grown stronger, more committed, and more interconnected over the years and our biggest achievements are still on the horizon."

As I look towards the future, my hope is that our work in digital health at Stanford can first be better understood by those in the external community and then amplified to better the health and wellbeing of the world for many years to come. Our dozens of teams, centers, labs, and initiatives have been working for years on solving some of healthcare's biggest problems and we are proud to showcase their work in this report.

Euan A. Ashley, MD

Associate Dean, School of Medicine, Professor of Medicine (Cardiovascular), of Genetics, of Biomedical Data Science and, by courtesy, of Pathology at the Stanford University Medical Center

Euan Ashley, MD

" We are in the midst of a data transformation in medicine. Digital technologies, and the data they bring, are providing new opportunities to detect disease earlier and manage it better. Our "old world" of questionnaires and recall is being replaced by one of real-world sensors and technology that allow us true transparency in respect of the lives of our patients as they live them. We have an unprecedented opportunity to change how we practice medicine and how we prevent disease.

At Stanford, we have worked for many years to explore the potential of digital technologies to improve cardiovascular health. Through the MyHeart Counts Cardiovascular Health Study, in collaboration with Apple, we recruited 60,000 people willing to share their health data and combine it with data gathered from their smartwatches and phones. Most recently, we completed the first entirely digital randomized clinical trial, with digital recruitment, digital consent, digital randomization, digital intervention, digital return of results, and digital publication. We demonstrated small but significant increases in physical activity in response to simple digital nudges.

We are increasingly moving towards a world of proactive medicine — one where smartwatches sit in the background monitoring our hearts or our gait or our cognition and trigger early warnings when they detect signs of heart disease or neurodegenerative disorders, and we can do this globally. The world's high GDP per capita countries average one or more mobile phones per person. But this number falls little even in countries with vastly fewer resources.

Digital communication and digital technology could be the key to preventing the rise of the world's biggest killer, cardiovascular disease, in the developing world.

In Silicon Valley, we are ideally situated to translate such ideas to reality. We hope to amplify this potential through a new program at Stanford: Catalyst. Catalyst aims to transform health by the rapid prototyping and scaling of new ideas across diagnostics, therapeutics, medical technology, and data/digital. The last provides perhaps the shortest runway towards transformative change. By marrying Stanford's famously innovative faculty with experts in digital application and by connecting these teams to experts in technology commercialization, we hope to improve the lives of millions around the world. "

We are increasingly moving towards a world of proactive medicine — one where smartwatches sit in the background monitoring our hearts or our gait or our cognition and trigger early warnings when they detect signs of heart disease or neurodegenerative disorders, and we can do this globally.

David Entwistle

David Entwistle

President and CEO, Stanford Health Care

"COVID-19 has ushered in a new era in patient care, marked by the widespread adoption of digital technologies. At Stanford Health Care, our virtual visits surged from 2% of total volume to 70% in just a few weeks, driving a sea change in the way we operate. Far from being a temporary phenomenon, the shift to virtual care, with its capacity to empower patients and increase health care access, is here to stay.

Organizations at the forefront of the transition must recognize the significance of this moment: right now, we are laying the groundwork for our industry's future. Rising to this challenge means integrating digital solutions at every step of the patient journey; finding the right organizations to partner with in creating this digital-first experience; and giving patients — particularly those from underserved groups — opportunities to participate in the development process.

At Stanford Health Care, we are building this future, and it starts with the new Stanford Hospital. Within its walls lives an ecosystem of novel technologies that empower patients at the bedside and support them long after they arrive home. From the hospital's Internet of Things infrastructure to the MyHealth app that guides patients through the care journey, our vision for digital health is "high-tech enabling high-touch care."

As we continue to navigate the extreme challenges posed by COVID-19, there has never been a more critical or meaningful time to consider what kind of system we want to emerge from this crisis. With digital technology at the forefront, we can build a better foundation – one that is far more responsive, connected, and empowering for patients."

Far from being a temporary phenomenon, the shift to virtual care, with its capacity to empower patients and increase healthcare access, is here to stay. Organizations at the forefront of the transition must recognize the significance of this moment: right now, we are laying the groundwork for our industry's future.

Michael Halaas

Michael Halaas

Deputy CIO, Stanford Health Care and School of Medicine, Associate Dean – Industry Relations and Digital Health, Technology and Digital Solutions

"It's an amazing time in the evolution of digital health and Stanford is poised to play an increasingly influential role in the innovation, advancement, and application of new approaches to health care. In the Office of Industry Relations and Digital Health as part of Stanford Medicine's Strategy Team, we are seeing a steady increase in the number of strategic alliances with the digital health ecosystem. This includes some of the largest technology companies in the world as well as small startups working on new ideas that may turn out to be transformative. We have tremendous capabilities at Stanford to work with these partners in a research context and the potential to deploy them in an active health care setting.

This July, we launched a Pop-Up version of the Catalyst Program, inspired by the tremendous changes we've seen as a result of COVID-19. The program has an emphasis on fostering innovations coming from within the Stanford Community in digital health to capitalize and extend the rapid expansion of virtual health care delivery that has occurred during the pandemic. We made a call for proposals and selected 3-5 initiatives to move forward with financial, operational and logistical support. The goal is to find innovations in digital health that are ready to be applied and leveraged by Stanford's health system to evolve these ideas and ultimately export them so they can scale and have maximum impact on health care in the broadest sense. This is being done with support from the CEO's of Stanford Health Care and Stanford Children's Health as well as Dean Minor. We know we have amazingly creative individuals in our community and the Catalyst will provide deep institutional support to bring great ideas to life and to succeed in improving health.

Stanford is in a position to provide leadership and there truly has not been a more exciting time to be working in this field at a magnificent place."

> It's an amazing time in the evolution of digital health and Stanford is poised to play an increasingly influential role in the innovation, advancement, and application of new approaches to health care... Stanford is in a position to provide leadership and there truly has not been a more exciting time to be working in this field at a magnificent place.

Priya Singh

Priya Singh

Chief Strategy Officer & Senior Associate Dean, Stanford Medicine

"We at Stanford Medicine are proud of how we have enabled digital innovation to permeate our tripartite mission. From our connected patient care apps to cutting-edge research and innovations with Silicon Valley technology partners, digital capabilities are changing how we perform groundbreaking research, educate the next generation of biomedical leaders, and deliver preeminent patient care.

Leveraging digital tools and data science in novel ways, Stanford Medicine researchers have developed critical responses to the COVID-19 pandemic at our organization, in our local community, and across the globe. As we look to the future, digital innovation will become even more embedded in Stanford Medicine's strategy and vision.

The health consumers of tomorrow will demand digitally-connected journeys and experiences that rival those other consumer industries provide today. Researchers will increasingly use AI, machine learning, and other digital technologies to fuel discoveries and develop new therapies. Ultimately, this digital transformation will enhance care delivery.

To achieve this shared vision, we have engaged leaders from across the organization to shape an enterprise Digital First Strategy – a roadmap of new digital opportunities to pursue and paths for strengthening our ability to accelerate innovation. We're committed to continuing Stanford Medicine's pioneering legacy by defining the frontier of digital health at Stanford Medicine and beyond."

The health consumers of tomorrow will demand digitally-connected journeys and experiences that rival those other consumer industries provide today. Researchers will increasingly use AI, machine learning, and other digital technologies to fuel discoveries and develop new therapies. Ultimately, this digital transformation will enhance care delivery.

OVERVIEW AND METHODOLOGY

The purpose of this report is to provide a comprehensive overview of Stanford's digital health landscape. As part of this overview, we present information from 1) a literature review of digital health publications from Stanford affiliated authors, 2) surveys of Stanford faculty engaged in digital health work, 3) interviews with key opinion leaders in the digital health space at Stanford, and 4) results from a Center Outreach Initiative profiling groups in Stanford's digital health ecosystem. Methodology for the literature review, survey, interviews, and Center Outreach Initiative are presented below. To our knowledge, this report is the first of its kind at Stanford.

Literature Review

Search Queries

We sought to perform a bibliometric analysis of digital health literature indexed in PubMed with at least one Stanford-affiliated author. To perform the analysis, we first generated and categorized an expansive list of digital heath keywords and MeSH terms (Table 1). These keywords and MeSH terms were selected from various definitions of digital health and also included lay terms. We created three search strings from identified keywords and MeSH terms using PubMed search field tags. The keyword "Stanford" was added to each query to identify Stanford-affiliated publications (see query structure and example search string below).

Query 1: Stanford AND ([Digital Health Terms] OR [Technology Terms - specific] OR [Additional Mesh Terms])
Query 2: Stanford AND ([Adjective Terms] AND [Technology Terms - unspecific])
Query 3: Stanford AND ([Health Terms] AND [Technology Terms - unspecific])

Example Search String:

Stanford AND (online[tw] OR wearable[tw] OR web[tw] OR smart[tw] OR wireless[tw] OR virtual[tw] OR remote[tw] OR mobile[tw] OR digital[tw] OR electronic[tw]) AND (intervention[tw] OR innovation[tw] OR technolog*[tw] OR device[tw] OR wearable[tw] OR sensor[tw] OR application[tw] OR app[tw] OR platform[tw] OR informatics[tw])

Data Collection

Using Pubmed, we identified 9,744 unique publications with these search strings published through 12/31/2019[1]. Two reviewers screened titles and abstracts in parallel (Marius Mainz and Shannon O'Hara) to confirm each publication was relevant to digital health. Disagreements were settled by a third reviewer (Clark Seninger). During screening, we excluded 7,354 publications, resulting in an analysis cohort of 2,390 digital health publications. We used publications' PubMed ID to obtain additional bibliometric data from Dimensions.ai on 01/29/2020. Dimensions.ai is an open access literature database that provides citation data that is not available in PubMed.

1. Unless otherwise stated, all data in the report was collected as of 12/31/2019. This includes patents, surveys, and other information listed throughout the report.

Health Terms	Digital Health Terms	Adjective Terms	Technology Terms—unspecific	Technology Terms—specific	Additional Mesh Terms
health*[tw]	"Telemedicine" [MeSH Terms]	online[tw]	intervention[tw]	"Data mining"[tw]	"Wearable Electronic Devices"[Mesh]
ambulatory[tw]	"eHealth"[tw]	wearable[tw]	innovation[tw]	"big data"[tw]	"Electronic Health Records"[Mesh]
home[tw]	"electronic health"[tw]	web[tw]	technolog*[tw]	"machine learning"[tw]	
rehabilitation[tw]	"digital health"[tw]	smart[tw]	device[tw]	"deep learning"[tw]	
care[tw]	"mHealth"[tw]	wireless[tw]	wearable[tw]	"artificial intelligence"[tw]	
medic*[tw]	"mobile health"[tw]	virtual[tw]	sensor[tw]	EHR[tw]	
clinic*[tw]	"telemedicine"[tw] telemedicine"[tw]	remote[tw]	application[tw]	"electronic health record"[tw]	
	"telehealth"[tw]	mobile[tw]	app[tw]	"electronic patient record"[tw]	
		digital[tw]	platform[tw]	"virtual reality"[tw]	
		electronic[tw]	informatics[tw]	"augmented reality"[tw]	
				"health information"[tw]	
				"Personalized health"[tw]	
				"Clinical workflow"[tw]	
				"health technology"[tw]	
				"consumer health"[tw]	
				"mobile application"[tw]	
				"wireless technology"[tw]	
				"clinical decision support"[tw]	
				HIT[tw]	

Table 1

Data Categorization

We reviewed analysis cohort publications' titles and abstracts, assigning each publication to a technology category (see list of technology categories in Table 2) based on the article's primary topic. These assignments required agreement by two reviewers (Marius Mainz and Shannon O'Hara), with disagreements settled by a third (Clark Seninger). The technology groups were identified through iterative qualitative clustering in parallel to article review, with categories novel to this report.

Technology Categories
Wearables, Sensors, and Other Devices
Mobile and Web Applications
Artificial Intelligence (AI), Machine Learning (ML), and Algorithms
New Clinical Care Models
Health IT, Infrastructure, and Data Management

Table 2

We also assigned each publication to 1 of 16 clinical areas or 1 of 8 application areas. We defined "application area" as any research that is not focused on a specific clinical area (e.g., medical informatics, data management, clinical workflow, etc.). These clinical and application areas were based on an existing classification scheme (Chen, Harrington, Desai, Mahaffey, & Turakhia, 2019). Four existing areas were modified and 10 areas were added to accurately classify the analysis cohort (Tables 3 and 4).

Clinical Areas		
Autoimmune	Musculoskeletal System, Pain, Chronic Conditions**	Vision and Hearing*
Cardio-metabolic	Neurology	Pulmonary
Critical care/ICU*	Obstetrics, Gynecology, Reproductive Health, Urology**	Renal
Dermatology*	Infectious disease	Sleep*
Digestive System*	Mental health	Substance abuse
Hematology-oncology		

Table 3

*Additional areas added (new); **area modified from existing classification scheme

Application Areas	
Drugs & Medication Management*	Other
Imaging*	Research, Trials, & Studies*
Medical Informatics, Data Management, & Workflow*	Surgery and Anesthesia**
Omics*	Well-being**

Table 4

*Additional areas added; **area modified from existing classification scheme

Faculty Survey

We surveyed individuals affiliated with Stanford regarding their digital health experiences, opinions, and insights across three themes: 1) patient care, 2) research, and 3) product development. A total of 53 questions were included in the survey. Questions were created with input from the CDH liaison network and core team members. The survey was administered through Qualtrics and distributed via Stanford's internal email list. A total of 137 respondents answered survey questions (117 faculty, 20 staff/other hospital personnel).

Interviews

We conducted 30-minute interviews of five Stanford faculty, chosen for their contributions to high-impact research and expertise across digital health and related domains. As key opinion leaders, they provided valuable perspectives to illustrate how digital health has influenced their work and how it may evolve in the future.

Center Outreach Initiative

We profiled various centers and groups across Stanford University, Stanford Health Care, and Stanford Children's Health that are active in the digital health space. These centers and groups were identified through the CDH's previous collaborations, workshops, and educational programs. Additionally, we supplemented our collaborator list with a search of health technology efforts across schools, departments, and divisions at Stanford. In total, we identified 32 groups, all of which were included in the outreach. We captured the following information from each group:

- Center or group operations (number of staff and faculty, year established, key personnel)
- Digital health projects, programs, and initiatives
- Internal and external collaborations
- Funding

LITERATURE REVIEW

Stanford Digital Health Publications

The volume of Stanford digital health publications in the academic literature has increased over the last three decades, with an exponential rise since 2010. The increase in digital health publications has coincided with landmark developments in digital health, including wider internet availability, the introduction of smartphones, the rise of intelligent computing, and the subsequent proliferation of mobile applications in the past 10 years.

All Publications By Volume Over Time

1984-2019

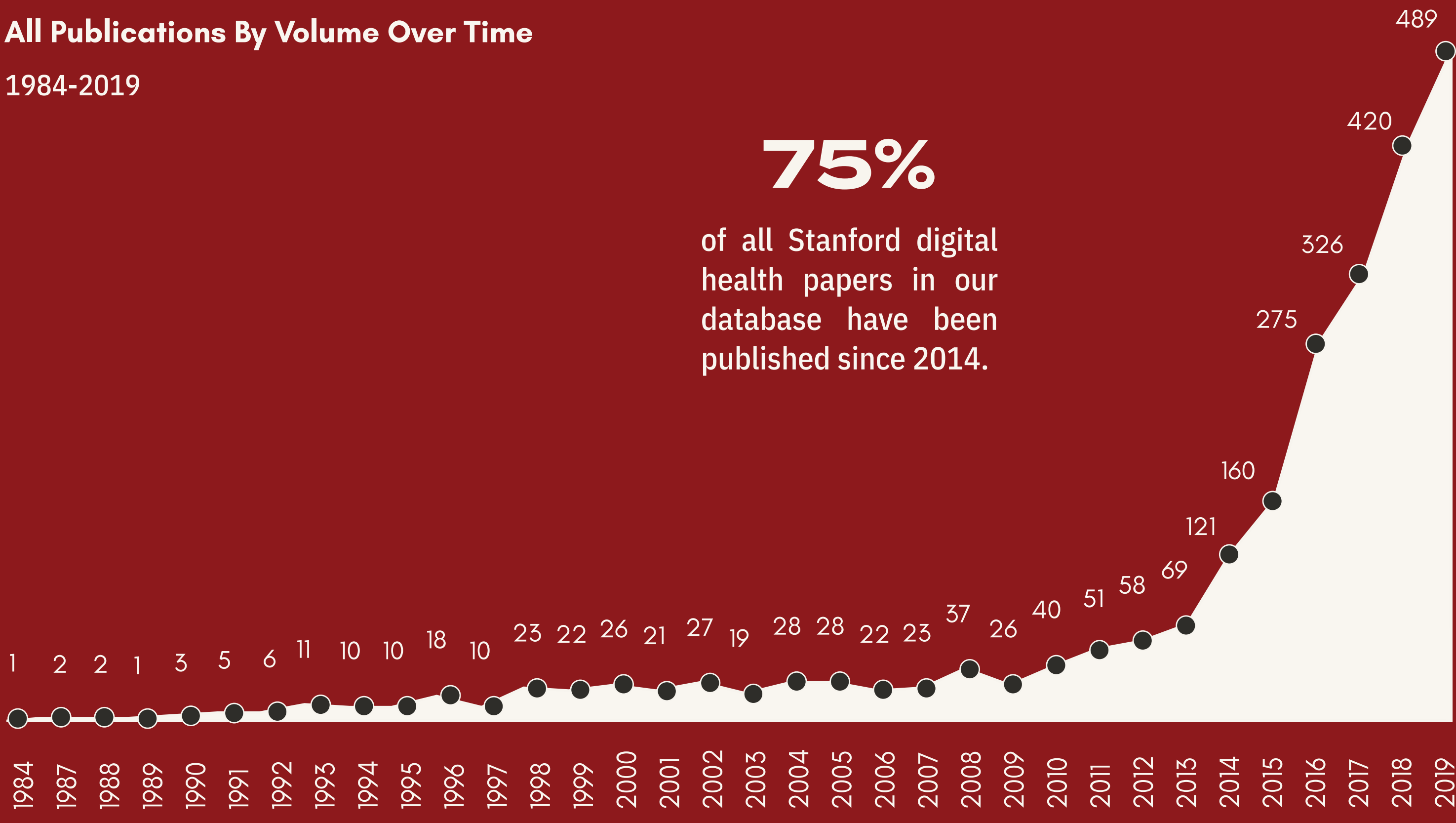


Figure 1

Over the last decade, there has been an approximate twelve-fold increase in the number of digital health publications authored by Stanford-affiliated researchers. 75% of all Stanford digital health publications identified in our literature search were published since 2014 (Table 1).

Over the last 35 years, 2,390 digital health publications from Stanford-affiliated researchers were published in 889 unique journals, books, and proceedings. Ten journals (Table 5), with a median impact factor of 4.5, published 13% of the digital health publications from Stanford. Four of these journals had a specific thematic focus on digital health (JAMIA, JMIR, JBI, NPJ Digital Medicine), two were general interdisciplinary scientific journals (PLoS ONE, PNAS), and four were medical journals without a digital health focus (JAMA, Medical Physics, Diabetes Technology and Therapeutics, Diabetes Care).

In analyzing the total number of publications in the database, the average number of authors per paper was 8 (including Stanford authors and external collaborators). For reference, 3,046 Stanford researchers were authors on at least one digital health publication since 1984. Among all Stanford digital health publications, Dermatologist-level classification of skin cancer with deep neural networks, published in Nature in 2017, had the most overall citations (1,904), the highest Relative Citation Ratio (147.2), and the highest Altmetric Attention Score (2,880).

Top Journals Overall

Impact Factor 2018 (JCR)	H Index	Journals	Number of Stanford Digital Health Papers
4.3	132	Journal of the American Medical Informatics Association	64
2.8	268	PLoS ONE	38
4.9	116	Journal of Medical Internet Research	35
51.3	622	JAMA (Journal of the American Medical Association)	29
3.0	83	Journal of Biomedical Informatics	29
3.2	159	Medical Physics	28
4.5	79	Diabetes Technology and Therapeutics	26
*N/A	N/A	*NPJ Digital Medicine	23
15.3	328	Diabetes Care	21
9.6	699	Proceedings of the National Academy of Sciences	21

Table 5

The JCR (Journal Citation Reports) impact factor is the number of current year citations divided by the source items published in that journal during the previous two years. H index is "an estimate of the importance, significance, and broad impact of a scientist's cumulative research contributions" (J. E. Hirsch, 2005). Impact Factor 2018 (JCR) numbers have been rounded to the nearest tenth.
*Journal does not currently have an impact factor.

Funding

Funding information was available for 1,330 papers, 56% of the publication database[1]. We identified 354 unique sources of funding for Stanford digital health publications, with 274 public sources (e.g., National Institutes of Health [NIH]) and 80 private sources (e.g., Google). When compared to other technology categories, AI had the highest percentage of funded publications at 67% (Table 6) and the highest number of unique sponsors at 241 (Table 7).

In aggregate, there were 2,893 funding activities (not unique). Because a sponsor can fund research that can lead to multiple publications, a funding activity is defined as a sponsor's association with one research article. The number of funding activities by technology category can be seen in Figure 2. Funding activities by clinical and application area can be seen in Table 8 and unique sponsors by clinical and application areas can be found in Table 9.

The top private sponsors by number of publications were Google (15), Philips (10), General Electric (9), Varian Associates (9) and Roche (9).

Percent of funded publications (public or private source) by technology category:

- 67% for AI
- 50% for health IT, infrastructure, and data management
- 55% for mobile and web applications
- 41% for new clinical care models
- 52% for wearables, sensors, and other devices

Digital Health Funding:

354
unique sponsors

80
private sources

274
public sources

Public funding made up the majority of funding activities based on the available information in the publication database.

Funding Information By Technology Category: All Publications

	AI	Health IT	Mobile/Web	New Clinical Care	Wearables
Total Papers	728	603	436	206	417
Papers with Funding Info (N, %)	486, 67%	302, 50%	241, 55%	84, 41%	217, 52%

Table 6

1. In the majority of cases, missing funding information is attributed to non-funded research.

Number of Funding Activities By Technology Category

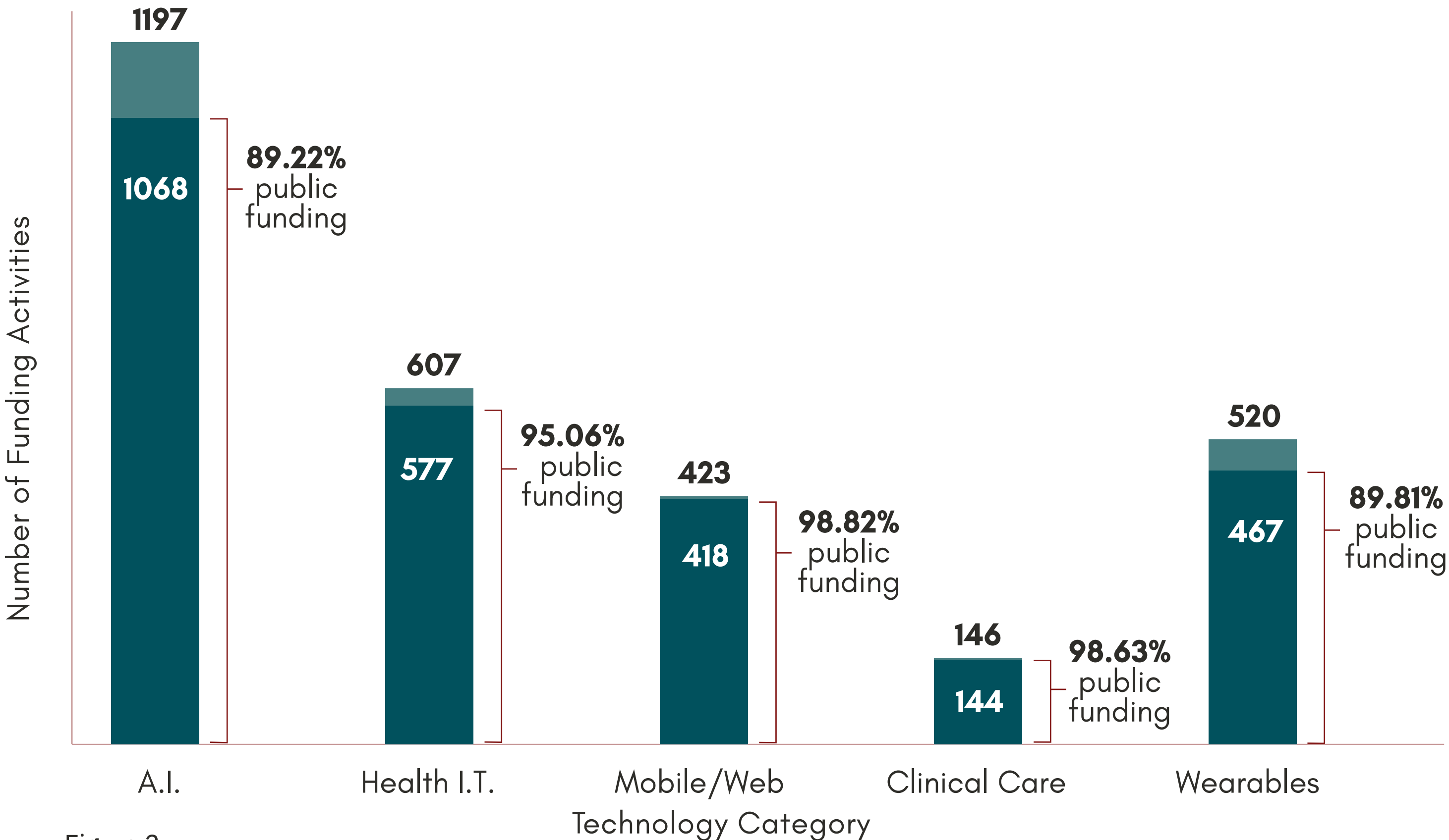


Figure 2

Unique Sponsors By Technology Category

	AI	Health IT	Mobile/Web	Clinical Care	Wearables
Unique Sponsors	241	143	84	63	147
Unique Public Sponsors (N, %)	180, 75%	119, 83%	79, 94%	62, 98%	118, 80%

Table 7 Unique sponsors are individual organizations that funded any number of research projects. In AI research, 75% of all sponsors were public organizations.

Funding Activities By Clinical and Application Area

	Surgery and Anesthesia	Cardio-Metabolic	Hematology-Oncology	Informatics, Data, Workflow	Mental Health
# Funding Activities	56	369	288	343	204
Public Funding Activities (N, %)	51, 91%	318, 86%	269, 93%	324, 94%	199, 98%

Table 8

Unique Sponsors in Clinical and Application Areas

	Surgery and Anesthesia	Cardio-metabolic	Hematology-Oncology	Informatics, Data, workflow	Mental health
Unique Sponsors	33	97	108	87	66
Unique Public Sponsors (N, %)	29, 88%	71, 73%	97, 90%	69, 79%	61, 92%

Table 9: Unique sponsors are individual organizations that funded research. In the case of surgery and anesthesia, 88% of all sponsors were public organizations

Clinical and Application Areas

Among Stanford digital health publications, the clinical areas with the highest representation were cardiometabolic (n=301) and hematology-oncology (n=224). Across application areas, defined as any research that is not focused on a specific clinical area, the largest number of publications were in medical informatics, data management and workflow (n=338), surgery and anesthesia (n=146), and well-being (n=141). Over the last five years we observed rapid growth in publications across the top clinical areas outlined in Figure 3: neurology, musculoskeletal, mental health, hematology-oncology, and cardiometabolic. Figure 4 details the rise of digital health publications in imaging, omics, medical informatics, data management, and workflow, and surgery and anesthesia since 2014.

Top 5 Clinical Areas by Volume Over Time

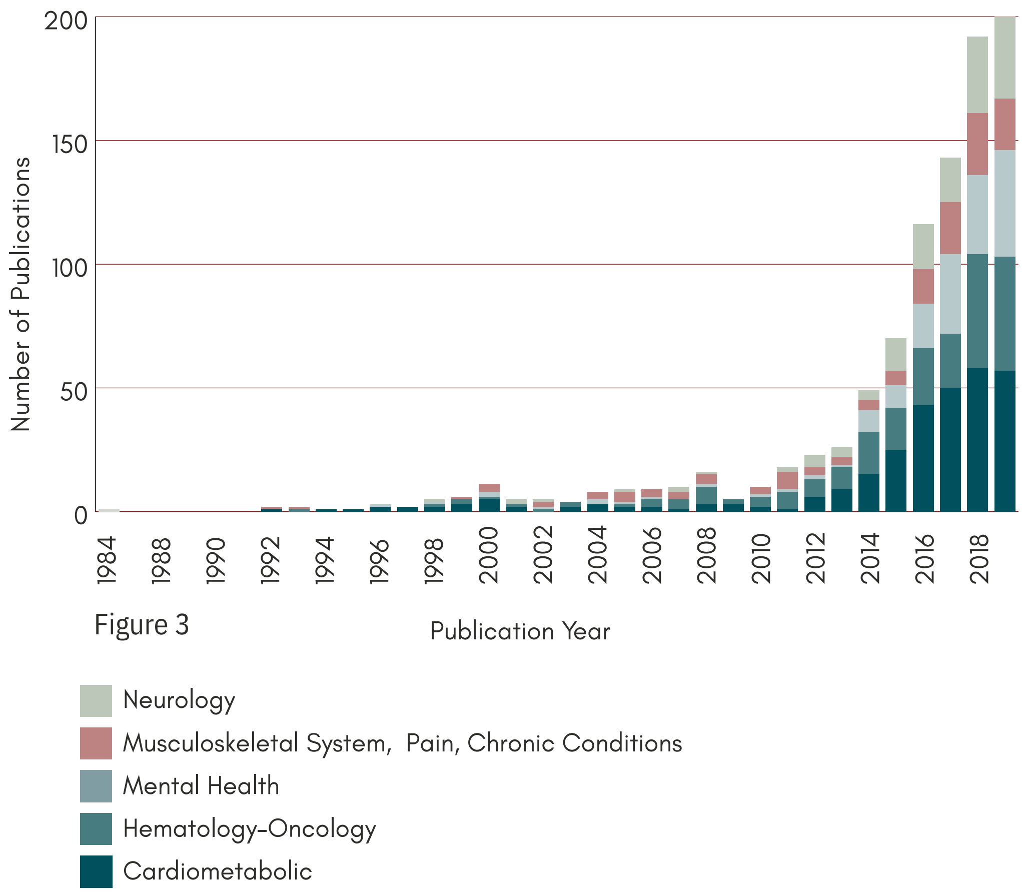


Figure 3

Top 5 Application Areas by Volume Over Time

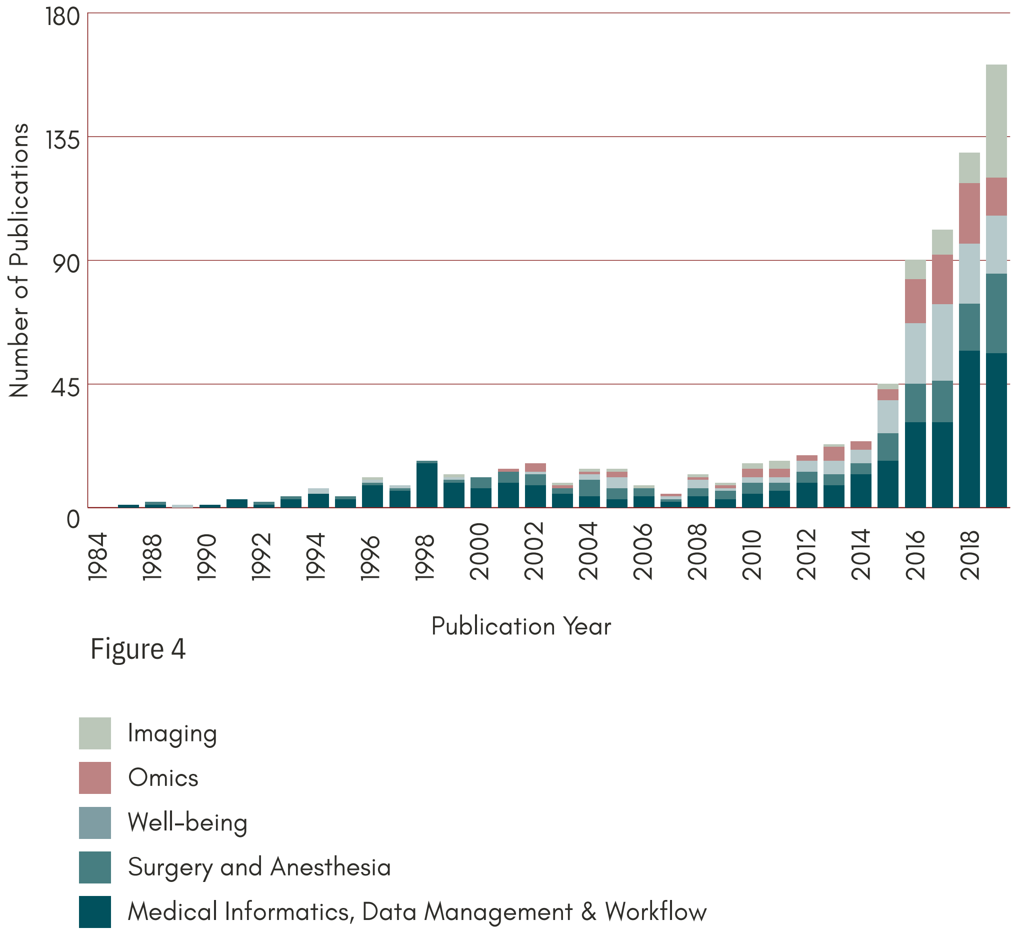


Figure 4

Top Clinical Areas All Publications (Figure 3)

- Cardiometabolic (301)
- Hematology-oncology (224)
- Mental health (158)
- Neurology (136)
- Musculoskeletal system, pain, chronic conditions (133)

Top Application Areas All Publications (Figure 4)

- Medical informatics, data management, and workflow (338)
- Surgery and anesthesia (146)
- Well-being (141)
- Omics (101)
- Imaging (84)

Stanford Digital Health Licensable Technologies

Stanford has an established history of commercializing medical advances, as evidenced by the volume of digital health patents facilitated by the [Stanford Office of Technology Licensing (OTL)](). The OTL was established in 1970 to manage the intellectual property assets developed at Stanford University and provides an established pathway for promoting Stanford technology for society's use and benefit while generating unrestricted income to support research and education. The OTL database offers over 1600 available technologies, 126 of which relate to digital health (as of 12/31/2019). In addition to the available technologies listed in the database, numerous digital health technologies have either been licensed or are under the control of a joint owner. Using the same methodology from our literature review, we categorized the 126 digital health technologies into clinical and application areas as seen in Table 5 and 6. Available data from OTL showed that within the field of digital health, the top application area was imaging and the top clinical area was neurology. Additionally, the highest represented technology categories (not shown) included wearables (n=59) and AI (n=53)

Clinical Areas: Licensable Technologies

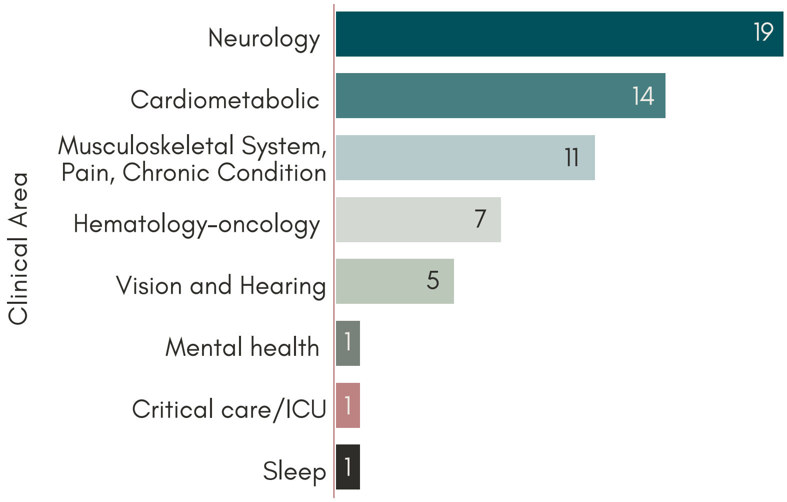


Figure 5 Number of Licensable technologies

Application Areas: Licensable Technologies

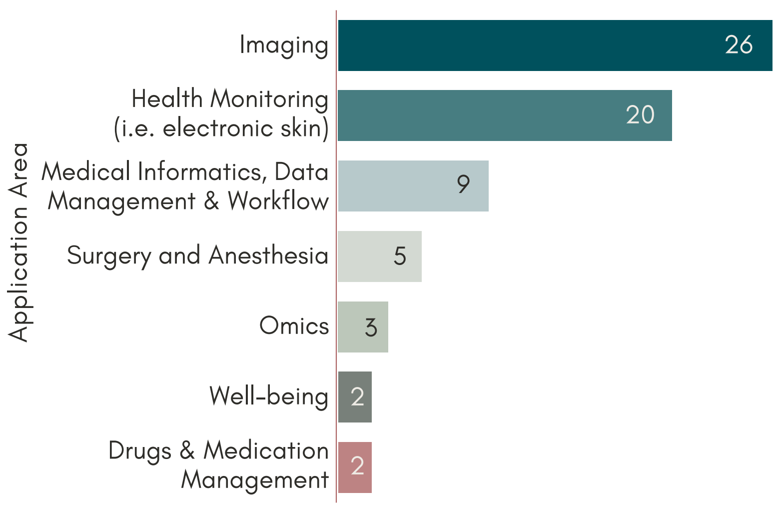


Figure 6 Number of Licensable technologies

Citations and Impact

By analyzing citation data, we observed Stanford's impact in the field of digital health. 24% of Stanford digital health publications have been cited more than 25 times and 12% of publications more than 50 times (Figure 7).

Among the 10 highest cited publications shown in Table 10, five pertained to the engineering and development of wearable technologies. Their impact is likely driven by their incorporation and reference in subsequent studies focused on developing, testing, and implementing similar technologies in the clinical domain.

Number of Citations Per Publication

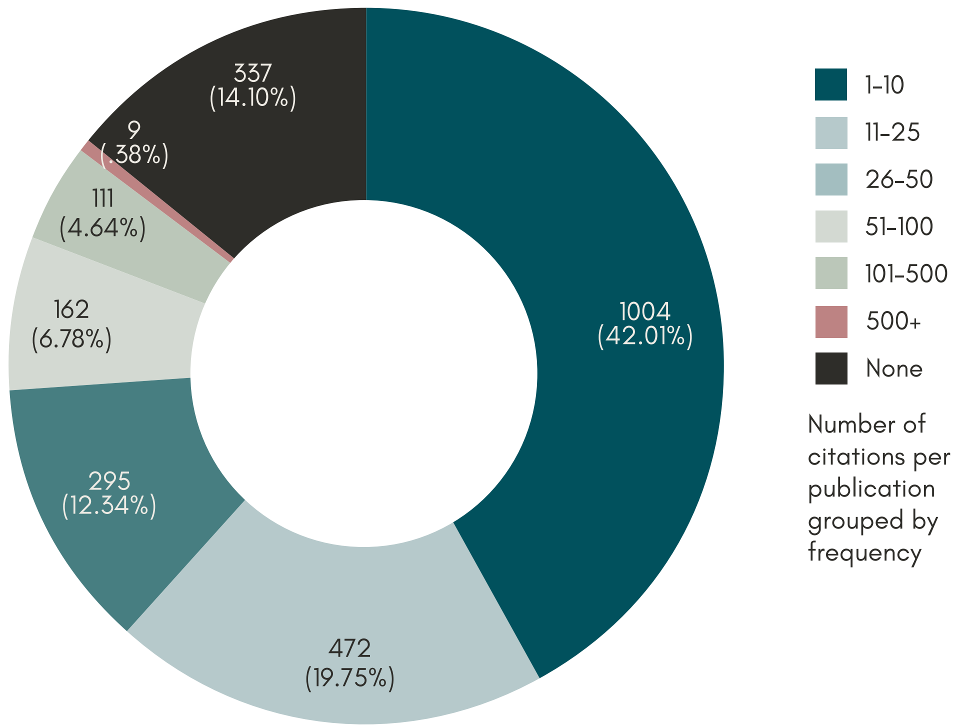


Figure 7

Top 10 Most-Cited Publications

Times cited	Title	Pub. Year
1904	Dermatologist-level classification of skin cancer with deep neural networks	2017
1332	Highly sensitive flexible pressure sensors with microstructured rubber dielectric layers	2010
1031	Noncovalent functionalization of carbon nanotubes for highly specific electronic biosensors	2003
991	Fully integrated wearable sensor arrays for multiplexed in situ perspiration analysis	2016
954	Stretchable, porous, and conductive energy textiles.	2010
852	Flexible polymer transistors with high pressure sensitivity for application in electronic skin and health monitoring	2013

Top 10 Most-Cited Publications Continued

Times cited	Title	Pub. Year
824	Use of the Internet and E-mail for Health Care Information: Results From a National Survey	2003
803	Personal Health Records: Definitions, Benefits, and Strategies for Overcoming Barriers to Adoption	2006
564	Effect of Structured Physical Activity on Prevention of Major Mobility Disability in Older Adults: The LIFE Study Randomized Clinical Trial	2014
451	A Video Game Improves Behavioral Outcomes in Adolescents and Young Adults With Cancer: A Randomized Trial	2008

Table 10

Relative Citation Ratio and Altmetric Scores

The Relative Citation Ratio (RCR) is calculated as the number of citations of a paper normalized to the citations received by NIH-funded publications in the same area of research and year. Because the bibliometric data in our database was retrieved on 01/29/2020 and an article has to be at least 2 years old in order to receive an RCR score, publications after 2017 do not have RCR scores[1].

Top Publications: Relative Citation Ratio

RCR	Source Title	Title	Pub. Year
147.2	Nature	Dermatologist-level classification of skin cancer with deep neural networks	2017
54.4	Nature	Fully integrated wearable sensor arrays for multiplexed in situ perspiration analysis	2016
36.7	JAMA	Effect of Structured Physical Activity on Prevention of Major Mobility Disability in Older Adults: The LIFE Study Randomized Clinical Trial	2014
22.4	JAMA	International Consensus on Use of Continuous Glucose Monitoring	2003
19.6	Nature Communications	Glucose Outcomes with the In-Home Use of a Hybrid Closed-Loop Insulin Delivery System in Adolescents and Adults with Type 1 Diabetes	2013

Table 11

1. The RCR is calculated for all PubMed publications which are at least 2 years old and also have at least one citation. Values are centered around 1.0 so that a publication with an RCR of 1.0 has received the same number of citations as would be expected based on the NIH-norm, while a paper with an RCR of 2.0 has received twice as many citations as expected (Dimensions.ai).

In total, 1,477 (62%) of Stanford's digital health publications included an RCR score and 781 (53%) of the publications had an RCR >1. 124 (8%) of the publications had an RCR >= 5.0. The top publications by RCR score are shown in Table 11. In our publication database, the articles with the highest Altmetric Attention Scores (Table 12), are part of the top 5% of all research outputs scored by Altmetric. The Altmetric Attention Score is the weighted count of all of the online attention a publication receives including mentions in public policy documents, references in Wikipedia, the mainstream news, social networks, blogs etc.

Top Publications: Altmetric Attention Score

Altmetric Score	Source Title	Title	Pub. Year
2880	Nature	Dermatologist-level classification of skin cancer with deep neural networks	2017
2311	Nature Biomedical Engineering	Prediction of cardiovascular risk factors from retinal fundus photographs via deep learning	2018
2096	npj Digital Medicine	Scalable and accurate deep learning with electronic health records	2018
1669	Journal of Personalized Medicine	Accuracy in Wrist-Worn, Sensor-Based Measurements of Heart Rate and Energy Expenditure in a Diverse Cohort	2017
1646	JAMA Internal Medicine	Smartphone-Based Conversational Agents and Responses to Questions About Mental Health, Interpersonal Violence, and Physical Health	2016

Table 12

Collaborations

In our analysis, Stanford affiliated digital health publications were linked to 1,349 unique external research partners since 1984. Figure 8 shows that out of 2,390 total publications that were affiliated with Stanford, 1,142 included both a first and last author from Stanford. 423 publications had a first-author Stanford affiliation, while 205 publications had a last-author Stanford affiliation.

1,349

unique external research partners since 1984

Stanford Authorship Contribution

2,390 Total Stanford Digital Health Publications

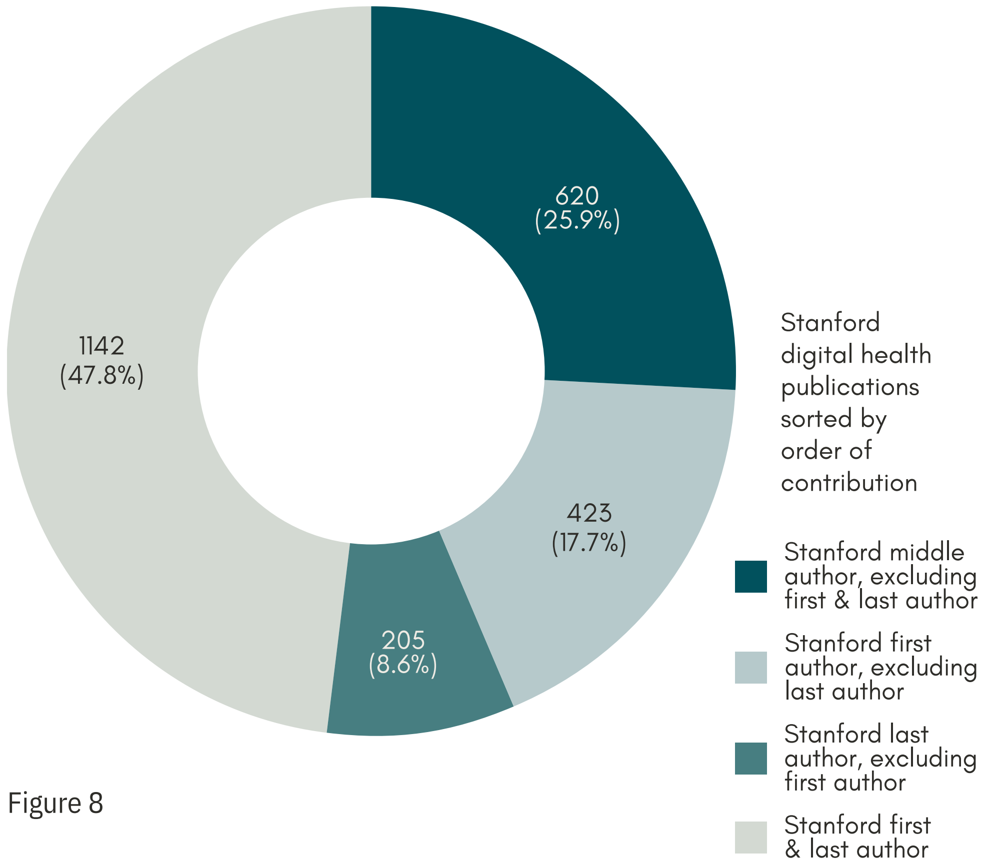


Figure 8

Domestic Collaborations: Research Organizations

Geographically, Stanford's academic collaborations cover the entire country. While two of the top 10 U.S. collaborators are in California, the other eight represent public and private research institutions from various locations across the country (Table 13). It is worth noting that the top domestic collaborator (University of California, San Francisco) also has a specific focus on digital health and precision medicine.

Top 10 Collaborative Research Organizations

	Research Organization	# of collaborative papers
1	University of California, San Francisco	126
2	Harvard University	91
3	University of California, San Diego	71
4	Yale University	61

Table 13

Top 10 Collaborative Research Organizations (Continued)

	Research Organization	# of collaborative papers
5	University of Michigan	60
6	Duke University	60
7	Johns Hopkins University	60
8	University of Washington	57
9	Northwestern University	49
10	University of Pennsylvania	44

Table 13 (Continued)

International Collaborations

24% of Stanford's digital health publications involved international collaboration. While the most frequent collaborators were from Europe and China, Stanford collaborations extend across 59 countries and six continents (Table 14 and Figure 9).

24%
of publications involved international collaboration

59
Countries

6
Continents

Top 10 Collaborative Countries

	Collaborating Countries	# of collaborative papers
1	China	160
2	United Kingdom	157
3	Canada	154
4	Germany	128
5	Australia	108
6	South Korea	69
7	Italy	54
8	Netherlands	50
9	Switzerland	42
10	Israel	41

Table 14

Top 10 Collaborative Countries

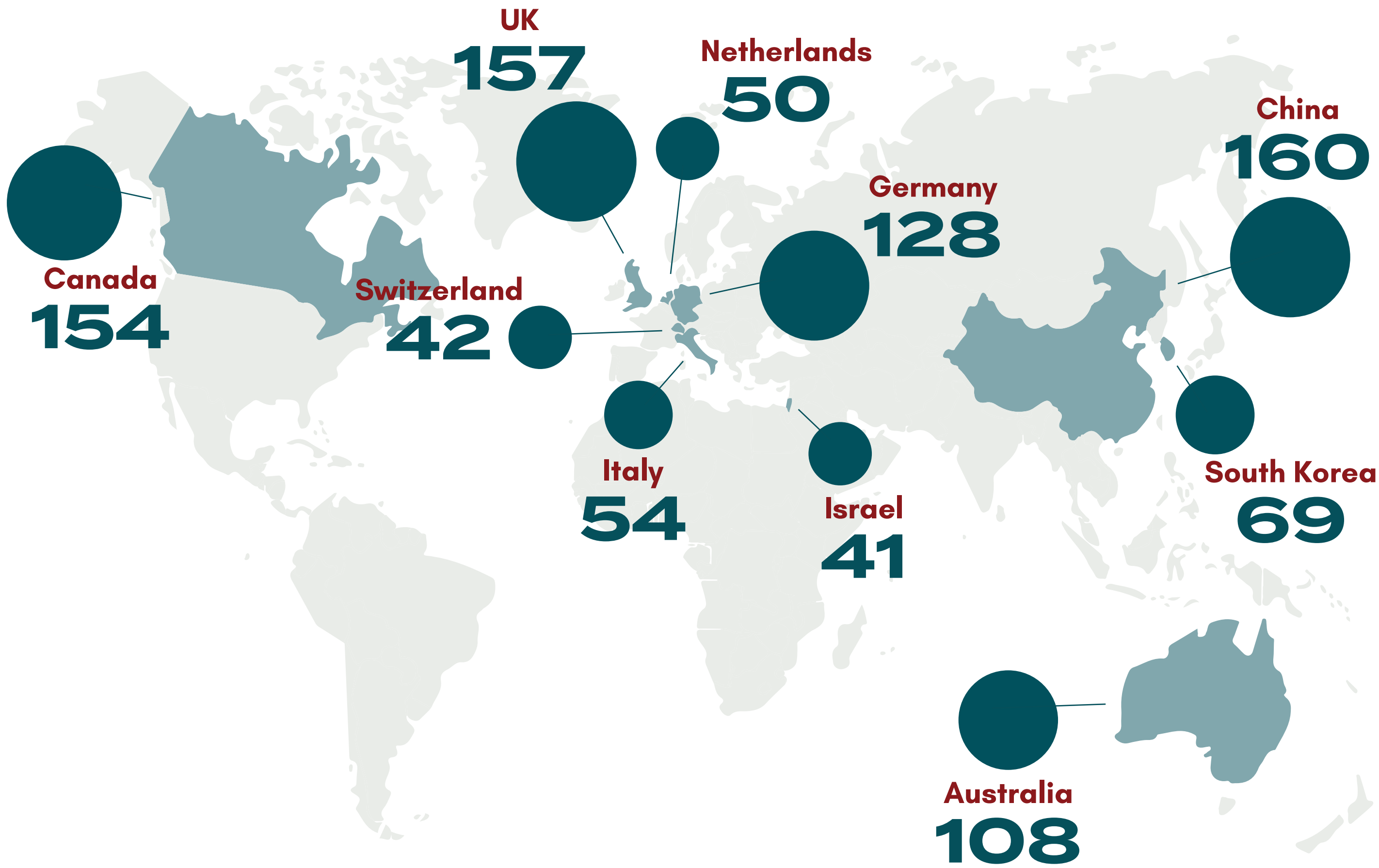


Figure 9: Top 10 countries that have collaborated with Stanford University in digital health as identified in the publication database.

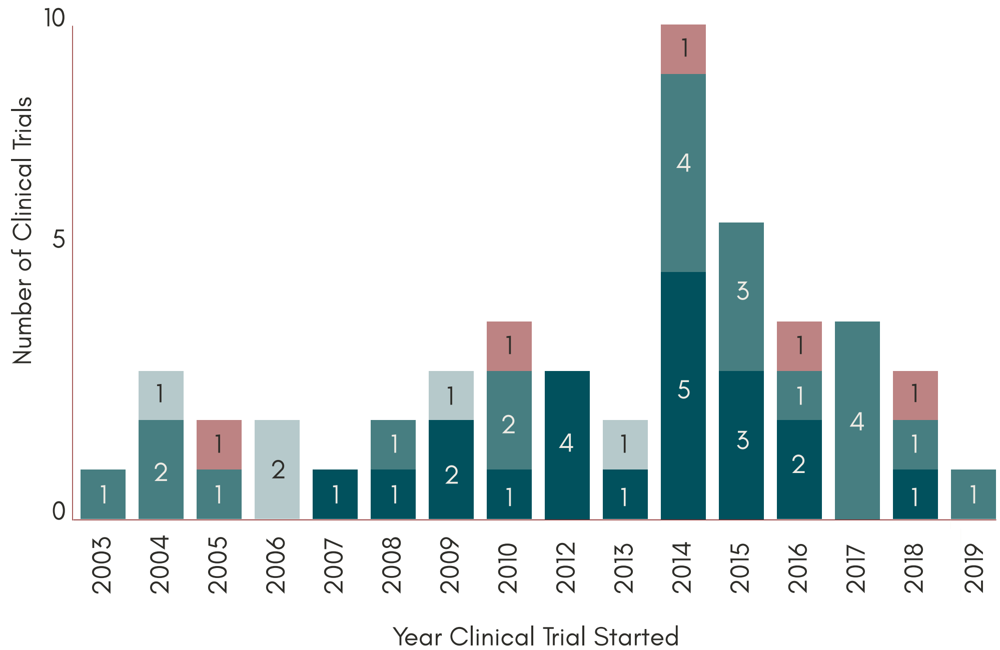
Industry Collaborations

Stanford has collaborated with 83 unique industry partners on a variety of digital health publications. Although the majority of these industry collaborators are located in the United States (n=68), Stanford has also had multiple collaborations with organizations based in China (State Grid Corporation of China), Germany (Bayer, Siemens, Boehringer Ingelheim, etc.), the Netherlands (Philips), and South Korea (Samsung).

Digital Health Clinical Trials

A total of 118 publications included a National Clinical Trial number (NCT) which were linked to 105 unique clinical trials on the ClinicalTrials.gov database. The median cohort size of the 105 Stanford digital health clinical trials was 187 patients, with 69 trials recruiting at least 100 patients over the trial duration. While the number of trials has increased in the last decade, the ratio of smaller to larger trials has largely stayed the same. Additional research from CDH investigators on digital health clinical trials shows that smaller pilot studies trials have been trending in recent years. From the 105 Stanford digital health clinical trials, 84% have been completed and 12% were still ongoing as of 12/31/2019. Table 15 shows the number of digital health clinical trials by clinical and application area.

Stanford Digital Health Clinical Trials Over Time by Cohort Size



Cohort Size

- Over 1000 (9.8%)
- From 501-1000 (9.8%)
- From 100-500 (41.2%)
- Below 100 (39.2%)

Figure 10: Number of trials in a given year denotes the trial was started that year. These clinical trials were either conducted by Stanford or included Stanford's participation.

Digital Health Clinical Trials: Clinical and Application Areas

Stanford Digital Health Clinical Trials	Number of Trials	%
Cardiometabolic	38	36%
Mental health	16	15%
Well-being	13	12%
Substance Abuse	7	7%
Obstetrics, Gynecology, Reproductive Health, Urology	6	6%
Hematology-Oncology	5	5%
Neurology	4	4%
Surgery and Anesthesia	3	3%
Autoimmune	3	3%
Pulmonary	3	3%
Musculoskeletal System, Pain, Chronic Conditions	2	2%
Sleep	2	2%
Infectious Disease	2	2%
Renal	1	1%

Table 15

COVID-19

Assessment of the COVID-19 Research Study Landscape

COVID-19 has led to massive activation of clinical research resources across the globe, with high expectations placed on this work. However, the strength of these studies has not been characterized.

Investigators from the Center for Digital Health evaluated the quality and expected strength of evidence of all COVID-19 studies registered in ClinicalTrials.gov, the largest registry of clinical research studies and trials worldwide (Pundi, Perino, Harrington, Krumholz, & Turakhia, 2020).

There were 2,690 COVID-19 studies registered through July 25, 2020, including 1086 randomized clinical trials (RCT's). However, only 31% of those registered in ClinicalTrials.gov have the potential to result in Oxford Center for Evidence Based Medicine Level 2 evidence. Of the randomized trials, only 33% were placebo-controlled and blinded. Only 54 RCTs were also multi-center studies with intended enrollment >500 patients. Finally, relatively few studies examined important clinical outcomes such as mortality. Most examined surrogate outcomes including clinical course and persistence of infection (Figure 11). Although a few large trials may generate strong evidence, we found the large proportion of studies with expected low-quality evidence to be of major concern. Rapid dissemination of low-quality evidence is concerning, as these data can disproportionately influence public opinion, government actions, and policy. In this paper, CDH investigators propose a number of solutions, including the creation of a scientific response for the next pandemic. Such a response, we argue, should include, "rapidly deployable systems for multicenter registries and trials should be created but with an emphasis on quality, not just speed. These systems could be activated for global health crises, leading to streamlined operations."

Primary Outcome of Randomized Clinical Trials by Enrollment Size

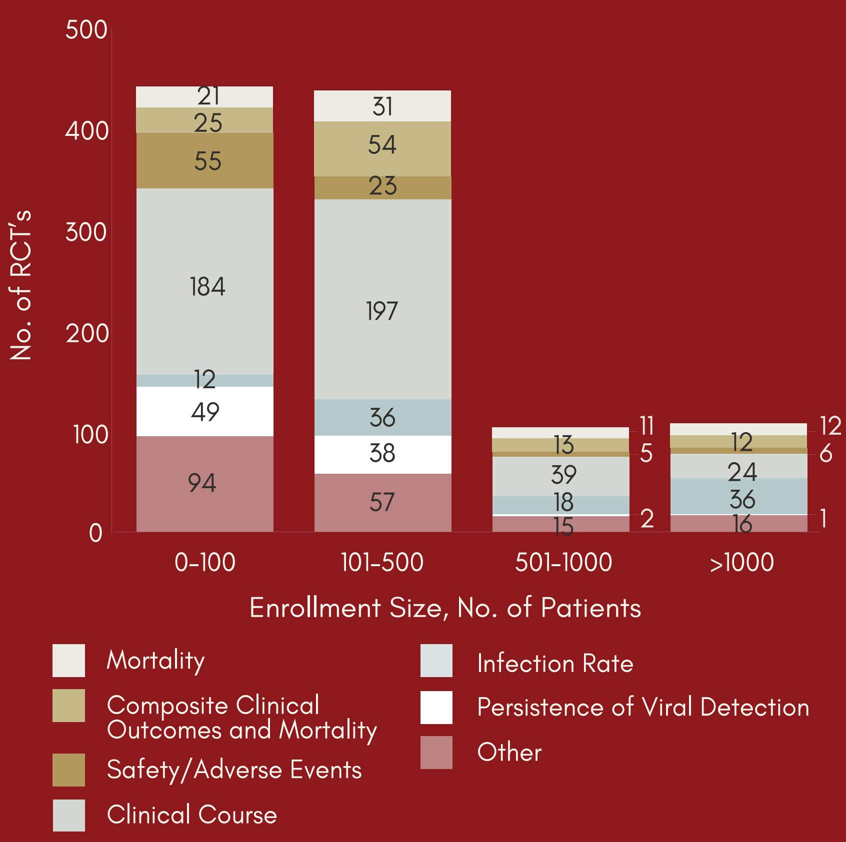


Figure 11

COVID-19 and Digital Health at Stanford

While local, national, and global responses to COVID-19 have varied greatly, the widespread use of telehealth during the pandemic has opened the door for digital health technology adoption in numerous areas across healthcare. In response to COVID-19, Stanford is leveraging the expertise and resources of its interdisciplinary community and continues to work at the forefront of the pandemic.

Digital health technologies provide safer mechanisms for patient-physician interactions, scalable and flexible alternatives to traditional in-person care, continuous monitoring capabilities, and they require fewer resources when compared with standard care pathways (e.g.,, physical office space). Across campus, members of the Stanford community are using these technologies in research on testing, transmission, vaccination and treatment, and data science and modeling. Additionally, researchers in epidemiology, immunology, and cardiology are using technology to understand the spread of the virus and its effect on our immune and cardiovascular systems.

Stanford research on COVID-19 includes studies tracking the biological parameters of individuals who are ill or at risk for the disease using smart watches, determining pathogenicity of variants and strains of COVID-19, and using 3-D printing technology to generate N-95 filters for snorkel masks. Other projects include bed- and resource-use projections for Stanford Health Care and radiological imaging of COVID-19 patients for allocation of hospital resources. Stanford is also working with the state of California on CalCAT, a tool that assesses the spread of COVID-19 across 21 California counties.

The following figure provides a high-level overview of COVID-19 related activities at Stanford. For more information on COVID-19 research initiatives, Stanford Medicine has provided a curated selection, including summaries, of ongoing research projects.

First Responder COVID-19 Guide App

Repurposing Snorkel Masks for Personal Protective Equipment

Tracking COVID-19 with Wearables

Enhancing the Public Health Data Ecosystem for COVID-19 Prevention

Predicting the Onset of Viral Infections Through a Smartwatch

Genomic Surveillance to Identify Silent Transmission Clusters of COVID-19

Rapid-Response Ventilators

Answering COVID-19 Clinical Research Questions With Electronic Health Record Data

Using Artificial Intelligence to Predict Drugs That May Inhibit COVID-19

Stanford Medicine National Daily Health Survey

COVID Imaging Utilization per Patient

The Stanford-Cide Novel Coronavirus Simulation Model

DIGITAL HEALTH TECHNOLOGY CATEGORIES

This report utilizes a novel framework to categorize technologies into five intuitive groups, designated as digital health technology categories. Digital health work at Stanford will be explored by these five technology categories in the following section. To reiterate, these categories are:

1. **Wearables, sensors, and other devices** (not including traditional medical devices)
2. **Mobile and web applications** (including online SaaS (Software as a Service) platforms, cloud-based software tools, and social media)
3. **Artificial intelligence (AI), machine learning (ML), and algorithms** (including deep learning, image processing, and advanced analytics)
4. **New clinical care models** (including telemedicine, patient engagement, and patient–physician interaction)
5. **Health IT, infrastructure, and data management** (including Electronic Health Record systems)

Total Publications in Each Technology Category

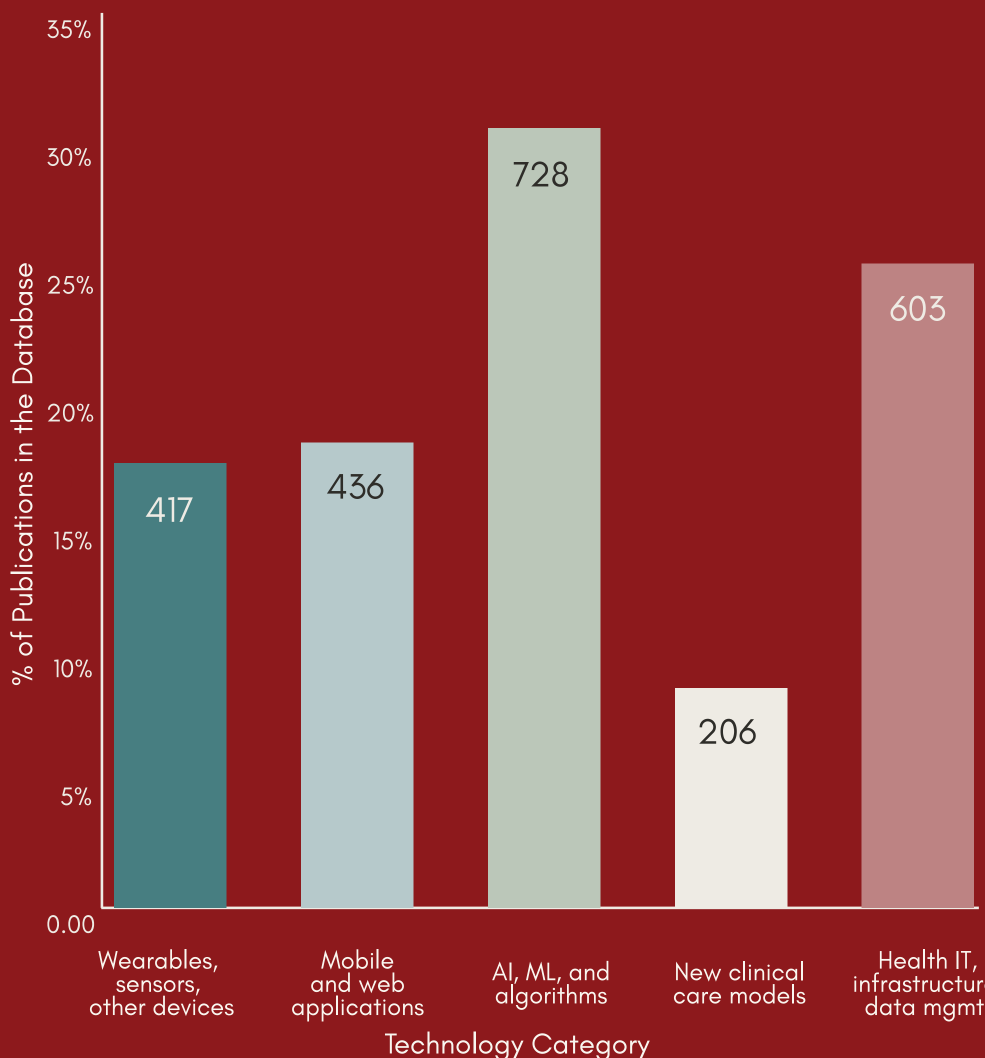


Figure 12: Total number of publications per technology category.

Wearables, Sensors and Other Devices

Definition

Throughout the report, wearables, sensors, and other devices refers to a broad and expanding category of hands-free electronic devices (those with micro-controllers), that collect and process a variety of data. These devices are frequently connected to a smartphone or network, allowing for streamlined data transfer. These devices are often available direct-to-consumer, without gatekeeping by the medical establishment. Common examples include wrist-based activity trackers, wearable ECG monitors, continuous glucose monitors, wearable blood pressure monitors, and other body-mounted sensors used to collect and transmit biological data. Other devices in this category include virtual reality headsets, flexible pressure sensors (electronic skin), nanoelectronics, neurostimulators, implantables, and other novel biosensors.

Literature Review

Wearables can provide accessible, engaging, and novel avenues to promote fitness, track health, and manage a health condition. However, investigation into the impacts of these products on health is critical, with Stanford making substantial contributions to the wearable literature base. Since 1984, Stanford-affiliated authors have published 417 publications on wearables, sensors, and other devices. Over the past five years, the leading clinical and application areas included:

Clinical Areas (Figure 13)

1. Cardiometabolic (76)
2. Neurology (37)
3. Musculoskeletal system, pain, and chronic conditions (26)
4. Vision and hearing (23)
5. Obstetrics, gynecology, reproductive health, and urology (14)

Application Areas (Figure 14)

1. Surgery and anesthesia (30)
2. Well-being (22)
3. Other (14)
4. Omics (14)
5. Medical informatics, data management, and workflow (7)

Based on affiliations of listed co-authors, Stanford-affiliated authors are collaborating broadly with the international research community on wearable research. Collaborations with South Korea and China are particularly strong, which both have strengths in wearable technology development.

Stanford-affiliated publications on wearables, sensors, and other devices with the highest number of citations were largely published in the last decade (four out of five as shown in Table 16). In contrast to other technology categories, wearable publications have focused on technology development and

Top 5 Clinical Areas in Wearables, Sensors, and Other Devices Over the Last 5 Years

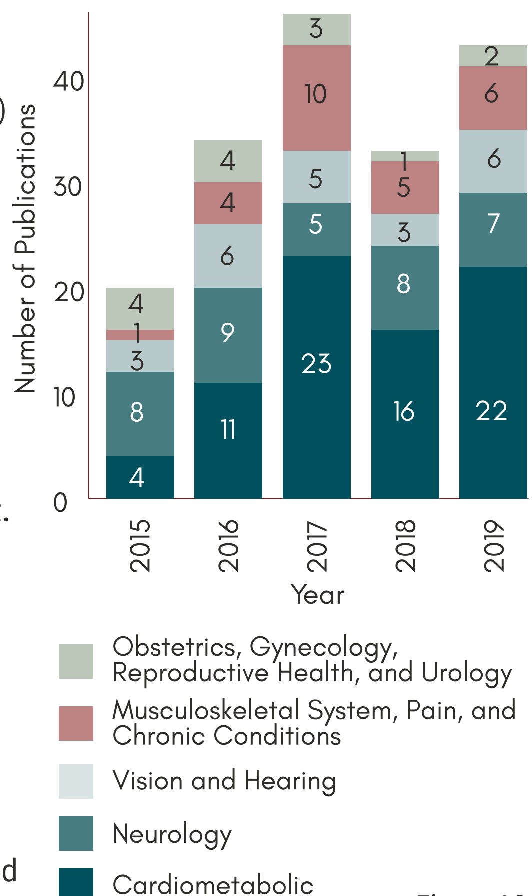


Figure 13

proof of concept, rather than clinical or patient reported endpoints or healthcare implementation. This finding may reflect that the science for this area is in its early stage, with clinical studies to follow. Notably, the journal Diabetes Technology & Therapeutics (Table 17), compared to other journals, published the largest number of papers from Stanford-affiliated authors on wearables. This may reflect the diabetes epidemic driving overall research interest and funding for this disease, treatment gaps for diabetes patients being uniquely suited for current digital health technologies, or researchers at Stanford investigating issues around diabetes having shared expertise in digital health technologies.

Most-cited Publications: Wearables

Times cited	Title	Pub. Year
1332	Highly sensitive flexible pressure sensors with microstructured rubber dielectric layers	2010
1031	Noncovalent functionalization of carbon nanotubes for highly specific electronic biosensors	2003
991	Fully integrated wearable sensor arrays for multiplexed in situ perspiration analysis	2016
954	Stretchable, porous, and conductive energy textiles.	2010
852	Flexible polymer transistors with high pressure sensitivity for application in electronic skin and health monitoring	2013

Table 16

Top 5 Application Areas in Wearables, Sensors, and Other Devices Over the Last 5 Years

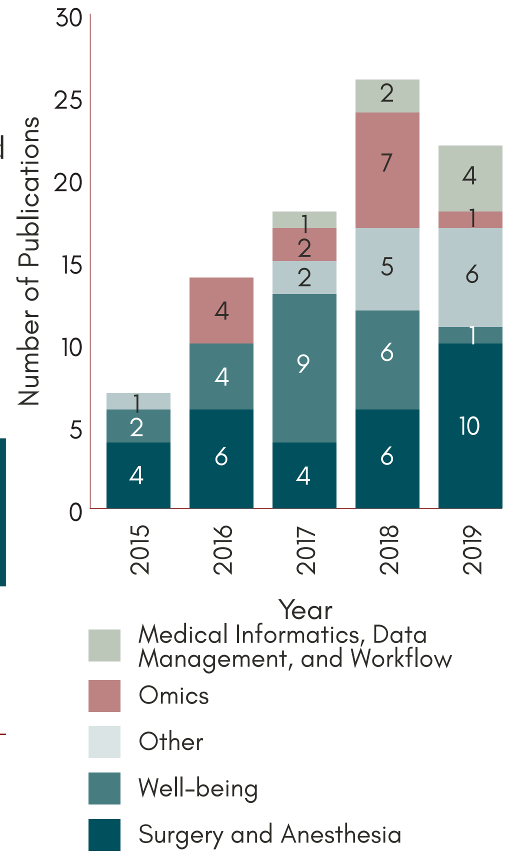


Figure 14

Top Journals: Wearables

Impact Factor 2018 (JCR)	Sources	# of papers
4.5	Diabetes Technology & Therapeutics	16
9.6	Proceedings of the National Academy of Sciences	10
2.8	PLoS ONE	10
15.3	Diabetes Care	9
n/a	Journal of Diabetes Science and Technology	9

Table 17

Top Publishing Authors: Wearables

Author	# of papers
Buckingham, Bruce A.	35
Bao, Zhenan	22
Hood, Korey K.	19
Maahs, David M.	18
Ly, Trang T.	13
Ekhlaspour, Laya	10
King, Abby C.	10
Kollman, Craig	9
Turakhia, Mintu P.	8
Camarillo, David B.	7

Total Contribution, Wearables: 36%

Table 18

Featured Faculty

Zhenan Bao, PhD

K.K. Lee Professor of Chemical Engineering & Chair, Dept of Chemical Engineering

Prior to joining Stanford in 2004, Zhenan Bao was a Distinguished Member of Technical Staff in Bell Labs, Lucent Technologies. She received her PhD in Chemistry from the University of Chicago in 1995. She has over 500 refereed publications and over 65 U.S. patents with a Google Scholar H-Index >160. She pioneered a number of molecular design concepts for organic electronic materials. Her work has enabled flexible electronic circuits and displays. In the past ten years, she pioneered the field of skin-inspired organic electronic materials, which resulted in unprecedented performance or functions in medical devices, energy storage and environmental applications.

Bao is a member of the National Academy of Engineering and the National Academy of Inventors. Bao was selected as one of Nature's Ten people who mattered in 2015 as a "Master of Materials" for her work on artificial electronic skin. She was awarded the AICHE Andreas Acrivos Award for Professional Progress in Chemical Engineering in 2014, the L'Oréal-UNESCO For Women in Science Award in the Physical Sciences 2017, the Wilhelm Exner Medal by Austrian Federal Minister of Science 2018, and the inaugural ACS Central Science Disruptor and Innovator Prize in 2020.

Wearable Technology at Stanford

Adjacent to Silicon Valley, Stanford University has long been at the forefront of innovation and implementation of wearable technology in a variety of medical contexts. This includes projects across the continuum of care including consumer wellness, prevention, and disease management. At Stanford, researchers are developing wearable devices and sensors with diverse applications, including tracking physiomes, diagnosing, and analyzing disease, remote patient monitoring, measuring depression, tracking sleep, assessing functional mobility, sensing blood-flow through nanoelectronics, studying atrial fibrillation, treating symptoms of stroke, flexible and stretchable electronic materials, diabetic smart contact lenses, implantable devices, and ingestibles.

Stanford Center Outreach Initiative

Stanford groups focused on the development and use of wearable technology include PHIND (The Precision Health and Integrated Diagnostics Center), eWear (Stanford Wearable Electronics Initiative), The Wearable Health Lab, Stanford Byers Center for Biodesign, and the Mobilize Center among others. Stanford Children's Health and Stanford Health Care also have a variety of applications using wearable technologies and sensors.

The PHIND Center develops, tests, and disseminates the next generation of healthcare mechanisms for precision health, integrating diagnostic information collected from multiple sources on the body and in the home. It also studies the fundamental biology underlying early transitions from health to disease, and the associated biomarkers. The PHIND team is working on many innovative projects, including: Wearable Wireless Sleep Monitoring System for Precision Health, Detection and Prevention of Autism Through Wearable Artificial Intelligence, Multidimensional Predictors of Major Depressive Disorder and Suicidal Behaviors In Adolescents, and VascTrac: Passive Mobile Screening for Peripheral Artery Disease as Biomarker and Risk Assessment Tool for Cardiovascular Disease.

Stanford eWear is a university-wide multi-disciplinary program that brings together expertise in materials, electronics, systems, data, and clinical science, providing a forum for discussing and setting future directions of wearable electronics. eWear helps foster collaborations between Stanford researchers and industry, promotes the early communication of new results, pushes the forefront of wearable technologies, and helps to set standards for wearable electronics devices, data analysis, and testing protocols.

The Wearable Health Lab harnesses the power of wearable biosensor data using both qualitative and quantitative approaches to research, prevent, and treat orthopedic and neurological diseases. They use research grade inertial measurement units (IMUs) and off-the-shelf sensing solutions like smartphones and smartwatches for clinical mobility assessment, innovative free-living tracking of physical performance, and personalized interventions. To date, researchers at the Wearable Health Lab have co-developed the largest known databases of accelerometer data for individuals with lumbar stenosis.

The Stanford Byers Center for Biodesign was founded to create an ecosystem of training and support for Stanford University students, fellows, and faculty with the talent and ambition to become health technology innovators. When Stanford Biodesign was founded in 2000, the initial focus was on "medical technology," referring to medical devices such as catheters and implantables. Over time that focus has expanded, and Biodesign trainees now invent a broad range of solutions to problems across healthcare including device-based diagnostics, health information systems, traditional devices with a digital component, and pure digital health solutions. ZioPatch by iRhythm, a wearable heart rhythm monitor for arrhythmia detection and diagnosis, came out of the Biodesign Innovation Fellowship in 2006 and was one of the first solutions to a healthcare problem with a purely digital health component. Biodesign is bridging the gap between traditional medical device development and digital health innovation by providing expertise in the evolving regulatory landscape for digital health products, clinical evidence parameters for regulatory approval, business model development, and payment/reimbursement planning. Biodesign has a number of digital health innovation case studies online.

The Mobilize Center is an NIH-funded Biomedical Technology Resource Center (BTRC) whose mission is to advance the state-of-the-art in biomechanical and machine learning models for understanding human movement across a wide range of conditions. The Center's tools generate new insights from diverse datasets, including clinical notes, time-series data from smartphones and wearable sensors, medical images, and videos acquired from clinical labs as well as consumer devices.

Large-Scale Studies and Projects

Other notable projects by Stanford Medicine researchers involving wearable devices include the Apple Heart Study, Project Baseline, the Humanwide Project, and MyHeart Counts. The Apple Heart Study used data from Apple Watches to identify irregular heart rhythms, including those from potentially serious heart conditions. Stanford Medicine conducted this research study in collaboration with Apple to improve the technology used to detect and analyze irregular heart rhythms, like atrial fibrillation, a leading cause of stroke.

Project Baseline by Verily is an initiative to make it easy and engaging for the layperson to contribute to the map of human health and participate in clinical research. In collaboration with researchers, clinicians, engineers, designers, advocates, and volunteers from Google, Duke University School of Medicine, Stanford Medicine, the American Heart Association, and government agencies, Project Baseline is building the next generation of healthcare tools and services by collecting phenotypic health data through wearables and other devices from over 10,000 participants over the course of at least four years. Participants are able to test new tools, devices, and technologies, and help shape the future of healthcare. The goal is to establish well-defined reference parameters, or a "baseline", of what good health entails. The data-rich Baseline platform can help researchers better understand how patients transition from a healthy state to a disease state and what additional risk factors may be associated with that transition.

60,000+

participants enrolled in the MyHeart Counts study

Through the Humanwide Project, primary care teams at Stanford Medicine's Primary Care 2.0 Clinic in Santa Clara, California merged high-tech and high-touch interventions to provide a diverse group of 50 patients with care that treated the whole person based on his or her unique factors, from genetics to lifestyle. This project used mobile monitoring devices, including a glucometer, pedometer, scale, and blood pressure cuff, to regularly measure key health metrics. The data automatically uploaded to the participant's EHR, where it was remotely monitored by the healthcare team. This Stanford Medicine pilot program combined cutting-edge tools of biomedicine with a collaborative, team-based method to offer a new approach to personalized healthcare that captures the promise of precision health: to predict, prevent, and cure disease based on the individual patient.

The MyHeart Counts Study is a first-of-its-kind cardiovascular health investigation and research tool. Powered by Apple's ResearchKit platform, the MyHeart Counts application enables users to track their physical activity in the context of heart health-related parameters such as blood pressure. The study gathers sensor and health data directly from wearables and smartphones, and sends that data to a secure database. The data is then de-identified, randomized, combined with other data sources, and used to support research. Over 60,000 participants have joined the initial study. The methods, study design, and cohort characteristics are detailed in this publication and the data is freely available for secondary research purposes.

The MyHeart Counts platform allows researchers to obtain informed consent for study participation and data sharing, and enables the large-scale collection of real-world physical activity, fitness, sleep, and cardiovascular health data. While patient-reported outcomes are collected from surveys in the app, sensors, including the motion coprocessors built into iPhones and other connected devices provide data via Apple's HealthKit. The app provides return of information to participants by helping them measure and view daily activity, fitness, and cardiovascular risk. In December 2016, the study platform and app were enhanced to study interventions, the first being an embedded notification-based coaching program on physical activity. The next version of the app will be based on the framework developed by the FDA sentinel MyStudies App demonstration project, and will also have AndroidOS support.

Digital Transformation in the Hospital

At Stanford Children's Health, the world-class Orthopedics and Sports Medicine Center uses a suit of wearable retro-reflective markers to measure sprinting in field sports and assess the ability of young athletes to recover after intense exercise. Researchers have also published several studies on intermittent workload and recovery during field sports, and on stress fractures caused during sprinting, cutting, and landing.

In recent years, virtual reality (VR) has increased in popularity and is now used for surgical preparation, patient illness education, and as an adjunct to medical therapies. Researchers at Stanford Children's Health are exploring the potential of using Google Glass to teach children with autism how to recognize emotions and make eye contact. Additionally, virtual reality is being used as a means of therapy to help young patients handle terrifying and painful experiences, offering an alternative to pain medication.

Stanford Medicine pediatric cardiologists are revolutionizing education on congenital heart disease using VR to assist in the diagnosis and treatment of heart disorders and related conditions. In the Department of Psychiatry and Behavioral Sciences at Stanford Medicine, the Virtual Reality and Immersive Technology (VR-IT) Clinic is helping patients by providing sensory feedback retraining via biometric sensing devices to treat a variety of psychiatric illnesses including simple phobias, obsessive compulsive disorder, post-traumatic stress disorder, addiction, psychosis, and social anxiety.

Preventive Care and Early Detection

In the LS-HAPI study, Stanford Medicine and Leaf Healthcare analyzed the effect of a wearable patient sensor in preventing pressure injuries in acutely ill adults. As part of the study, 1,312 ICU patients received either device-informed turning practices (treatment group) or traditional care (control group). A small wireless device, which transmits data about patient position, orientation, movement, and activity, was placed on the chest of those in the treatment group. Software then determined intervals for manual turning to reduce pressure points and blood flow impairments that cause pressure ulcers. Results showed fewer pressure injuries in the treatment group and indicated that compliance with regular turning can significantly improve outcomes. Patients treated with the sensor were 73% less likely to develop a pressure injury.

The Stanford Partnership in AI Assisted Care is currently designing an integrated solution to help remotely monitor seniors living independently at home. Stanford Medicine is collaborating with Onlok home-care facilities to install non-intrusive sensors as part of a pilot project to help automatically detect activities and design algorithms for interpreting continuous, long-term, low-sensorial sensor data. These sensors allow researchers to monitor daily living activities, emotional states, vital signs, and other lifestyle patterns.

Wearables have also been used as part of a longitudinal big data approach to precision health where Stanford Medicine scientists and their collaborators followed more than 100 people over several years, collecting an extensive amount of genetic, molecular, and wearable data to better understand true markers of health and early signs of disease. In contrast to studies that identify participants with a shared disease or biological abnormality, the grounding factor was the long-term collection of big data through wearables. Through genetic testing, researchers identified 13 possible disease-causing abnormalities, and subsequent cardiac testing revealed that some participants had heart disease. While many cohort members had an increased risk for conditions such as diabetes, other conditions including lymphoma and pre-cancers were discovered prior to clinical symptomatology, and the majority at a clinically actionable stage.

The Healthcare Innovation Lab at Stanford Medicine (SHIL) is building the future of precision medicine through wearables and other digital health technologies. With the mission of accelerating precision health technology research/development and advancing clinical adoption, the medical innovators at SHIL are leading the field at the intersection of computer science and biology. Current projects include a COVID-19 Wearable Study, The Wearable Biosensor Initiative, Global COVID-19 Relief Hackathon, Integrated Personalized 'Omics Profiling (IPOP), Personalized Health Dashboard, and others.

The Future of Wearable Devices

Continued adoption of wearable devices by mainstream society promises to provide new avenues for diagnosis, treatment, and monitoring of patients. In the Stanford School of Engineering, Ada Poon, PhD, Associate Professor of Electrical Engineering, is developing tiny implantable wirelessly controlled devices the size of a grain of rice that have the potential to transform the way illnesses are treated. Dr. Poon's work is part of an emerging field called bioelectronics or "electroceuticals." Such work centers on the understanding that the body is regulated by circuits of neurons that communicate through electrical impulses. Researchers in this field are leveraging existing digital health knowledge to develop tiny electrodes that can be used to better understand neural patterns of disease with the intention of improving health by altering malfunctioning pathways.

At Stanford, Ada Poon is developing tiny implantable wirelessly controlled devices the size of a grain of rice that have the potential to transform the way illnesses are treated. Dr. Poon's work is part of an emerging field called bioelectronics or "electroceuticals." Such work centers on the understanding that the body is regulated by circuits of neurons that communicate through electrical impulses.

Mobile and Web Applications

Definition

Mobile health (mHealth) refers to the use of mobile devices and wireless technology for patient care, which includes 1) virtual visits such as telemedicine; 2) asynchronous communication, such as messaging through email or health apps; and/or 3) remote data collection and transfer.

Mobile apps are the poster child of this technology category, which can be utilized from a variety of devices. In a collaboration between the CDH and Rock Health, the 2019 Consumer Adoption Survey found that digital health tracking usage has increased from 18% to 42% between 2015-2019. From the clinician perspective, 93% of physicians believe that mobile health apps can improve patients' health and over 80% of physicians use mobile devices and apps to assist in day-to-day care for their patients.

Although app development has accelerated in parallel to rapid advances in the computing space, including mobile smartphones and broadband internet, cloud-based systems and SaaS (software as a service) solutions have existed in healthcare and medical research for decades providing essential services such as record management, scheduling, billing, and other operational aspects. For this report, "web applications" include patient portals, clinical support tools, and other internet-based software tools with a user interface. However, on-premise "legacy" software and modern-day cloud-based solutions that integrated into the electronic health record (EHR) systems service are included in the health IT category. Automated clinical decision support tools are included in the artificial intelligence section.

Literature Review

436 publications from Stanford-affiliated authors were published on mobile and web applications since 1984. Over the past five years, the leading clinical and application areas included:

Clinical Areas (Figure 15)

1. Mental health (74)
2. Cardiometabolic (27)
3. Substance abuse (25)
4. Hematology-oncology (22)
5. Musculoskeletal system, pain, and chronic conditions (11)

Application Areas (Figure 16)

1. Well-being (53)
2. Surgery and anesthesia (12)
3. Medical informatics, data management, workflow (10)
4. Other (8)
5. Omics (6)

The leading categories in both clinical and application areas, mental health and well-being, show how mobile and web apps are being used to identify problems and encourage behavioral changes as opposed to other types of interventions such as drugs or therapy. In some cases mobile apps are being used as "digital therapeutics." Stanford-affiliated authors published on mobile and web technologies prior to the contemporary "digital health" era. For example, Stanford-affiliated authors identified that online patient communities, handheld computers, and video games had medical applications (Table 19). These studies were some of the first experiments in using mobile technologies to improve patient care.

Abby King, PhD and C. Barr Taylor, MD, featured in Table 20, were early pioneers of these technologies and conducted early studies using “handheld computers,” computer-assisted solutions, and other types of media for interacting with patients.

In contrast to the other technology categories in this report, the most represented journals for mobile and web app publications have both clinical and technological focuses, including crossover journals such as the Journal of Medical Internet Research (Table 21). Publication data in web and mobile development also shows a strong relationship between Stanford and other top-tier research institutions such as Washington University in St. Louis, Harvard University, and Johns Hopkins University. Stanford is committed to developing transformative and innovative relationships that translate research into clinical practice by using the most common and practical technologies to make an impact at scale.

Top 5 Clinical Areas in Mobile and Web Over the Last 5 Years

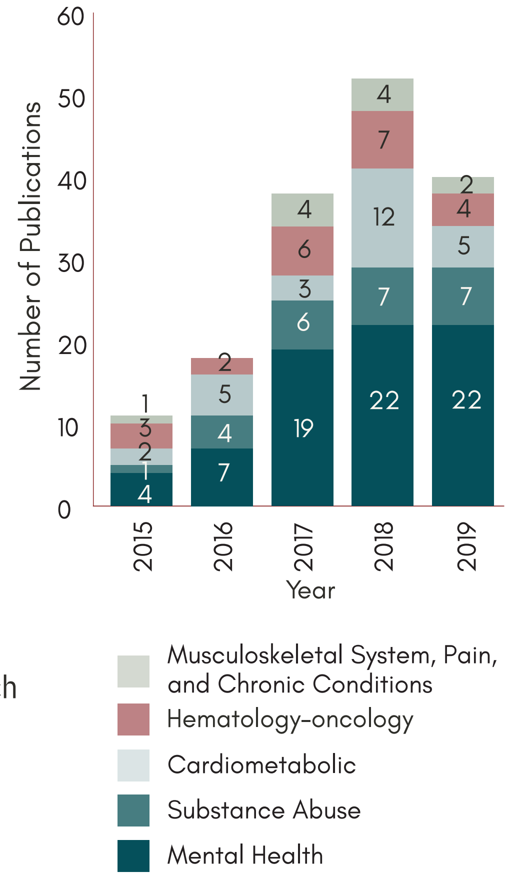


Figure 15

Top 5 Application Areas in Mobile and Web Over the Last 5 Years

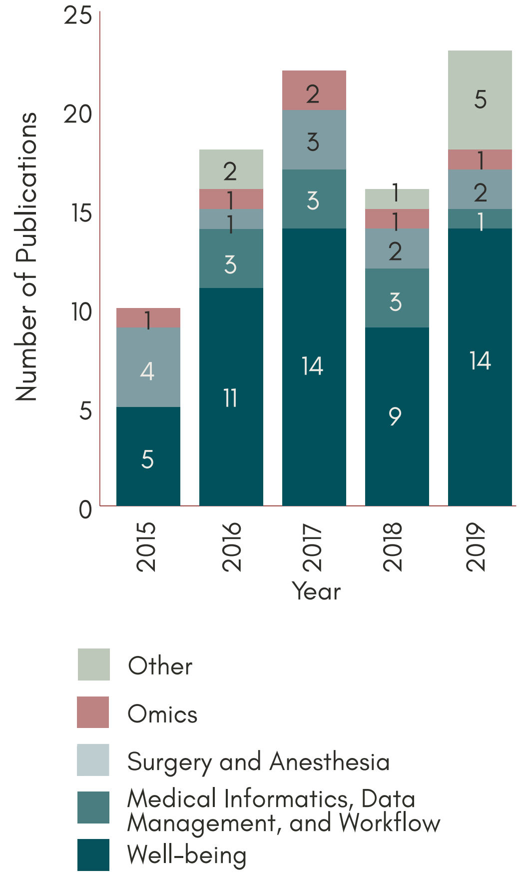


Figure 16

> Stanford-affiliated authors identified that online patient communities, handheld computers, and video games had medical applications. These studies were some of the first experiments in using mobile technologies to improve patient care. Abby King, PhD and C. Barr Taylor, MD were early pioneers of these technologies and conducted early studies using “handheld computers,” computer-assisted solutions, and other types of media for interacting with patients.

Most Cited Publications: Mobile and Web

Times cited	Title	Pub. Year
824	Use of the Internet and E-mail for Health Care Information: Results From a National Survey	2003
451	A Video Game Improves Behavioral Outcomes in Adolescents and Young Adults With Cancer: A Randomized Trial	2018
360	The smartphone in medicine: a review of current and potential use among physicians and students.	2012
334	Internet-Based Chronic Disease Self-Management	2006
325	Evaluation of an internet support group for women with primary breast cancer	2003

Table 19

Top Publishing Authors: Mobile and Web

Author	# of papers
Taylor, C. Barr	39
King, Abby C.	24
Dev, Parvati	17
Kuhn, Eric	16
Prochaska, Judith J.	15
Trockel, Mickey	14
Lorig, Kate	12
Ritter, Philip L.	10
Winzelberg, Andrew J.	10
Laurent, Diana	8

Total Contribution, Mobile and Web Apps: 36%

Table 20

Top Journals: Mobile and Web

Impact Factor 2018 (JCR	Sources	# of papers
4.9	Journal of Medical Internet Research	14
4.3	JMIR mHealth and uHealth	10
2.8	PLoS ONE	8
2.3	Contemporary Clinical Trials	8
3.5	International Journal of Eating Disorders	7

Table 21

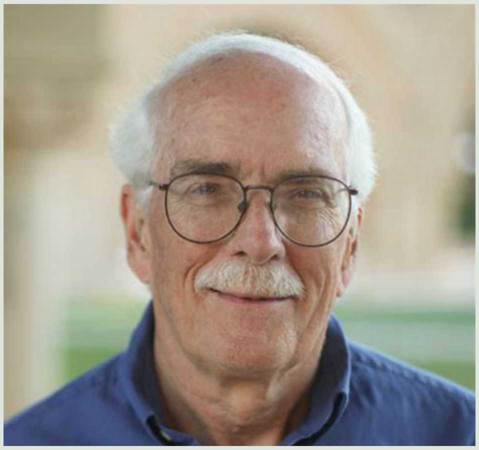
Mobile and Web Applications at Stanford

Initially designed as tools for communication and personal entertainment, smartphones have provided a platform for the rapid proliferation and use of mobile applications throughout healthcare. Across Stanford, mobile applications are being used to promote physical activity, deliver cognitive behavior therapy to treat depression, reduce smoking habits in veterans with posttraumatic stress disorder (PTSD), assess the effects of meditation on physician burnout, and screen patients for stroke clinical trials.

Technology in the Hospital

Stanford Health Care and Stanford Children's Health are striving to reinvent the patient experience by providing patients with direct access to hospital services and ownership of their personal health information. This starts with MyHealth, an industry-leading digital ecosystem known for its advanced capabilities, deep integrations with EHR systems, and convenient patient navigation experience. Patients can schedule appointments, view test results, pay medical bills, renew medications, request services, view data related to their treatment or condition, and communicate with primary and specialty physicians. Patients can get step-by-step directions to appointments

Featured Faculty



C. Barr Taylor, MD

Professor of Psychiatry and Behavioral Sciences, Emeritus

Dr. Taylor is developing and evaluating innovative electronic and computer-assisted programs to increase the cost-effectiveness and availability of treatments proven effective for treating various lifestyle and psychosocial problems. His work focuses on exploring how digital technologies can optimize outcomes for defined populations. Research projects include the evaluation and development of computer-assisted and other innovative, preventive, and clinical treatments for panic disorder, generalized anxiety disorder, social phobia, depression, eating disorders and for cardiovascular risk-reduction. Other studies have examined the use of advanced data analytic techniques to examine the effects of digital therapist/ client interactions and to identify individuals who might benefit from intervention from search history. He is a PI on a large, multisite, long-term NIMH-funded study designed to determine the effects of an on-line, guided self-help program to prevent/treat anxiety, depressive, and eating disorders among college students. He is also a Co-PI in the Centre of Research Excellence in Interactive Digital Technology, funded by the NHMRC in Australia, and served as senior scientific advisor to the recently completed European Commons iCARE project that examined digital interventions to prevent a number of problems, provided in a number of settings, in many countries and languages. He is a Research Professor and Director of the Center for m2Health at Palo Alto University and has helped start the eClinic there.

within buildings and talk with providers through secure video conferences. Hospital View, which is activated when a patient is admitted, helps guide patients through their hospital stay and provides information about medication use, test results, and progress towards discharge. Stanford Health Care has collaborated with a number of leaders in the digital health space to help build this mobile friendly digital ecosystem, including Epic, Vidyo, InTouch, and Lumeris. These collaborations provide a comprehensive digital strategy to serve patients across the continuum of care.

The digital health program at Stanford Children's Health focuses on creating a "digital front door" for patients through mobile and web services. This strategy converts many of the traditional interactions between patients and the hospital into digital experiences. These include online appointment scheduling, obtaining second opinions (in collaboration with Stanford Health Care), and finding specialists through the Stanford Children's Health Mobile app. Additionally, the recent launch of ZocDoc in 2019 provides new patients with a method to schedule visits with care teams in the Stanford Children's Health network of care throughout the San Francisco Bay Area.

Stanford Children's Health also uses a mobile app called "Link" for home health monitoring, utilizing Apple's CareKit application. When prescribed by a provider, patients can authorize data entered in Link to be visible in the Stanford Children's Health EHR system for review by clinicians. This integration is achieved through HealthKit and the Epic MyChart mobile application. Designed to automate the flow of data for the Stanford Children's Health Single Ventricle Home Monitoring Program, clinical data such as vital signs (e.g., heart rate, oxygen saturation), weight, and body temperature can be shared through the app. The app also includes the ability to create a daily medication checklist, review data trends, and store contact information for providers and other caregivers. It was designed to improve the patient experience and is integrated into the provider workflow to enhance clinical care.

Stanford Center Outreach Initiative

At Stanford Medicine, SPADA, the Stanford Predictives and Diagnostics Accelerator, assists interdisciplinary innovations in research, development, and deployment of technologies that improve human health through disease prediction and diagnosis. Some of the projects from SPADA include validation assessments of consumer mobile applications for sleep monitoring, mobile autism research, Veterans Affairs Health System mobile app development, and digital mental health interventions for eating and bipolar disorders.

The Stanford Byer's Center for Biodesign created one of the first curricula addressing the development of mobile applications to solve important unmet medical needs. One mobile application to come out of Biodesign was VascTrac, a passive mobile screening tool for peripheral artery disease and a risk assessment tool for cardiovascular disease. Other approaches have included a massive open online nutrition and cooking course for improving eating behaviors, mining Twitter data to improve detection of schizophrenia, and using social media and mobile technology for cancer prevention and treatment.

The Center for Digital Health has also had a number of collaborators develop apps for research purposes as part of the Apple Watch Seed Research Program. These projects include harnessing "mindset" in health technology (a virtual therapist for stroke patient arm recovery), reducing hyperactivity and supporting attention for youth with attention deficit hyperactivity disorder (ADHD), exploring an artificial approach to support adherence behaviors in psychiatric clinical care, and individualized migraine attack prediction with self-reported and passively collected data.

Physical Activity and Mobile Applications

> "There have been wonderful health surveys done, but our new study provides data from more countries, many more subjects, and tracks people's activity on an ongoing basis in their free-living environments versus a survey in which you rely on people to self-report their activity. This opens the door to new ways of doing science at a much larger scale than we have been able to do before."
>
> Scott L. Delp, PhD, Director of the Mobilize Center

Mobile applications can have unexpected roles in research, as evidenced by the influence of Pokémon GO on physical activity. Using sensor data and search engine logs from over 32,000 Microsoft Band users over the course of a 3-month period, computer scientists from Stanford and Microsoft quantified the impact of Pokémon GO, a game that promotes physical activity by having players roam around parks and streets to capture, train, and battle their virtual Pokémon, on physical activity. The study found that Pokémon Go led to significant increases in physical activity over a 30-day period, increasing daily activity by over 25% for active users. This study also showed that augmented reality mobile apps that combine game play with physical activity can lead to significant short-term activity increases and provide more impactful interventions in activity-poor populations.

As part of a global study on daily step counts and activity inequality using the free Azumio Argus activity monitoring app, Stanford researchers found intriguing obesity and health trends. The Stanford Data Science Initiative and Stanford Mobilize Center analyzed data from over 700,000 users in a study that is 1,000 times larger than any previous study on human movement. About the project, Scott L. Delp, PhD, director of the Mobilize Center said "There have been wonderful health surveys done, but our new study provides data from more countries, many more subjects, and tracks people's activity on an ongoing basis in their free-living environments versus a survey in which you rely on people to self-report their activity. This opens the door to new ways of doing science at a much larger scale than we have been able to do before." In this study, the gap between activity rich and activity poor populations (activity inequality) was a strong predictor for obesity. Results indicated that people from the five countries with highest activity inequality are 196% more likely to be obese when compared with individuals from the five countries with lowest activity inequality.

Other Real-World Use Cases

Stanford researchers recently collaborated with frontline health workers in India to promote reproductive, maternal, newborn, and child health and nutrition using mobile technology. This interventional study utilized the Information Communication Technology-Continuum of Care Service (ICT-CCS) tool to increase the coverage, quality and coordination of services from frontline health workers in Bihar, India.

In a collaborative effort, researchers from Stanford, Northwestern University, and UCSF looked at the effectiveness of conversational agents (Apple's Siri, Alphabet's Google Now, Samsung's S Voice, and Microsoft's Cortana) to assess whether users were able to obtain accurate and appropriate mental health information. Although this technology has improved significantly since the initial study was conducted, these smartphone-based conversational agents responded inconsistently and incompletely when asked about mental health, interpersonal violence, and physical health.

Media are critically important in areas of health and wellbeing, democracy, poverty, violence, education, climate action and more. But in spite of big data promises, no one really knows what people actually see and do on their screens in an increasingly complex digital world. Consequently, research, and policy are often incomplete, irrelevant, or wrong. To fill these major gaps in scientific discovery, a transdisciplinary team of Stanford University PIs including Professors Byron Reeves (Department of Communication), Nilam Ram (Departments of Psychology and Communication) and Thomas Robinson (Departments of Pediatrics and Medicine, and the PI on the previously described pediatric weight management grant) launched "The Human Screenome Project." The project includes a technology platform, analysis process and data repository that facilitates precise mapping of media use via detailed moment-by-moment capture and machine analysis of all the actual content, actions and sequences that appear on personal screens – defining what is called the 'screenome.' Compared to previous attempts to track human–computer interactions through the use of logging methods, experience sampling, diaries, and questionnaires, this approach is more accurate and comprehensive. It follows screen use across platforms and applications and it samples more frequently (currently every five seconds). So far, 30 million screenshots — or 'screenomes' — from more than 600 people were collected. Among a diverse range of applications, the screenome provides the framework to analyze how content viewed on our devices affects our thoughts, behaviors, health and mental well-being. In one example, the screenome was found to contain drug and disease-related signals for diabetes.

Web Applications

In addition to the many mobile solutions at Stanford, there are a number of web-based tools being developed by researchers, engineers, and physicians. One of these projects is ePAD, a freely available quantitative imaging informatics platform developed by the Rubin Lab at Stanford Medicine (Diagnostic Radiology). Thanks to its plug-in architecture, ePAD can be used to support a wide range of imaging-based projects and has been used for research in automated tracking of tumor burden in clinical trials. ePAD was designed to provide a freely-accessible method of universal access to radiology image metadata and to provide a rich client architecture that runs on web browsers.

Another web platform created at Stanford is "My Surgical Success." This was developed as part of a randomized controlled clinical trial to evaluate the efficacy of digital tools on pain reporting and opioid cessation after surgery. This project demonstrated that perioperative digital behavioral pain medicine may be a low-cost, accessible adjunct that could promote opioid cessation after breast cancer surgery.

In oncology, Stanford collaborated with Danish researchers to create a web-based virtual environment to empower young cancer patients in their care and provide a safe space to discuss their conditions. A three-dimensional web-based platform was designed to support adolescent cancer patients with features including customizable appearances of preconfigured avatars and in-world synchronous conversations with other participants in the study. Another web application in oncology research is a custom family-building decision aid and planning tool for young adult females experiencing fertility problems after cancer treatment.

Artificial Intelligence, Machine Learning, and Algorithms

Definition

This category includes artificial intelligence (AI), machine learning (ML), algorithms, and other advanced statistical approaches in computational health. The field of AI can generally be described as a machine's capability of abstracting high- and low-level concepts from prior experience and transferring knowledge between domains with an ultimate goal of achieving a level of intelligence similar to that of humans.

AI healthcare applications include computer vision for medical imaging; natural language processing for healthcare documentation and medical record mining (structured and unstructured data); chatbots for patient interaction; digital signal analysis and prediction, and multi-modality data integration for tumor boards; prediction models from big data to warn clinicians of high-risk conditions (such as sepsis, heart failure, mortality); genetic profiling for cancer diagnosis; and assessing disease risk in population health.

AI is also being used to support drug development and clinical trial design, reducing the time it takes to bring drugs to pharmacies and patients themselves through "in silico trials."

A 2016 Stanford University report titled One Hundred Year Study on Artificial Intelligence (AI100) cites a useful definition of AI from Nils J. Nilsson:

"Artificial intelligence is that activity devoted to making machines intelligent, and intelligence is that quality that enables an entity to function appropriately and with foresight in its environment."

As in many digital health domains, there is currently no one, universally accepted, definition for artificial intelligence. "Intelligence" is rather seen as a general sense of direction heading towards characterizing AI by hardware and synthesized software tools that provide "foresight" in assisting humans in day-to-day activities.

Literature Review

Since 1984, artificial intelligence, machine learning, and algorithms have provided 728 total publications with a Stanford-affiliated author. Over the past five years, the leading clinical and application areas included:

Clinical Areas (Figure 17)

1. Hematology-oncology (80)
2. Cardiometabolic (69)
3. Neurology (48)
4. Musculoskeletal system, pain, and chronic conditions (27)
5. Mental health (15)

Application Areas (Figure 18)

1. Medical informatics, data management, and workflow (75)
2. Imaging (53)
3. Omics (38)
4. Surgery and anesthesia (16)
5. Drugs and medication management (12)

Data-rich areas such as hematology-oncology, neurology, and imaging are all highly ranked in the top clinical and application areas. This may be due to these areas being more well-suited for current AI and ML methods. The research in this field is largely published in journals that do not have a primary clinical focus, with the highest cited publications providing methods or proof-of-concepts for new algorithms (Table 22).

While some of the most cited papers in AI reflect more theoretical and computational approaches to implementation, work by Stanford researchers in computer vision has been highly-visible in the field–"Dermatologist-level classification of skin cancer with deep neural networks" has been cited over 1,900 times since being published in 2017 (Table 23). Stanford researchers compiled almost 130,000 images representing over 2,000 different skin diseases in order to train an algorithm to visually diagnose a potential cancer. As machine learning algorithms develop more momentum, incorporating a stronger clinical focus in the field of artificial intelligence may represent a path forward for more impactful research endeavors and grant success.

Top 5 Clinical Areas in Artificial Intelligence, Machine Learning, and Algorithms Over the Last 5 years

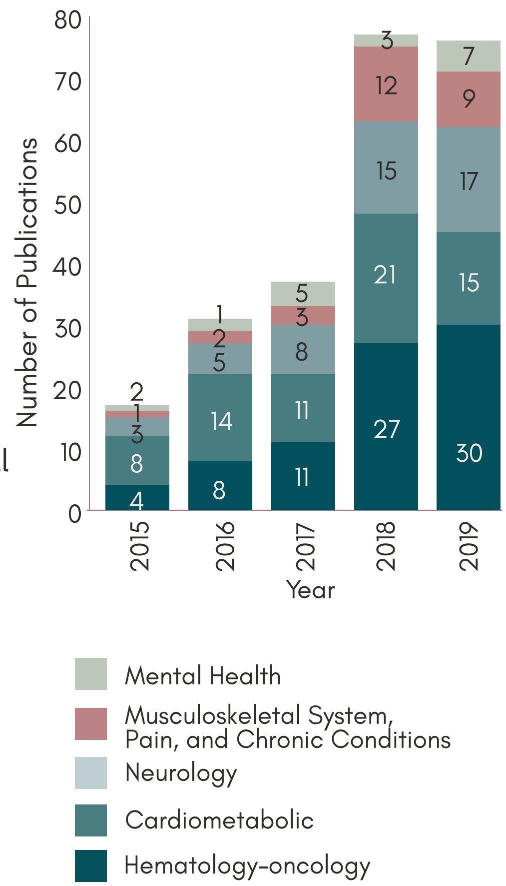


Figure 17

Top 5 Application Areas in Artificial Intelligence, Machine Learning, and Algorithms Over the Last 5 years

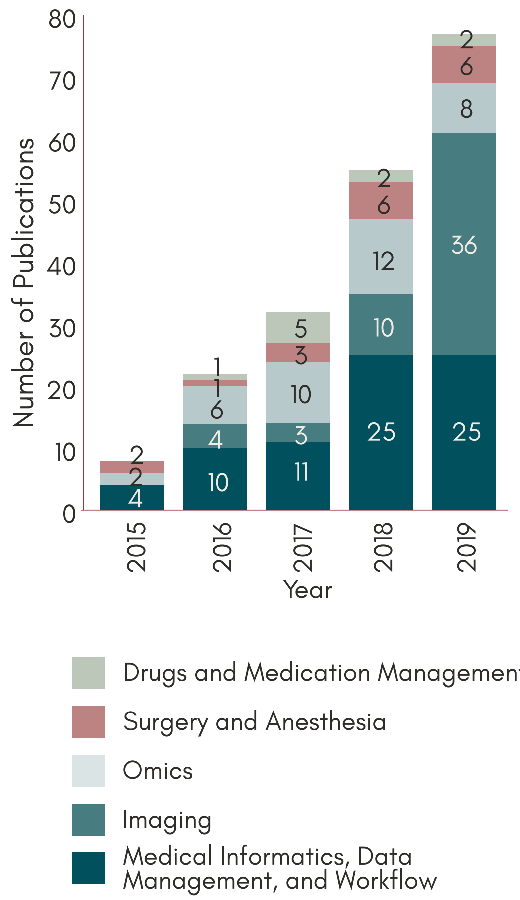


Figure 18

"Dermatologist-level classification of skin cancer with deep neural networks" has been cited

1,900+

times since being published in 2017

Top Journals: Artificial Intelligence, Machine Learning, and Algorithms

Impact Factor 2018 (JCR)	Sources	Number of Papers
3.2	Medical Physics	25
4.3	Journal of the American Medical Informatics Association	20
3	Journal of Biomedical Informatics	16
4	Scientific Reports	14
4.5	Bioinformatics	11

Table 22

Most Cited Publications: Artificial Intelligence, Machine Learning, and Algorithms

Times cited	Title	Pub. Year
1904	Dermatologist-level classification of skin cancer with deep neural networks	2017
271	Dynamics and Control of Diseases in Networks with Community Structure	2010
247	Haptic rendering: introductory concepts	2004
242	Opportunities and obstacles for deep learning in biology and medicine	2018
241	Combining satellite imagery and machine learning to predict poverty	2016

Table 23

Top Publishing Authors: Artificial Intelligence, Machine Learning, and Algorithms

Author	# of Papers
Rubin, Daniel L.	37
Altman, Russ B.	35
Shah, Nigam H.	29
Xing, Lei	28
Musen, Mark A.	21
Langlotz, Curtis P.	20
Buckingham, Bruce A.	16
Chen, Jonathan H.	13
Lungren, Matthew P.	12
Napel, Sandy	12

Total contribution, AI: 31%. Table 24

AI, ML, and Algorithms at Stanford

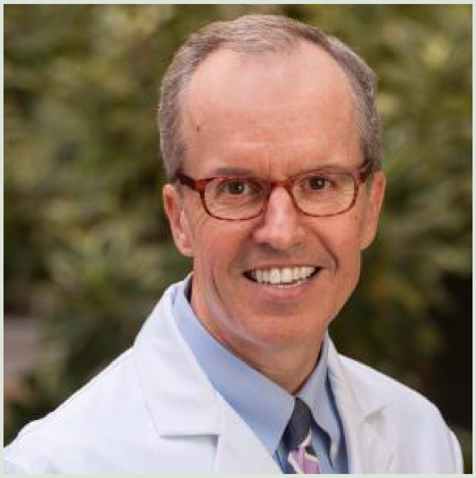
Stanford University has a long history in the advancement of artificial intelligence. Formally introduced in 1965 by the Stanford Heuristic Programming Project, early developments in AI included expert systems, which rely on IF-THEN-ELSE rules to process data, provide results, and mimic the decision-making abilities of human experts. Expert systems are still heavily used as part of EHR systems in healthcare settings today because they use automated calculations and logical processes with clearly established rules and outcomes.

History of AI at Stanford

AI is transforming diagnostic and treatment applications through technologies like computer vision, medical imaging, and detection of diseases through algorithms. Treating disease and providing accurate diagnoses has been central to the development of AI since at least the 1970s, when MYCIN was developed at Stanford. MYCIN was one of the earliest backward chaining expert systems that used artificial intelligence to identify bacteria that cause severe infections such as meningitis. The technology was designed to recommend antibiotics and adjust dosage based on a patient's body weight. Despite MYCIN's innovative approach, it was not adopted into clinical practice due to poor integration with existing clinical workflows and EHR systems. Today, healthcare organizations are transitioning away from these rule-based systems and are using algorithms, advanced analytics, and other machine learning techniques to enhance their precision medicine capabilities.

In addition to MYCIN, the legendary Stanford University Medical Experimental Computer for Artificial Intelligence in Medicine, SUMEX-AIM, provided many of the early

Featured Faculty



Curtis Langlotz, MD PhD

Professor of Radiology and Biomedical Informatics
Director, Center for Artificial Intelligence in Medicine & Imaging

Dr. Langlotz's laboratory investigates the use of deep neural networks and other machine learning technologies to help radiologists detect disease and eliminate diagnostic errors. His laboratory's translational approach facilitates rapid evaluation and dissemination of the resulting algorithms. He is responsible for the information technology that supports Stanford's radiology practice, including six million imaging studies that require 0.5 petabytes of storage. Dr. Langlotz has led many recent national and international efforts to improve the quality of radiology communication, including the RadLex™ terminology standard, the RadLex™ Playbook of radiology exam codes, the RSNA report template library, and a technical standard for communication of radiology templates. He has published over 100 scholarly articles, and authored the recent book "The Radiology Report: A Guide to Thoughtful Communication for Radiologists and Other Medical Professionals."

programs using AI techniques for medical decision-making. A national computer resource funded by the National Institutes of Health (NIH) between 1973 and 1992, SUMEX-AIM was designed to promote and develop applications of artificial intelligence in biomedical sciences and demonstrate the value of network-based computer resource sharing within a national community.

Another homegrown AI solution developed at Stanford is ATHENA. Developed in the 1990s, ATHENA was one of the first intelligent decision-support systems for managing patients with chronic diseases. An advanced version of ATHENA is still used in some applications at the VA Palo Alto Health Care System such as opioid therapy and hypertension management.

Stanford Center Outreach Initiative

Stanford's strong commitment to AI is demonstrated through the number of teams, organizations, labs, and centers dedicated to the advancement of healthcare initiatives throughout the field. These dedicated AI groups include The Center for Artificial Intelligence and Medical Imaging (AIMI), Stanford Institute for Human-Centered Artificial Intelligence (HAI), The Stanford Artificial Intelligence Laboratory (SAIL), AI for Health, Laboratory of Quantitative Imaging and Artificial Intelligence (QIAI), the Shah Lab, and many others. Outside of these groups, there are also many faculty, researchers, and students in the School of Medicine, School of Engineering, and Graduate School of Business (GSB) who are building AI applications for healthcare. Notable projects from AIMI include deep learning for computer vision, imaging labeling and natural language processing, and clinical validation of AI algorithms. HAI focuses on using AI to improve healthcare delivery by looking to inspirations from neuroscience for better models of human-like intelligence. SAIL is utilizing computer vision for health applications (surveillance, hand washing, etc.), extracting and creating training data from unstructured "dark data," and exploring AI applications in genomics. The flagship project at AI for Health is called ALTE: AI for Literacy, Transparency and Engagement. The goal of this project is to advance patient literacy, engagement, and healthcare transparency through natural language processing of medical text, general jargon, and layperson descriptions for medical conditions. ALTE is designed to enable patients to be better informed when making healthcare decisions, streamline communication from call centers and providers to patients, and ultimately improve care outcomes and value. A full list of these groups' projects is included in their profiles at the end of the report.

The Laboratory of Quantitative Imaging and Artificial Intelligence (QIAI), run by Daniel L. Rubin, MD, MS, professor of biomedical data science, of radiology and of medicine, exemplifies a multidisciplinary effort to produce innovative solutions. QIAI is developing AI and computational methods and leveraging information from radiology images to enable biomedical discovery and guide physicians in personalized care practices. A recent focus of the lab is in deep learning methods for automated image classification, lesion detection, segmentation, and clinical prediction. They are also developing novel approaches to tackle recent challenges in AI including weak supervision, multi-task learning and multi-modal models. In addition to these efforts, they are tackling the challenge of making clinical predictions using longitudinal image and text data and have made several important advances in predicting patient survival and disease progression.

Nigam Shah, MBBS, PhD, leads a group at Stanford that uses machine learning, prior medical knowledge, and electronic health data on past patients to improve the care of future patients. The group runs the world's only bedside service that uses aggregate EHR and Claims data from roughly 200 million patients to answer point of care clinical questions across all medical service lines.

Dr. Shah's group also houses the Stanford Medicine Program for AI in Healthcare, which has the mission of bringing AI technologies to the clinic, safely, cost-effectively and ethically. As part of this program, they have built models for predicting future increases in care costs, improving palliative care, identifying patients with underlying genetic disorders, and predicting slow healing wounds as well as developed methods to build better models. In addition, the team develops novel methods to derive insights from diverse digital healthcare data. For example, for hip replacement prosthetics, they extracted implant details, complications, and pain reports from clinical notes in the EHR with up to 96.3% precision and 98.5% recall to identify over six times as many complications, than found using coded data. Other efforts include identifying effective treatment pathways in Type 2 Diabetes using claims data from multiple countries, monitoring point-of-care glucose meters using coincident testing with central laboratory measurements, detecting skin adverse reactions of cancer drugs by analyzing content in a health social network, finding adverse drug events by mining clinical notes, inferring physical function status from wearables data, and profiling digitized recordings of psychotherapy sessions.

AI in the Hospital

Researchers at Stanford Children's Health are part of a multi-site validation trial in which orthopedists use an algorithm that measures skeletal maturity in hand x-rays to guide treatment for growth disorders in children and teenagers. Other AI applications include the development of algorithms in a variety of areas such as chest x-rays (CheXNeXt), brain aneurysms (HeadXNet), and EHR data (Green Button). CheXNeXt is the first algorithm that simultaneously evaluates X-rays for a multitude of possible diseases and returns results that are consistent with the readings of radiologists in a matter of seconds. The goal of the project is to eventually leverage these algorithms to reliably and quickly scan a wide range of image-based medical exams for signs of disease without the backup of professional radiologists. For brain aneurysms, a team of researchers with expertise in machine learning, radiology, and neurosurgery built a tool called HeadXNet, which was designed to help improve clinicians' ability to identify intracranial aneurysms by using deep learning segmentation models. In other research, the previously mentioned Shah Lab "green button" has also been used as a clinical informatics service that sifts through millions of records to provide physicians with quick answers about individual cases.

Another example of AI implemented at Stanford Children's Health is the monitoring of hand sanitizer used by hospital staff. With the help of clinicians and electrical engineering students, research teams used imaging sensors at hospital room doorways and neural network technology to create an algorithm to detect hospital staff use and non-use of hand sanitizers, an important driver of patient safety. Depth and thermal sensors were used to create images of human shapes in motion without revealing the actual identity of the person, and doorway-mounted sensors were placed near patient rooms, adjacent to hand-hygiene alcohol gel dispensers. A neural network layer was used to label images and revealed that people were failing to use the wall-mounted alcohol gel dispenser.

With the help of clinicians and electrical engineering students, research teams used imaging sensors at hospital room doorways and neural network technology to create an algorithm to detect hospital staff use and non-use of hand sanitizers, an important driver of patient safety.

Large-Scale Initiatives

The Frontier of AI-Assisted Care (FAC) Scientific Symposium is a Stanford initiative that aims to accelerate progress and promote collaboration among AI researchers who share a vision of a computer-assisted, rapid learning healthcare systems to eliminate the chasm between potential and actual efficiency and improve quality of care. Projects from the Stanford Partnership in AI-Assisted Care (PAC), which is part of the FAC, include intelligent hand hygiene support, healthcare conversational agents, senior well-being support, and intensive care unit clinical pathway support.

Another prominent initiative in the field of AI at Stanford is the One Hundred Year Study on Artificial Intelligence (AI100). Launched in the fall of 2014, AI100 is a long-term investigation of the field of AI and its influences on people, their communities, and society with the goal of collecting a set of reflections about the impact of AI as the field advances. A robust AI Index was established as an independent project under the AI100 umbrella and is now managed by Stanford's Human-Centered AI Institute (HAI). This index focuses on tracking, collating, distilling, and visualizing data relating to AI, and aspires to be a comprehensive resource for policymakers, researchers, executives, journalists, and the general public to effectively comprehend this complex field.

Ethics and AI

As medical innovations push the field of digital health forward, researchers, patients, and physicians are faced with the potential ethical implications of AI as these technologies come into contact with existing provider workflows and patient care models. The current debate on data privacy and ethical implications of AI centers on data ownership: whether the patient or provider owns the data and whether it can be shared or sold without the patient's consent. Associate Chief Quality Officer for Improvement for Stanford Health Care and physician co-leader of the Stanford Medicine Center for Improvement David Larson, MD MBA, states that data are not "owned" in the traditional sense, but that all who interact with the data are "data stewards," with a fiduciary responsibility to both patients and society. This builds on the fiduciary model of healthcare delivery where providers are intentionally placed in a position of trust, safeguards are established to ensure that trust is maintained, and penalties are applied when trust is violated. Rather than assuming for-profit entities cannot be trusted, there must be an expansion of fiduciary roles and responsibilities and ethical obligations must be symmetrical. Patients, providers, and industry stakeholders all have the obligation to contribute to the improvement of care. Because legal paradigms regarding medical data were developed before modern AI technology, Dr. Larson discusses three approaches to the ethics of sharing clinical imaging data for artificial intelligence.

"One approach treats the patient as the owner of the data, implying that patient data should be shared only with the express consent of that patient. A second approach treats the care provider as the owner of the data, implying that the data can be bought and sold as any other commodity."

The third approach and the position of AIMI, is "Once clinical data have been used to provide care, the primary purpose for acquiring the data is fulfilled. At that point, in terms of the potential for secondary use, clinical data should be treated as a form of public good, to be used for the benefit of future patients."

As we move into an era where technology has the ability to prevent, predict, and diagnose disease with limited or no input from physicians, the ethical questions surrounding AI will be more important than ever to ensure the highest standards of patient care are maintained. Stanford is committed to the stewardship of AI and empowers researchers to explore the ethical implications of their work to ensure that the effects of these technological advancements can be safely addressed in decades to come.

New Clinical Care Models

Definition

A care model is a broad definition for the ways in which healthcare and associated services are delivered. These models are used to describe the treatment and care provided to any person, population, or cohort to ensure their needs are met across the continuum of care within a healthcare system. Care models can apply to any type of healthcare setting: hospital-based, family-centered, chronic disease, recovery-based, primary nursing, or patient-focused. As technology and communications infrastructure has improved over time, teleservices have grown exponentially, providing accessibility to healthcare for urban and rural populations through advances in mobile phones and computers.

Within healthcare, some of the most widely used teleservices include telecare, telehealth, telecoaching, and telemedicine. According to HealthIT.gov, telehealth is defined as “the utilization of electronic information and telecommunications technologies to support and promote long-distance clinical healthcare, patient and professional health education, public health, and health administration.”

Examples of teleservices in healthcare include: real-time interactive video communication or “virtual visits,” physician-guided behavior change, coordinated care management, text message interventions, community outreach programs, telesurgery, digital avatars, remote patient monitoring, virtual and augmented forms of telerehabilitation, automated call reminders, asynchronous teleconsultations, and patient engagement through social media.

In the clinical trial space, teleservices are used by pharmaceutical companies to enhance the process of drug development with digital health tools. This new clinical trial framework provides personalized digital pathways that allow patients to participate seamlessly in trials. Sponsors and investigators are now decentralizing aspects of traditional trials and incorporating tools like custom mobile apps, digital surveys, social media, patient management platforms, connected Bluetooth devices, and other remote monitoring technologies to achieve the goals of the trial. Large-scale trials like the Apple Heart Study demonstrate the immense potential of virtual trials and their role in streamlining clinical research and drug development.

Literature Review

Since 1984, Stanford-affiliated authors have published 206 publications on new clinical care models. Over the past five years, the leading clinical and application areas included:

Clinical Areas (Figure 19)

1. Mental health (24)
2. Cardiometabolic (18)
3. Dermatology (10)
4. Hematology-oncology (10)
5. Neurology (7)

Application Areas (Figure 20)

1. Well-being (13)
2. Medical informatics, data management, and workflow (11)
3. Other (10)
4. Surgery and anesthesia (6)
5. Drugs and medication management (2)

Given the ubiquity of cardiometabolic and mental health conditions and the overall challenges in their management, they represent a natural focus for novel approaches to clinical care. Increased digital health publication volume in neurology has made it the fifth highest category in new clinical care models from 2015-2019.

Research in new clinical care is primarily focused on health system-oriented and patient-facing solutions. Additionally, many of the highest cited publications in this category did not originate in the last decade (Table 25). Due to increased adoption and expansion of new clinical care models, telemedicine,

Top 5 Clinical Areas in New Clinical Care Models Over the Last 5 Years

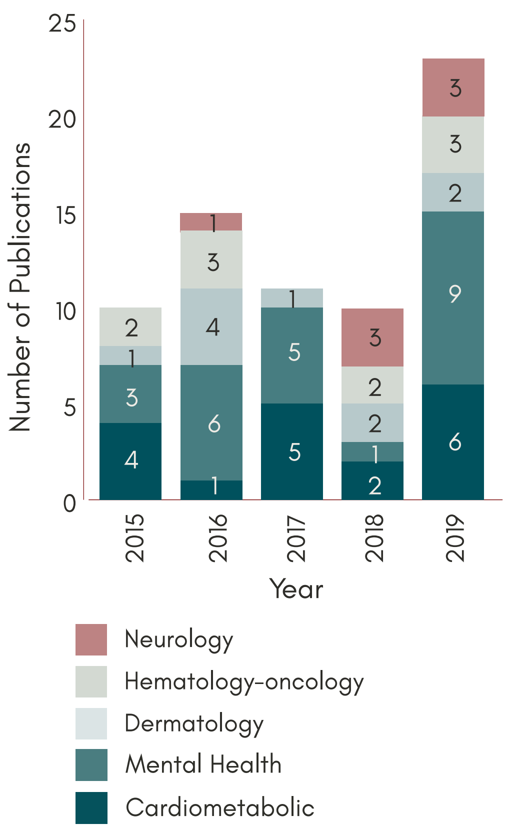


Figure 19

Top 5 Application Areas in New Clinical Care Models Over the Last 5 Years

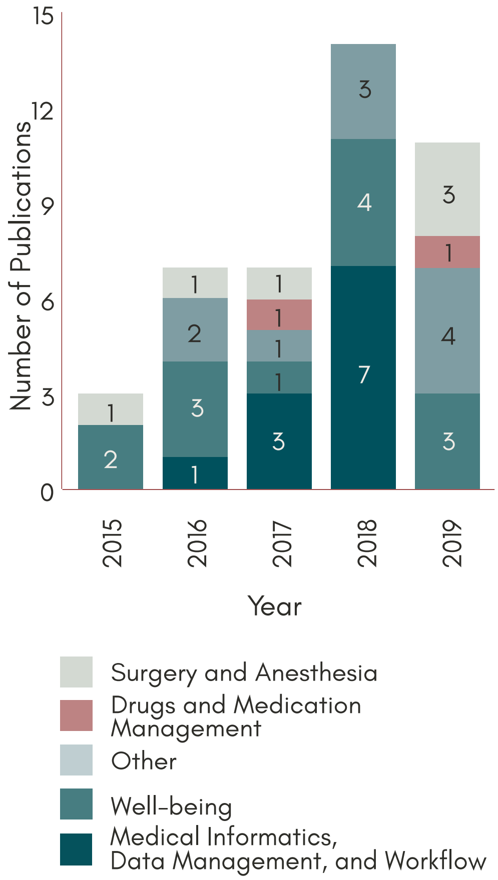


Figure 20

virtual clinical trials, and remote patient monitoring are all developing into their own research domains.

The journals with the most new clinical care publications have a range of technological and clinical foci, highlighting the diversity of research within this field (Table 26).

Another interesting trend shows that a large number of publications focused on both providers and health promotion, pointing towards advances in preventive and proactive care rather than more traditional, reactive healthcare measures.

The journals with the most new clinical care publications have a range of technological and clinical foci, highlighting the diversity of research within this field. Another interesting trend shows that a large number of publications focused on both providers and health promotion, pointing towards advances in preventive and proactive care rather than more traditional, reactive healthcare measures.

Most Cited Publications: New Clinical Care Models

Times cited	Title	Pub. Year
280	The Asgaard project: a task-specific framework for the application and critiquing of time-oriented clinical guidelines	1998
250	Impact of Automated Calls With Nurse Follow-Up on Diabetes Treatment Outcomes in a Department of Veterans Affairs Health Care System	2001
248	An Evidence-Based Approach to Interactive Health Communication: A Challenge to Medicine in the Information Age	1998
245	Diverse Applications of Nanomedicine	2017
210	The Effect of Automated Calls With Telephone Nurse Follow-Up on Patient-Centered Outcomes of Diabetes Care	2000

Table 25

Top Journals: New Clinical Care Models

Impact Factor 2018 (JCR)	Sources	Number of Papers
2	Telemedicine Journal and e-Health	9
4.9	Journal of Medical Internet Research	6
2.2	Journal of Telemedicine and Telecare	4
4.3	Journal of the American Medical Informatics Association	4
51.3	JAMA	3

Table 26

Top Publishing Authors: New Clinical Care Models

Author	# of papers	Author	# of papers
King, Abby C.	13	Lad, Eleonora M.	4
Moshfeghi, Darius M.	11	Murakami, Yohko	4
Castro, Cynthia M.	5	Silva, Ruwan A.	4
Chi, Jeffrey	4	Robinson, Thomas	4
Fogel, Alexander L.	4	Turakhia, Mintu P.	3

Total contribution, New Clinical Care Models: 27%

Table 27

Stanford Medicine scientists, led by Rusty Hofmann, launched a digital national daily health survey to identify the prevalence of COVID-19 symptoms across the United States. The goal of the study is to predict which geographical areas will be most impacted by coronavirus to inform local and national responses, such as redirecting medical resources or improving policy.

Featured Faculty

Lawrence "Rusty" Hofmann, MD

Professor of Radiology (Interventional Radiology) at the Stanford University Medical Center
Medical Director of Digital Health at Stanford Healthcare

Dr. Lawrence "Rusty" Hofmann is an actively practicing physician and Professor at Stanford School of Medicine, Chief of Interventional Radiology, the Medical Director of the Cardiac and Interventional Services at Stanford Healthcare, and the Medical Director of Digital Health at Stanford Healthcare. Additionally, he is the Co-Founder of Grand Rounds, Inc. and sits on the board. He has devoted his career to "solving unmet medical needs" for his patients at either Johns Hopkins, where he practiced for 10 years, or Stanford, where he has practiced for 15 years. He has published over 100 scientific articles on minimally invasive treatment of blood clots (acute and chronic DVT) and cancer. His career has focused on innovation and academic-industry partnerships with the goal of scaling his innovations globally, to help as many patients as possible. He holds two patents, invented the first dedicated device to treat chronic DVT, has worked as a consultant for numerous medical device companies (both start-ups and large companies), and is currently the Global-Principal Investigator for the first clinical trial testing a venous stent.

New Clinical Care Models at Stanford

Quality Care and Technology

Stanford has been a pioneer in the development of new therapies, care pathways, and clinical workflows that have changed the way healthcare is delivered. The new Stanford Medicine Center For Improvement is one example of Stanford's commitment to providing the highest quality care. Commenting on the launch of the center, Lloyd Minor, MD, Dean of Stanford School of Medicine said "In addition to our dedication to discovery and preeminent patient care, we strive to cultivate a culture that embraces continuous improvement in care delivery."

With a goal of improving the quality of life for people, the Lifestyle Medicine center works with researchers on five pillars: nutrition, sleep, fitness, stress management, and social relationships. Their overarching motive is to provide patients with evidence-based information to guide healthy decisions. This ultimately leads to a more informed patient-centered healthcare system, enabling individuals to attain a better quality of life.

Digital Health in Pediatrics

At Stanford Children's Health, Dr. Rajiv Kumar, MD, created an Apple HealthKit-enabled pediatric diabetes monitoring system and ran a pilot program for type 1 diabetes using digital health tools. This allowed remote tracking of blood sugar readings, real-time care plan modifications, and reduced the need for in-clinic appointments. Because data is recorded and transferred immediately, Dr. Kumar and other endocrinologists were able rapidly respond to improve blood sugar control. In addition to providing timely feedback to patients, the wealth of continuously collected and easily analyzable data also allowed physicians to spend more time having high-level discussions with patients during appointments.

Another example of digital health at Stanford Children's Health is a text messaging intervention program that is being used as a pragmatic approach for patient engagement for adolescents with celiac disease. This telemedicine intervention was designed to measure gluten-free diet adherence, patient activation, and quality of life.

Over the past two decades, Stanford Children's Health has been running a pediatric weight management program that has recently received funding from the CDC to expand nationwide. The program uses effective behavior change strategies to help local families and their kids maintain healthy weights. By using technology with principles from Stanford's Byers Center for Biodesign, design thinking, business-to-business models, and software-as-a-service (SaaS), researchers are building a more acceptable, affordable, and scalable program that can be administered by health professionals and community leaders anywhere to support high-risk populations. While there are established pipelines for translating medical research into medications and devices, Thomas Robinson, MD, Professor of Pediatrics and Medicine at the Stanford School of Medicine and principal investigator on the CDC grant, found that effective, widespread roll-out of public health interventions, and particularly weight control programs for children, face many more challenges. According to Dr. Robinson, although this program is efficacious, the challenge is getting it out to people in the communities where they live. The program uses technology to facilitate effective face-to-face weight-management counseling with groups of families and includes online videos, animations, assessment, monitoring and feedback tools, and group-management resources. These digital health tools allow providers to administer the weight-loss program in community centers, schools, hospitals and health centers, and family medicine and pediatrics offices.

Telemedicine Programs

Stanford Health Care has several live telemedicine programs that are part of the digital health portfolio including: Video Visits that expand access to care and improve business continuity; Second Opinions to help with new patient acquisition and expand the Stanford network; eConsults that provide improved access to specialty care and optimize the referral process; TeleStroke for improving stroke outcomes and enhancing access to Stanford Health Care stroke care; and Inpatient Virtual Care which offers provider mobility, increases billable consults, and reduces curbsides. Other programs under development include: Emergency Medicine Virtual Care, On-Demand Care, and Remote Patient Monitoring.

Through the eConsults program, patients receive recommendations via asynchronous provider-to-provider consult initiated by a primary care provider. Additional opportunities with the program are being assessed, including layering AI on top of submitted eConsults to provide initial recommendations. eConsults are currently available across 12 specialties. A recent publication on the eConsult program describes the implementation and evaluation of Stanford Health Care's store-and-forward teledermatology consultation workflow. While telemedicine programs were used across Stanford Medicine prior to the pandemic, COVID-19 has accelerated the use and adoption of these technologies in virtually every clinical area. Stanford Health Care's initial goal was to complete 24,000 video visits in FY20 (30,000 was the stretch goal). In FY20, Stanford Health Care, including the University HealthCare Alliance (excluding Stanford Children's Health) have completed 360,000 video visits. With the reopening of in-person care at Stanford clinics, video visits are beginning to stabilize at around 60,000 per month, which represents 30-40% of all ambulatory visits across more than 35 states. In response to the pandemic, Stanford Health care has accelerated the strategic roadmap for virtual health and will grow existing virtual care programs, enhance virtual care offerings and experience, and continue to develop "digital first" capabilities.

At Stanford Children's Health, the initial goal for telehealth was 5,000-6,000 visits for FY20. As a result of the pandemic, the actual number of telehealth virtual visits in FY20 was 86,479. Stanford Children's Health continues to utilize their robust digital ecosystem to provide remote services across the spectrum of care as they've launched additional programs since the start of pandemic including: inpatient video consults, inpatient monitoring, and a national daily health survey.

Stanford Health Care Telemedicine Programs

Video Visits	Second Opinions	eConsults
360,000 video visits in FY20	**2,000** second opinions in FY20	**2,000** eConsults completed in FY20
75% of SHC patients say they are either very likely or extremely likely to schedule another video visit	**20%** of cases with changed diagnosis	**~2** business days for patients to receive recommendations instead of 23+ days (traditional referrals)
1,900 unique providers actively offering	**65%** of cases with changed treatment plan	**87%** of cases resolved without additional follow-up

Telemedicine Programs and Virtual Trials

Stanford Health Care has other telemedicine programs such as the Clinical Advice Services (CAS), which was designed to improve transitions of care by reducing after-hours call volumes. The new system utilizes a novel call center approach, in which co-located, non-licensed clinical assistants and experienced registered nurses help handle the entire enterprise's after-hours patient calls. To maintain high-quality service, Stanford Health Care implemented customized nurse triage protocols for all specialties and identified key metrics to ensure success. Currently, up to 60% of calls are managed between clinical assistants and nurses and less than 10% of primary care calls are escalated to physicians.

ClickWell Care is another example of an innovative telemedicine program at Stanford. ClickWell Care is an online primary care program designed specifically for young patients. The goal of the program is to mitigate unnecessary emergency care visits by facilitating access to virtual primary care. By focusing on the 20% of patients who do not have regular contact with their primary care provider, ClickWell Care is able to prioritize the needs of low-utilization patients and provide a seamless user experience by building virtual visits into existing primary care pathways. As younger patients may be naturally well-suited for telemedicine services, Stanford sought to create a convenient system enabling tech-savvy patients to access healthcare services and build organic relationships with primary care physicians. In order to improve accessibility, Stanford integrated this virtual visit capability into the existing EHR framework (Epic), and provided wellness coaching and same-day medication delivery to meet the needs of a younger, healthier population. In the case of ClickWell Care as a "new" clinical care model, the program was not implemented as a substitute for care delivery, but rather to augment and enhance the ability of providers, extending the capacity of the existing system.

The DeTAP study aims to reduce the cost of on-site randomized control trial (RCT) design, accelerate recruitment, expand the geographic pool of recruited patients, and reduce exposure risk for study subjects and study personnel.

CardioClick, a cardiometabolic disease risk-reduction telemedicine program, was launched by Cardiologist Rajesh Dash, MD, PhD, who directs the Stanford South Asian Translational Heart Initiative (SSATHI). SSATHI is a clinic that focuses on preventing cardiometabolic disease in South Asians, who are at fourfold higher risk than other ethnicities. To support the virtual and in-person physician visits, the CardioClick program offers up to 12 virtual "lifestyle" sessions, based on an intervention program developed by SSATHI's dietitian and CardioClick program coordinator, Vijaya Parameswaran. In order to help these patients make effective lifestyle changes, a member of the care team checks in regularly on the patient's progress with diet, exercise, sleep and other health factors every session."

The recently launched Decentralized Trial in AFib Patients (DeTAP) Study is a decentralized trial study to validate the ability of a coordinated suite of digital health technologies to fully decentralize a medical intervention clinical trial. While the study is not testing a specific medication, it is designed to test the ability of digital tools to promote, monitor, and encourage patient adherence to an anticoagulant treatment plan with no on-site visits. The trial will be used to inform planning for future drug development.

The DeTAP study aims to reduce the cost of on-site randomized control trial (RCT) design, accelerate recruitment, expand the geographic pool of recruited patients, and reduce exposure risk for study subjects and study personnel. Primary outcomes of the trial include engagement with study protocol and kinetics of patient engagement.

The Apple Heart Study

Decentralized and virtual trial frameworks have shown great promise and are gaining increased traction throughout clinical research. The Apple Heart Study exemplified the power of virtual clinical trials. This study enrolled over 400,000 participants in a 9-month period and provided follow up through a robust telehealth system led by Vendor AmericanWell. Through the Apple Heart Study App, patients were able to connect with a board-certified, licensed primary care or urgent care physician from the Online Care Group (American Well's clinical collaborator). Audio and video consultations were offered 24-hours a day, seven days a week, as a means for participants to communicate with a physician and understand the recommended next steps based on data collected from the Apple Watch. If emergency medical care was not immediately required, Stanford provided the participant with an ECG patch from BioTelemetry, which allowed researchers to continuously monitor patients, and compare Apple Watch readings with the ECG data. The virtual design of the Apple Heart Study provides a strong framework upon which future research can be modeled to explore the health implications of wearable technology and remote monitoring. Recent developments in clinical care models and availability of telemedicine tools have allowed decentralized clinical trials to become a viable model for accelerating and scaling research using digital health solutions.

The virtual design of The Apple Heart study provides a strong framework upon which future research can be modeled to explore the health implications of wearable technology and remote monitoring. Recent developments in clinical care models and availability of telemedicine tools have allowed decentralized clinical trials to become a viable model for accelerating and scaling research using digital health solutions.

Behavioral Health and Telemedicine

Text message and phone interventions have long been used as telemedicine approaches to enhancing patient interactions and improving outcomes.
Abby King, PhD, Director of the Stanford Healthy Aging Research and Technology Solutions Lab and Professor, Departments of Epidemiology and Population Health and Medicine, has been working with technology in behavioral health for many years to try and better understand how providers can improve care delivery through web and mobile-based interventions. Examples of her work include motivational framing and design for smartphone apps to increase walking, evaluating human phone-based and automated advising systems for physical activity, diet, and stress management, developing goal-setting and behavioral feedback strategies through wearable monitors and texting programs, and testing the effectiveness of computerized virtual advisors compared to human advisors in promoting regular physical activity. Dr. King has focused on finding ways that precision behavioral health can enrich and contextualize data to build solutions that advance population health and improve outcomes.

Health IT, Infrastructure, and Data Management

Definition

Within the scope of this report, health IT refers primarily to electronic health record systems and information systems in hospital settings. EHR systems automate and streamline workflows within an organization and provide the ability for data to be shared between organizations. Digital forms of information allow specialists, external labs, pharmacies, clinics, and primary care providers to easily collaborate and share expertise when caring for patients.

Also included in this category are technologies and solutions that leverage big data, a field characterized by the systematic extraction and analysis of large, complex datasets that are too difficult for traditional data-processing application software. As part of this data-sharing digital infrastructure, a multitude of technologies provide the underlying foundation not only for large-scale data management but for interacting with physical and organizational structures and facilities– this includes robots or other tangible technologies not classified elsewhere.

Common examples of digital health tools in this category include data resources such as data lakes, registries, data warehouses; data streams that feed automated clinical decision support systems; digital value-stream maps to pinpoint opportunities for improving workflows and reducing waste; systems that enable point-of-care learning and reduce documentation burden; automated communication tools and reminder systems for appointment scheduling and care coordination; revenue cycle management software (cloud-based Customer Relationship Management); network solutions and cloud services for remote access of patient data; and electronic prescribing. Considerations were also made for physical forms hospital infrastructure that may fall into this category that relate to telehealth such as robot-assisted surgery.

Literature Review

Stanford-affiliated authors have published 603 publications on health IT, infrastructure, and data management since 1984. Over the past five years, the leading clinical and application areas included:

Clinical Areas (Figure 21)

1. Cardiometabolic (43)
2. Hematology-oncology (36)
3. Musculoskeletal system, pain, and chronic conditions (19)
4. Neurology (16)
5. Mental health (12)

Application Areas (Figure 22)

1. Medical informatics, data management, and workflow (89)
2. Surgery and anesthesia (21)
3. Drugs and medication management (16)
4. Omics (15)
5. Other (14)

In our analysis, health IT is the only technology category in which the volume of publications with an application area (340) exceeded the number of publications with an associated clinical area (263). This may be due to the types of technologies that are associated with health IT and the broader systematic implementation of these solutions that complement the existing EHR framework.

The top clinical areas in health IT have a major emphasis on fields with highly prevalent diseases (cardiometabolic, hematology, oncology). The most cited publications within this category were focused on technology implementation at a systems level rather than a specific disease area. Additionally, four out of the top five publications in this category were published before 2010 as shown in Table 28.

Top 5 Clinical Areas in Health IT, Infrastructure, and Data Management Over the Last 5 Years

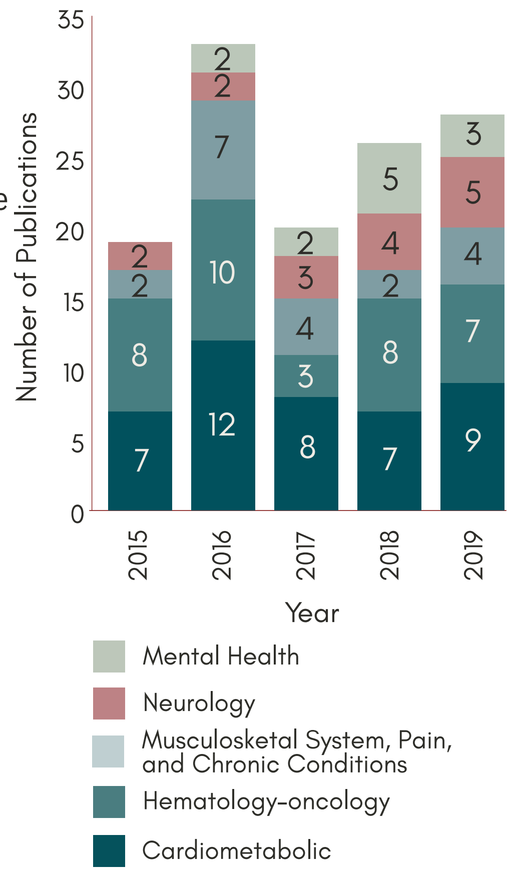


Figure 21

Top 5 Application Areas in Health IT, Infrastructure, and Data Management Over the Last 5 Years

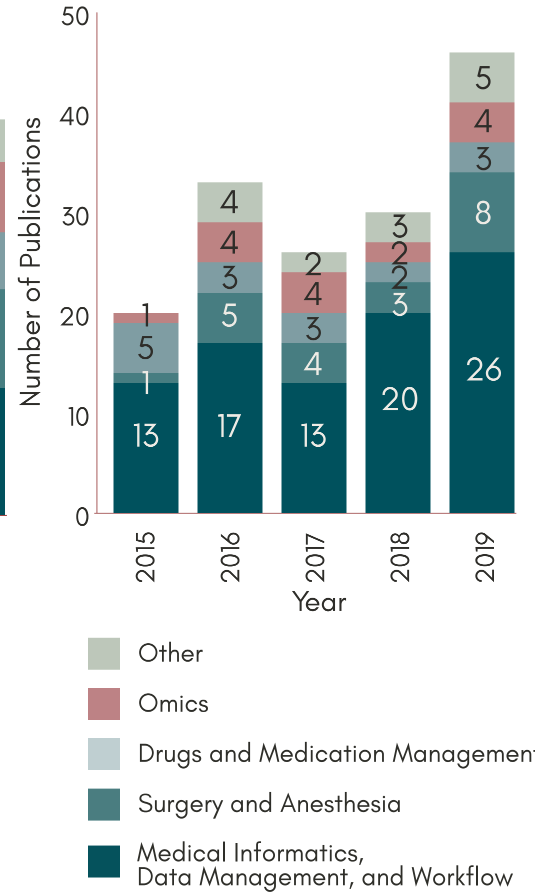


Figure 22

Most Cited Publications: Health IT, Infrastructure, and Data Management

Times cited	Title	Pub. Year
803	Personal Health Records: Definitions, Benefits, and Strategies for Overcoming Barriers to Adoption	2006
323	Image-guided robotic radiosurgery	1999
283	Robotic technology in surgery: Past, present, and future	2004
233	STRIDE – An integrated standards-based translational research informatics platform.	2009
223	NeuroVault.org: a web-based repository for collecting and sharing unthresholded statistical maps of the human brain	2015

Table 28

While research within this domain was most frequently published in journals with a technological or analytical focus, the Journal of the American Medical Association represents opportunity for major clinical impact as it is second highest on the list of journals (Table 29). While data sharing between institutions may seem difficult due to lack of interoperability, collaborating with external institutions may prove beneficial in this domain and allow researchers to demonstrate usability and viability of implementation methods across medical systems.

Top Journals: Health IT, Infrastructure, and Data Management

Impact Factor 2018 (JCR)	Sources	Number of Papers
4.3	Journal of the American Medical Informatics Association	34
51.3	JAMA	13
2.8	PLoS ONE	12
3	Journal of Biomedical Informatics	10
6.3	Clinical Pharmacology & Therapeutics	8

Table 29

Top Publishing Authors: Health IT, Infrastructure, and Data Management

Author	# of papers	Author	# of papers
Shah, Nigam H.	44	Altman, Russ B.	20
Musen, Mark A.	34	Das, Amar K.	17
Longhurst, Christopher	28	LePendu, Paea	13
Tu, Samson W.	26	Hernandez-Boussard, Tina	13
Goldstein, Mary K.	21	Rubin, Daniel L.	12

Total contribution, Health IT: 38%

Table 30

Health IT, Infrastructure, and Data Management at Stanford

Patient Mobilization and Computer Vision Technology

At Stanford Medicine, physicians, researchers, and healthcare professionals are utilizing various data management tools to improve internal operations and enhance physician capabilities. In a project combining AI and traditional brick-and-mortar methods for monitoring, researchers at Stanford developed computer vision technology for deep learning-based detection of patient mobilization activities in the intensive care unit. In this project, algorithms were used to detect patient movements like getting in and out of a bed or sitting on a chair. This project shows the complementary and synergistic nature of digital health technologies. Wall-mounted depth sensors captured data to train algorithms that could detect the frequency, duration, and number of personnel involved in a mobilization event. This project exemplifies how digital health technologies can synergize with traditional data capture. By quantifying patient mobility in real time, this approach could ultimately be used to improve patient care by identifying higher risk patients and enabling early and targeted mobilization of appropriate

Technology Infrastructure

The new Stanford hospital, which opened in November 2019, has numerous examples of technology-based infrastructure that are helping to improve operations and enhance the patient experience. In addition to the more than 5,500 Stanford Health Care employees working at the hospital, a fleet of robots has been deployed to help deliver medical supplies, control medication inventory, and streamline pill distribution processes. These "TUG" robots help to prevent injuries, reduce medication errors, and enable healthcare workers to spend more time

Featured Faculty

Russ B. Altman, MD PhD

Kenneth Fong Professor of Bioengineering, Genetics, Medicine and Biomedica Data Science (and Computer Science, by courtesy)

Dr. Russ Altman is the Kenneth Fong Professor of Bioengineering, Genetics, Medicine, Biomedical Data Science and (by courtesy) Computer Science, and past chairman of the Bioengineering Department at Stanford University. His primary research interests are in the application of computing and informatics technologies to problems relevant to medicine. He is particularly interested in methods for understanding drug action at molecular, cellular, organism, and population levels. His lab studies how human genetic variation impacts drug response. Other work focuses on the analysis of biological molecules to understand the actions, interactions and adverse events of drugs. He helps lead an FDA-supported Center of Excellence in Regulatory Science and Innovation.

caring for patients and less time worrying about logistics. In addition to the TUGs, automated medication selection machines called BoxPickers and PillPickers help find and package pills to improve efficiency and medication accuracy in the hospital pharmacy.

Another example of health IT is the universal device identifier (UDI) pilot program conducted by the Stanford Children's Health supply chain team which utilized a barcode scanning method for capturing medical device identifiers (DIs) that mapped directly to the EHR. Since 2016, point-of-use scanning of device barcodes at Stanford Medicine by nurses, technicians, and staff has allowed for rapid and accurate capture of DIs into the EHR and resource planning systems. This process ensures that the supply chain, clinical and financial departments, and electronic health record have aligned device identifiers and that all scanned unique device identifiers are available to be queried in a central data repository. The full process has been featured in a published case study.

At Stanford Children's Health, each room in the Pediatric Emergency Department has an iPad dedicated for patient use. Director of Pediatric Emergency Bernard Dannenberg, MD, said "One iPad is worth 10 milligrams of morphine." While it may seem like a simple solution, these tablets can comfort and calm a child by helping shift their focus on something besides their injury or illness. This allows healthcare providers to place IVs, interact with parents, and take critical steps in providing necessary treatment. In addition to catering to children, the built-in communication capabilities through the Stanford MyHealth App, FaceTime, and messaging allow parents to communicate with the emergency department staff, guest services, and for non-English speakers, an interpreter. This example outlines how digital health solutions can work within the existing hospital infrastructure to provide improvements across the care spectrum.

Clinical Decision Support

As outlined by HealthIT.gov, clinical decision support systems can improve clinical workflow by allowing clinicians, staff, patients, or others to access patient-specific information in an appropriate and timely manner to enhance health and healthcare. There are several such tools being used as part of the digital infrastructure at Stanford Medicine to improve clinical decision-making. In 2014, researchers from Stanford Pediatric Cardiology and Stanford Children's Health collaborated to optimize care using an electronic clinical decision support tool. This study evaluated the effect of tools such as data-triggered alerts, smart documentation forms, and conditional-logic order sets to improve surgical care compliance in adults recovering from cardiac surgery in a children's hospital. Results from this study showed that clinical decision support tools can have a major impact on achieving and exceeding Joint Commission standards. Stanford Medicine, Stanford Health Care, and Stanford Children's Health have collaborated on a number of projects in this space including: a practical approach to machine learning for clinical decision support, assessing practice patterns in the electronic health record, and improving communication with primary care physicians at the time of discharge.

Systems Utilization Research for Stanford Medicine (SURF) is a group that aims to facilitate the delivery of world class advances in medical care through world class advances in hospital operations. They strive to improve the quality of patient care, educate students, doctors, nurses, and hospital leaders, and share knowledge with Stanford medical and academic communities. SURF uses machine learning, mathematical optimization, simulation, and a variety of statistical, probabilistic, and computational tools in their research. In their most recent publication, Implementing Analytics Projects in a Hospital: Successes, Failures, and Opportunities, David Scheinker, MD and Margaret L. Brandeau, PhD describe recent work on a variety of analytical projects that were carried out at Stanford Children's Health.

In the publication, they focus on key reasons why projects have failed or succeeded at specific stages, and they outline lessons learned, principles, and best practices for the design of analytical projects intended for implementation in healthcare settings.

Clinical decision support tools are used throughout healthcare to improve efficiency and expand the organizational capacity. The Stanford heart failure dashboard used EMR-based measures to identify cohorts with high readmission rates and/or low intervention rates and improve intervention penetration, thereby reducing 30-day index hospital all-cause heart failure readmission rates. Other clinical decision support projects and studies include: Electronic Health Record-based Clinical Decision Support Alert for Severe Sepsis; Use of a Checklist and Clinical Decision Support Tool to Reduce Laboratory Use and Improve Cost; and Clinical Decision Support and Improved Blood Use in Patient Blood Management.

Stanford Center Outreach Initiative

While many provider-focused IT solutions are present at both Stanford Health Care and Stanford Children's Health, other groups across Stanford Medicine are focused on facilitating clinical and translational research and supporting essential research activities. These groups are part of the robust health IT infrastructure that makes Stanford Medicine a leader in conducting ground-breaking research. Stanford Population Health Sciences (PHS), the Department of Biomedical Data Science (DBDS), Spectrum, SPADA, DASHER (Data Science Resources), and the unified IRT (information resources and technology) team manage large datasets that are used by researchers, engineers, and scientists to develop many of the digital health tools mentioned in this report.

The Stanford PHS data platform enables the discovery, curation, and use of data from a wide range of sources. This includes datasets that the Center for Population Health Sciences (PHS) has acquired, and are accessed via the PHS Data Portal, where you can find the most up-to-date information with approximately 50 terabytes of data. The platform has 81 datasets, consisting of 154 billion patient records. 1,547 projects are supported by the PHS data and the platform has 901 members with data access.

The platform provides access to federal and commercial claims data sources (Medicare, HCUP, Optum®, MarketScan®), and hosts several unique and relevant datasets including IPUMS (census and survey data) and the Health Inequality Project.

1,547

projects supported by the PHS data platform

Stanford Medicine Research IT is another group that helps to supply infrastructure, tools, and services used by researchers, patients, participants, and clinicians to collect and combine data to make discoveries and to improve human health and wellness. Platforms by Research IT include Research Electronic Data Capture (REDCap), STAnford medicine Research data Repository (STARR), the mHealth Platform, and the Complex Event Processing Engine, a HL7 feed processing engine for real time recruitment. Research IT also has other platforms they've built with partners and collaborators including the CHOIR learning health platform and the Nero Research Computing Platform. The powerful STAnford medicine Research data Repository supports many different data models (e.g., STRIDE, OHDSI OMOP), tools, (STRIDE Cohort and Chart review tools, OHDSI ATLAS) and services (PACS Radiology Imaging data access and de-identification).

The Faculty Advisory Committee that governs Research IT's work includes co-chairs Dr. Ruth O'Hara, Sr. Associate Dean of Research, and Michael Halaas, Research IT's department head, and Nigam Shah, Stanford CTSA's Head of Informatics.

Physician Use of EHR Systems

For hospitals, the shift towards digitization is not a new trend; computers have been a part of medicine since at least the 1950s when first generation computers were used to automate transaction-oriented financial operations.
As seen throughout this report, modern hospitals are filled with technology. Increased integration, interoperability, outcomes-based reimbursement, IT mobility, and emerging cloud computing have led to the implementation of broad-based clinical decision support tools, operational departmental systems with EHR integrations, data warehousing, and analytics solutions. This emerging hospital IT framework has developed simultaneously with the evolution of the internet, wearable technology, algorithms, mobile health, and many other digital health tools leading to the birth of the modern-day digital health ecosystem.

Despite these advances, one glaring issue with current EHR systems seems to be the overall usability of these systems and the impact these processes have on provider quality of life. In 2018, Stanford Medicine and The Harris Poll conducted an online survey of over 500 primary care physicians and found that American physicians are increasingly dissatisfied with the state of EHRs. The study showed that while 63% of physicians agree EHRs have led to improved patient care, 59% think that EHRs need a complete overhaul and 40% believe that there are more challenges than benefits with the existing architecture of EHR systems. In addition, 74% of physicians agree that EHRs have increased the total number of hours they work daily and 71% stated that EHRs greatly contribute to physician burnout.

Stanford has also hosted an annual EHR National symposium featuring discussions on the future of EHR systems and the advancement of personalized and predictive medicine from experts in healthcare, technology, and policy. This symposium offers insight into the themes and trends that are defining the electronic health record in the digital age. Key among these trends is interoperability. With respect to digital health, interoperability refers not only to the sharing of medical information with healthcare professionals from all parts of the healthcare system, but also includes the integration of digital tools to help streamline this process. Results from the Harris Poll survey mentioned earlier indicate that more than two-thirds of doctors consider interoperability the most important feature needed in the long term, citing the need for a “radically different health IT infrastructure—one that promotes data sharing and is open to developers.”
The future of EHR systems will undoubtedly be impacted by the adoption and integration of digital health as these tools have the potential to significantly improve the interoperability of the current infrastructure.

How can digital health tools help to alleviate some of these issues? In a recent publication from Stanford’s N. Lance Downing, MD, solutions for improving the current state of physician burnout include updating outdated regulatory policies by stripping documentation requirements to bare essentials to improve accuracy, implementing value-based reimbursement programs, improving usability of systems and aligning function with value, and using natural-language processing and voice recognition technology. In addition to these solutions, digital health may improve efficiency through automating administrative tasks, supporting existing clinical workflows through artificial intelligence, and assisting decision making, and providing physicians the flexibility to focus on high-value activities.

In an examination of the most consequential developments and technologies that are changing healthcare delivery, the 2020 Stanford Medicine Health Trends Report outlines the rise of the “Data-Driven” physician, a trend highlighted by the skillset development of next-generation physicians. This convergence of skill, technology, and empathy illustrates the current trends in building a clinical environment where providers can leverage data-oriented skill sets like advanced statistics and data science to improve patient care. As a melding of technology and human workflow, it expands the use of traditional EHR systems and allows physicians to use AI, telehealth, and embedded sensors to improve their individual capacity.

CONCLUSIONS AND KEY FINDINGS

The Stanford Center for Digital Health Landscape Report paints the picture of a thriving ecosystem of interdisciplinary collaborators with the shared belief that technology can transform people's lives. The ability of digital health to flourish at Stanford comes from the commitment of leadership, the robust research infrastructure, the organic and collaborative nature of relationship building, partnerships with industry and proximity to Silicon Valley, a rich history of technological breakthroughs, and a pioneering spirit.

The results of this report demonstrate Stanford's unwavering commitment to improving the quality of care through digital health technologies. While not all technology trends will survive the future, a number have shown great potential for improving outcomes and combating the serious challenges ahead. If digital health is the future of medicine, what are the trends that are shaping the landscape at Stanford and the world?

While physicians, scientists, and engineers have long used advances in technology to improve medical practice, the last five years have seen unprecedented growth in the field of "digital" solutions in healthcare. While our publication database contains 2,390 publications dating back to 1984, 75% of all Stanford digital health papers have been published since 2014. One key takeaway is that Stanford has played a major role in developing and implementing technologies that have helped shape the broader landscape of digital health and will continue to enhance the capabilities of the next generation of providers. Stanford has a proven ability to produce influential and compelling research. Our analysis showed 24% of all digital health publications were cited more than 25 times and 12% more than 50 times.

Between 2012 and 2019, there has been steady growth in funding, authorship, and program development across the field of digital health– this is reflected in the trends observed in the five technology categories within this report. Although digital health has grown and matured significantly during this time at Stanford, applications in artificial intelligence have seen the greatest increase relative to other areas. This is reflected in AI having the highest proportion of funded papers (728, 31%) compared to the other technology categories, as well as the growth of numerous AI research centers across the Stanford ecosystem.

In our analysis, the top clinical and application areas across digital health were tied closely to the volume and accessibility of data, a shared understanding by patients and providers of the value of disease monitoring, and the intersection of personal and institutional adoption of digital health solutions. Throughout the report, medical informatics, imaging, surgery, and 'omics' were highly represented in each technology category and illustrate the reliance of digital health on established systems that capture, store, and analyze large amounts of data. Patient-facing solutions such as mobile apps and wearables support brick-and-mortar efforts to widen the capture of health data. Clinical areas, including neurology, cardiometabolic, oncology, and musculoskeletal, that operate almost exclusively as part of existing healthcare infrastructure and are represented by large patient populations, are benefitting from the adoption of digital health technologies that can improve outcomes and expand existing health system capabilities.

Continuing the theme of personal and provider use of digital health solutions, the literature review highlights mental health, substance abuse, and well-being as the highest represented areas in mobile and web applications, pointing to the use of these technologies by patients and consumers to manage their personal health. In addition, well-being and mental health were also highly represented in new clinical care models, demonstrating the dynamic relationship between patients and providers at the intersection of digital health. While telemedicine has seen increased adoption in recent years, the majority of patient care is still designed around traditional care pathways as part of existing health systems, although as we've seen during the pandemic, this paradigm is rapidly changing.

While the Stanford Biodesign program is just one example of an established pathway for developing products and companies, 126 digital health patents from the Office of Technology and Licensing point to the underlying hardware and software expertise represented by a number of groups in both medicine and engineering.

Another key finding from this report is the theme of collaboration represented by quantitative and qualitative measurements of partnership and teamwork with domestic and global collaborators. Stanford authors have collaborated with 1,349 external institutions across 59 countries and six continents, and 24% of Stanford's digital health publications involved international collaboration with Europe, China and the United Kingdom. 83 publications are associated with industry collaborations, although results from the center outreach initiative indicate that this number may be much higher as external partners are often connected to multiple touch points across the Stanford ecosystem. These trends underline Stanford's ability to build and maintain partnerships with academic research organizations, health systems, insurers, pharmaceutical partners, Big Tech, medical device companies, and other stakeholders throughout healthcare and beyond. This broad network of partners and collaborators supports the advancement of digital health through funding, domain expertise, and assistance in research coordination.

While some technologies struggle to demonstrate clinical viability, Stanford is leveraging internal clinical research capabilities to bridge this gap through groups such as the Stanford Center for Clinical Research who help to unlock the potential of digital health applications in research. With a robust research infrastructure and the ability to recruit from over 70 Bay Area locations through the Stanford Health Alliance, Stanford has produced effective clinical trial designs at scale that can generate tangible results in a short amount of time. This was most evident in the more than 400,000 patients that were recruited in less than nine months as part of the Apple Heart Study. In Stanford publications linked to clinical trials, 66% recruited at least 100 patients and 14% had more than 1000 participants.

We hope that the Stanford Digital Health Landscape Report was both informative and insightful. At the Center for Digital Health, we are fortunate to interact with many of the faculty and groups listed in this report and recognize the immense potential for digital health to advance healthcare in the years to come. Stanford is a place where people can come to thrive and explore the limits of medicine and technology. The achievements of the Stanford community in the field of digital health help support the legacy of Stanford Medicine as a leader in research and discovery.

By embracing the unknown, promoting collaboration, and working to ensure the future can benefit from the discoveries made today, members of the Stanford community are exploring the new frontier of medicine through digital health. Nowhere is the breadth and depth of digital health more evident than at Stanford. By having a specific focus on interdisciplinary collaboration, our faculty, students, and staff are building an environment of inclusion where out-of-the-box ideas and imaginative thinking are accepted and championed by the leaders of tomorrow. Stanford embodies the pioneer spirit on which the innovative breakthroughs in digital health are built on. From engineering to medicine, business to law, and everywhere in between, digital health is connecting and uniting groups from across campus and beyond.

FACULTY INSIGHTS

The Role of Faculty in Digital Health at Stanford

As part of our landscape analysis, we developed and distributed the first ever large-scale survey to gather information on the expertise and experience of Stanford faculty in the digital health space. We felt that this effort was a priority because of the inherent decentralization and variety of organizations across the Stanford ecosystem working in digital health. Without a school or department of digital health, the field is represented by a community of digital health faculty and groups listed in our center outreach initiative. To catalog the experience of the Stanford digital health community, we collected 78 data points on participants' digital health experience across three themes: patient care, research, and product development. We would like to thank the 137 digital health community members who contributed to the effort. (Note: 117/137 respondents identified as faculty; other respondents included staff and other hospital personnel)

How Many Years Have You Been in the Digital Health Space?

Despite the rapidly-evolving landscape of digital health, the majority of survey respondents reported an intermediate- to long-term presence in a field with broad opportunities for entrance. Almost 50% of respondents indicated between 1-5 years of involvement in digital health (Figure 23). While these findings may be attributable to responses from more established digital health stakeholders, a lack of respondents recently entering the space may suggest an unmet need for knowledgable digital health academics to mentor or "on board" peers, across the career spectrum, helping them explore new technology opportunities in addition to their clinical work. When asked "Have you used or do you currently use digital health technology in any professional capacity?" 72.3% of Respondents answered yes (99 out of 137).

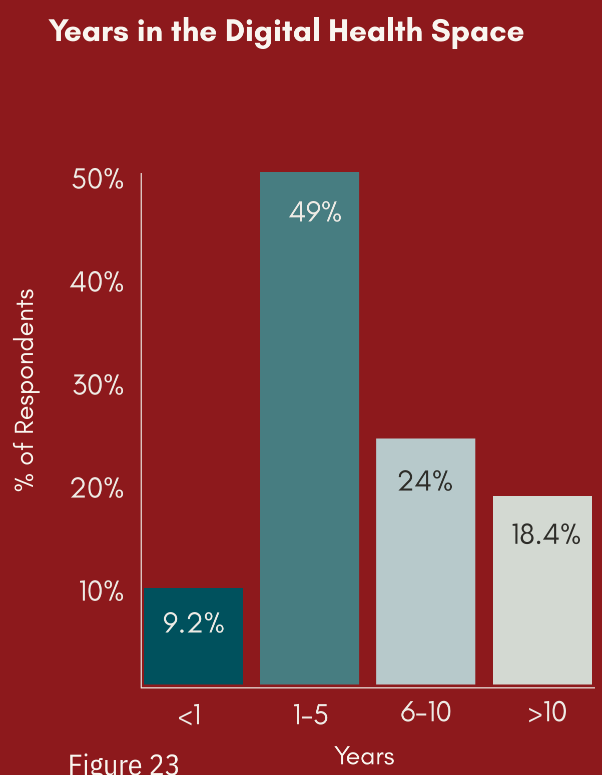


Figure 23

Faculty Interest in the Field of Digital Health

Interest in the field of digital health was primarily attributed to broadening research study enrollment and innovation in clinical care delivery (Figure 24). Similarly, leading reasons for use of digital health technologies in a professional capacity were treating patients and conducting research at 63% and 65%, respectively (Figure 25). Stanford Medicine's focus on research and patient care as indicated by these faculty responses highlights the broad potential of digital health to align with the vision of predicting, preventing, and curing disease precisely. Over a third of respondents also reported use of digital health technology in developing a product or company. With the adjacency of Silicon Valley, the relationship between industry and Stanford Medicine is evident in the number of commercialized products and companies developed by Stanford faculty as outlined in the center outreach initiative. This dynamic is further solidified through the many faculty that serve in advisory capacities to digital health or biotech startups. Other interest statements for digital health technology submitted by respondents included: empowering patients to make informed healthcare decisions for themselves and dependents, using technology and electronic health records to improve family education and outcomes, ethical aspects of digital health (particularly in mental health and research), and development of novel digital biomarkers of disease.

Why Are You Interested in the Field of Digital Health?

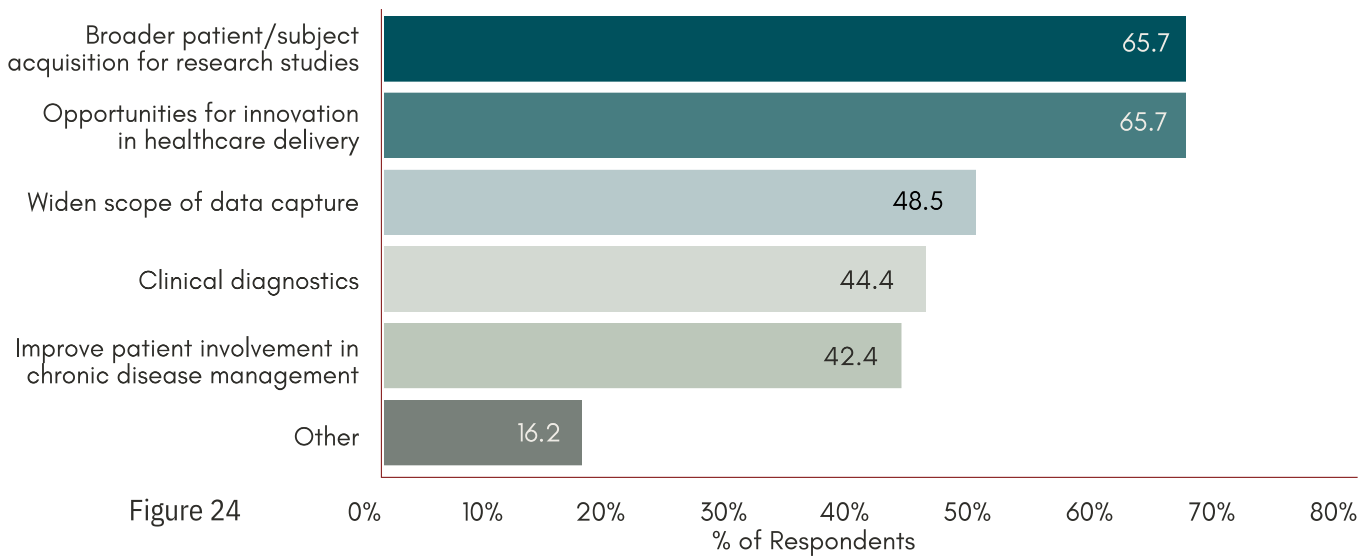


Figure 24

For Which of the Following Purposes Have You Used Digital Health Technology?

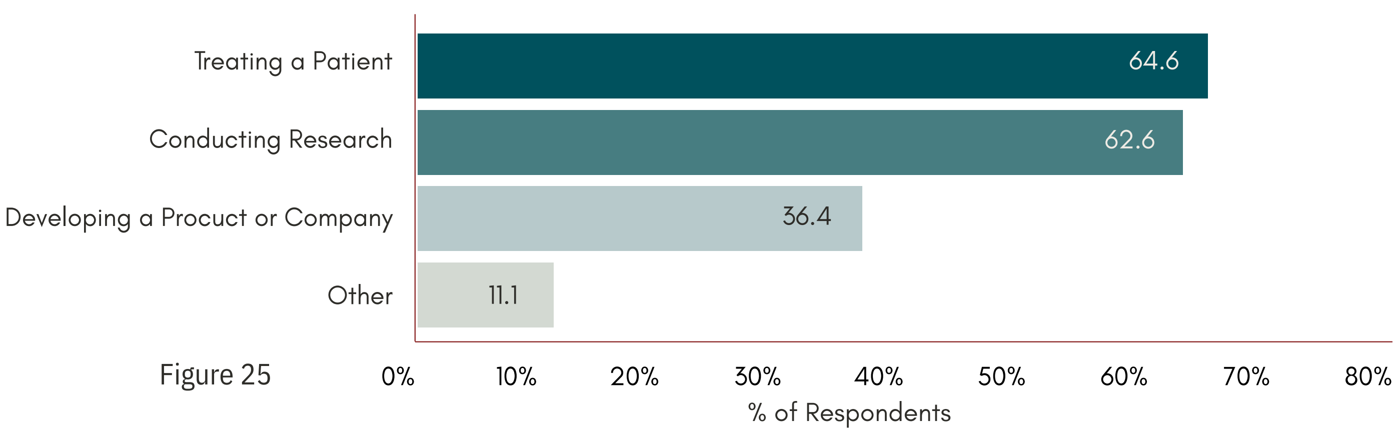


Figure 25

Global Impact

Stanford University is a melting pot of culture and diversity, with a wide range of opinions, cultures, communities, perspectives, and experiences. The results of the survey demonstrate the inclusive nature of the Stanford Community as research, patient care, and digital health product development have been conducted in many countries across the globe. The survey responses support the results of the literature review which show that Stanford is a global community of students, physicians, researchers, engineers, and working professionals that are pioneering the future of digital health. These results show that there are no boundaries to improving the lives of patients through innovation. Figure 26 shows the locations where faculty have worked on digital health research projects, cared for patients using digital health tools, and developed digital health products.

Research
Australia, Canada, China, Colombia, Germany, India, Mexico, South Africa, Taiwan, Thailand

Patient Care
China (3), India (2), Germany, Indonesia, Singapore, Tanzania, Thailand

Product Development
China (2), India (2), Canada, Italy, Japan, Taiwan, South Africa, Thailand

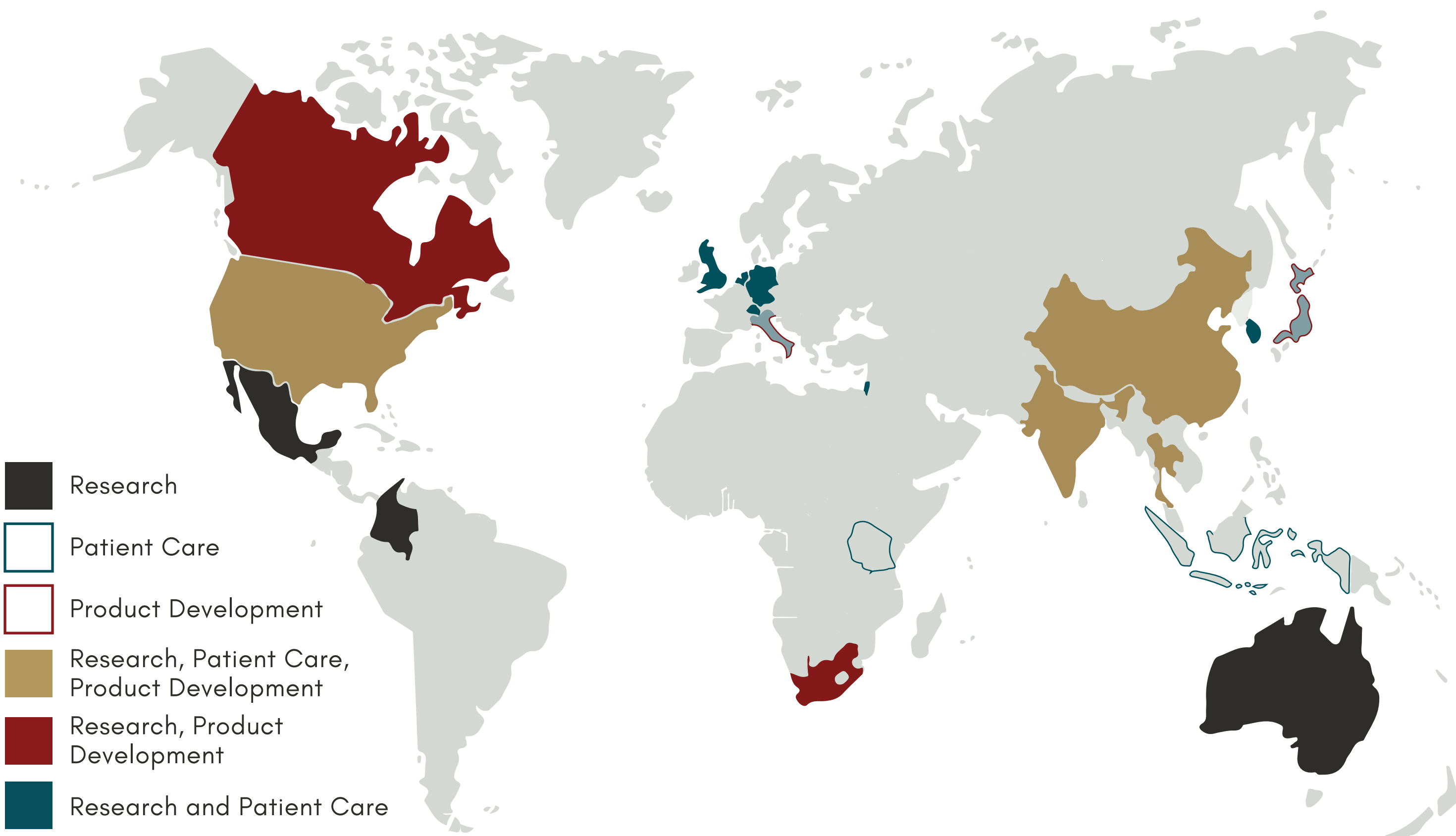


Figure 26

Digital Health Tech Use for Treating Patients

Indicate Your Current Level of Experience in the Following Categories with Respect to Treatment of Patients

(0=none, 1=little, 2=some 3=area of expertise)

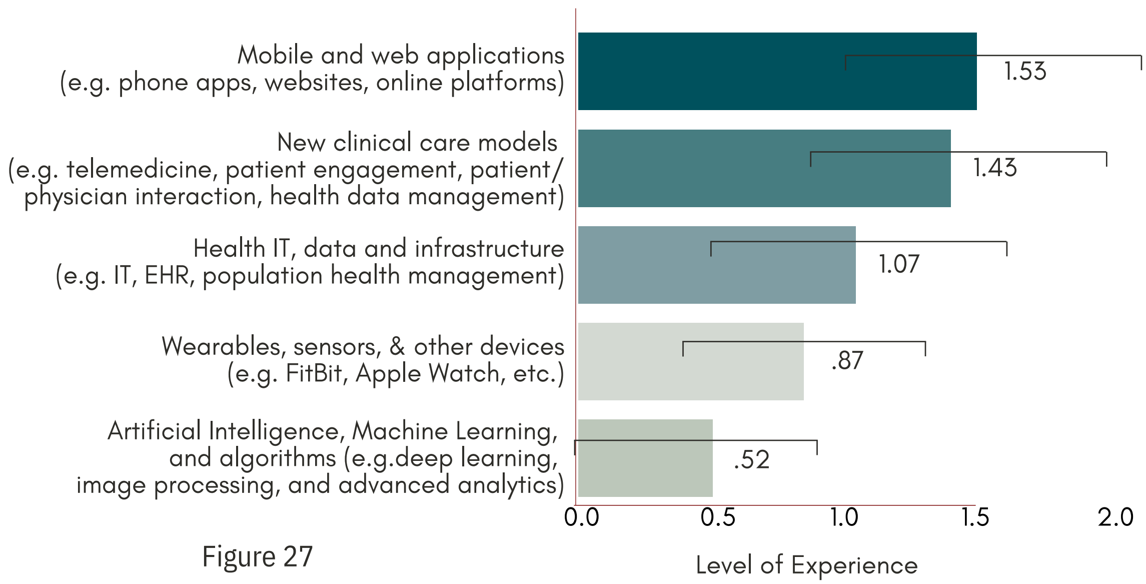


Figure 27

With respect to clinical care, respondents reported the most experience with mobile/web applications and new clinical care models (Figure 27). Surprisingly, despite the seemingly ubiquitous nature of wearables and sensors in the healthcare space, respondents on average reported little experience with this sector of digital health for patient care. Additionally, the lowest experience ratings were seen in AI, which may point to the highly specialized nature of this technology as it is currently used in clinical practice. Considering respondents were primarily from the Stanford digital health community, this is likely an overestimate of the broader medical community's experience with these products and highlights the need to invest in clinical integration. With increasing adoption of wearables by patients to manage health conditions and the evolution of AI in healthcare, failure to accelerate clinical integration of these products may weaken the patient-clinician relationship, exacerbating the "doctor google" phenomenon. Despite these challenges, Stanford's commitment to establishing dedicated wearable technology and AI programs across the university has led to unprecedented growth in these areas and a combined 112 patents and 1,145 publications.

With increasing adoption of wearables by patients to manage health conditions and the evolution of AI in healthcare, failure to accelerate clinical integration of these products may weaken the patient-clinician relationship, exacerbating the "doctor google" phenomenon.

Types of Digital Health Research

In the research space, respondents indicated that digital health technology was largely utilized for trial enrollment or novel observational cohort creation (Figure 28). Similar findings from the literature review demonstrate the use of digital health tools in clinical research as 105 unique clinical trials were conducted by Stanford researchers. A deeper dive into digital health research initiatives shows that digital health technologies are being incorporated or investigated across the research spectrum, including in policy and cost-effectiveness work and methodology development.

What Types of Digital Health Research Have You Worked on?

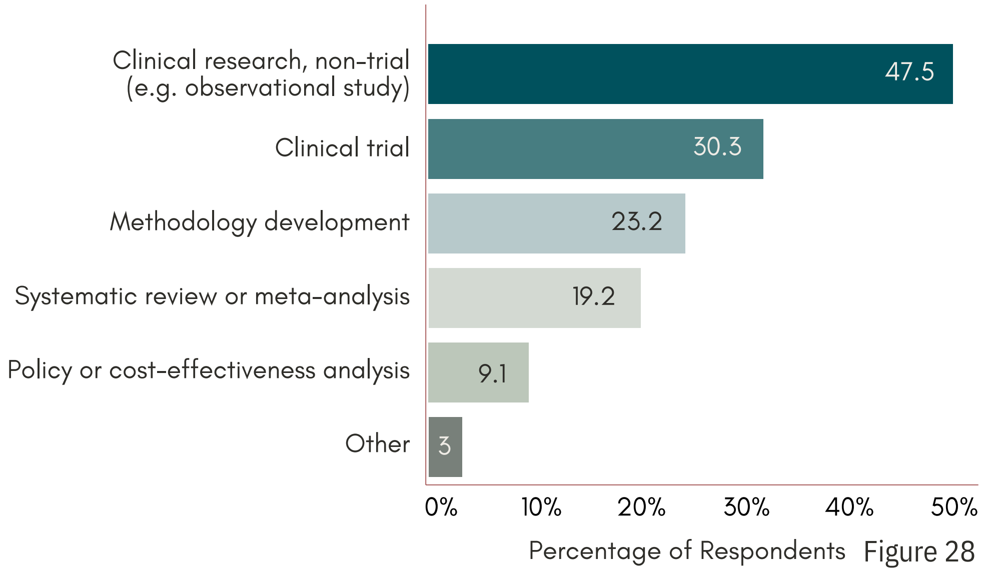


Figure 28

Stanford School of Medicine Collaborators

Who Have You Collaborated with in Research Outside of the Stanford School of Medicine?

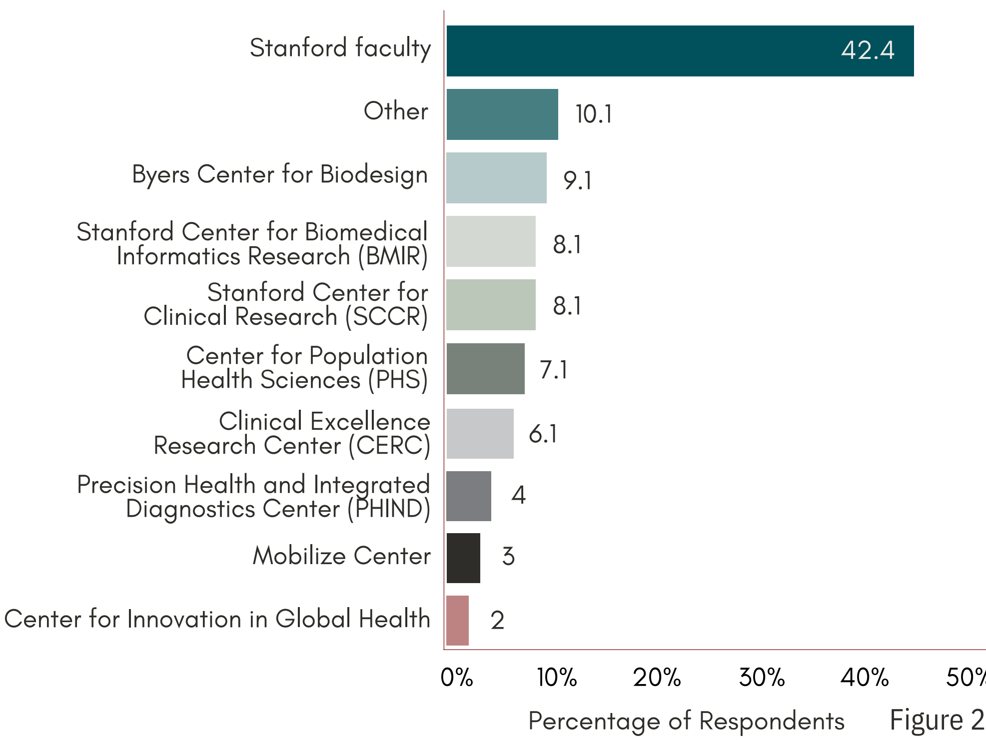


Figure 29

Internal and External Collaborations

Internal and external collaborations by members of the Stanford digital health community are broad and numerous, as shown in Figure 29 and Figure 30. Internally, respondents indicated that they most often collaborated with individual faculty members, more than with Stanford centers or groups, highlighting the decentralized nature of digital health expertise and the organic synergies arising from relationship development as expressed in the faculty and leadership interviews. The identified 32 centers, labs, and teams spread across the Stanford ecosystem demonstrate the collaborative and interdisciplinary approach that makes Stanford a leader in the field of digital health. While not all personnel in these organizations work directly in digital health, more than 4,800 faculty, researchers, administrators, postdocs, fellows, and other working professionals are involved in building up the digital health community at Stanford.

Who Have You Collaborated with in Research Outside of Stanford?

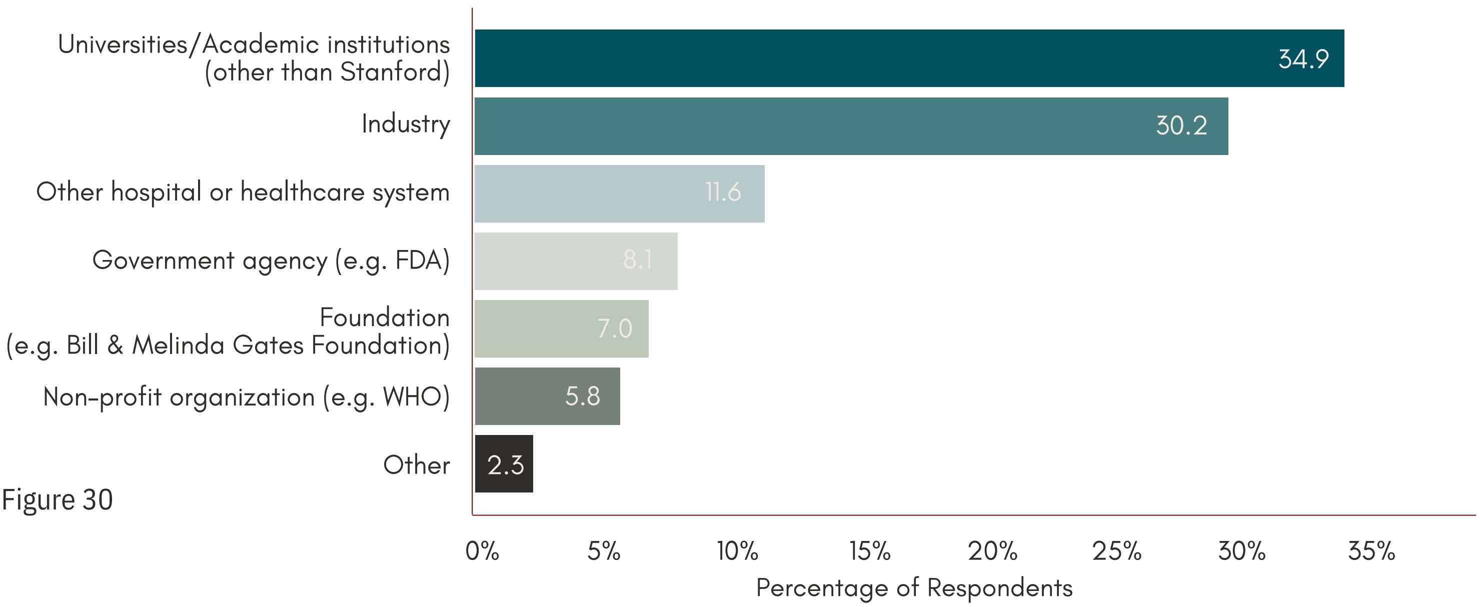


Figure 30

Digital Health Product Development

Who Builds and Develops the Materials for Your Digital Health Product?

Materials might include mobile or web applications, machine learning algorithms, wearables, other devices, etc.

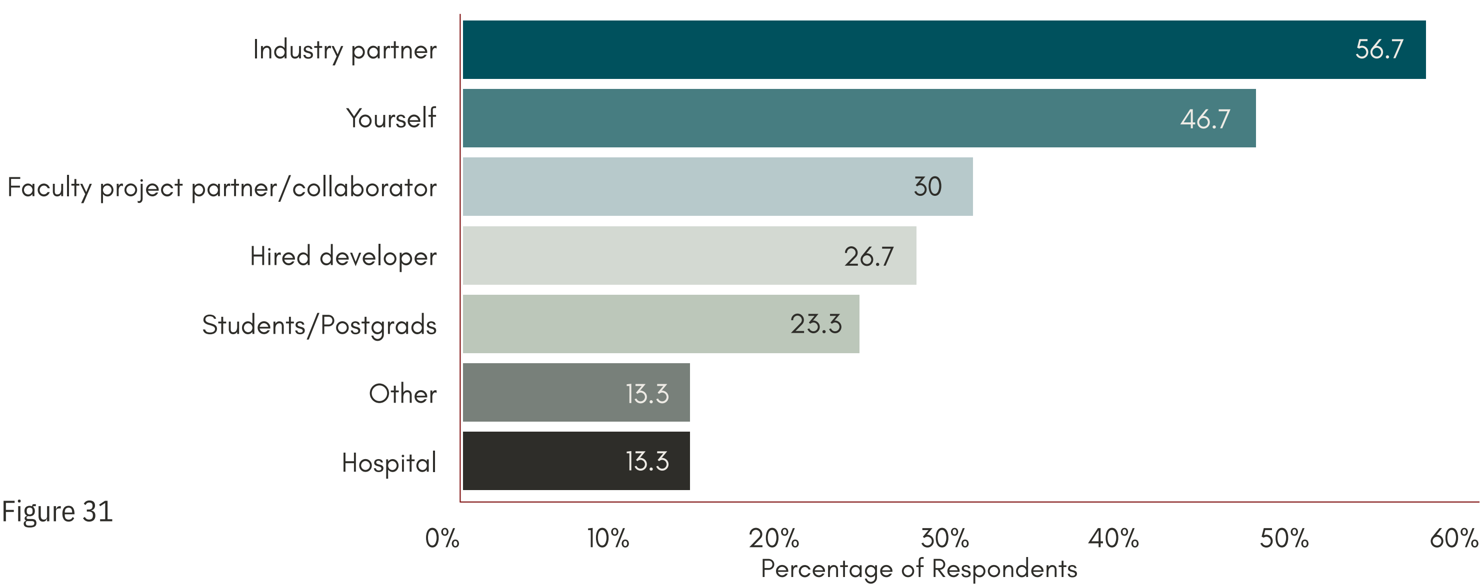


Figure 31

From which source do you receive the majority of your funding?

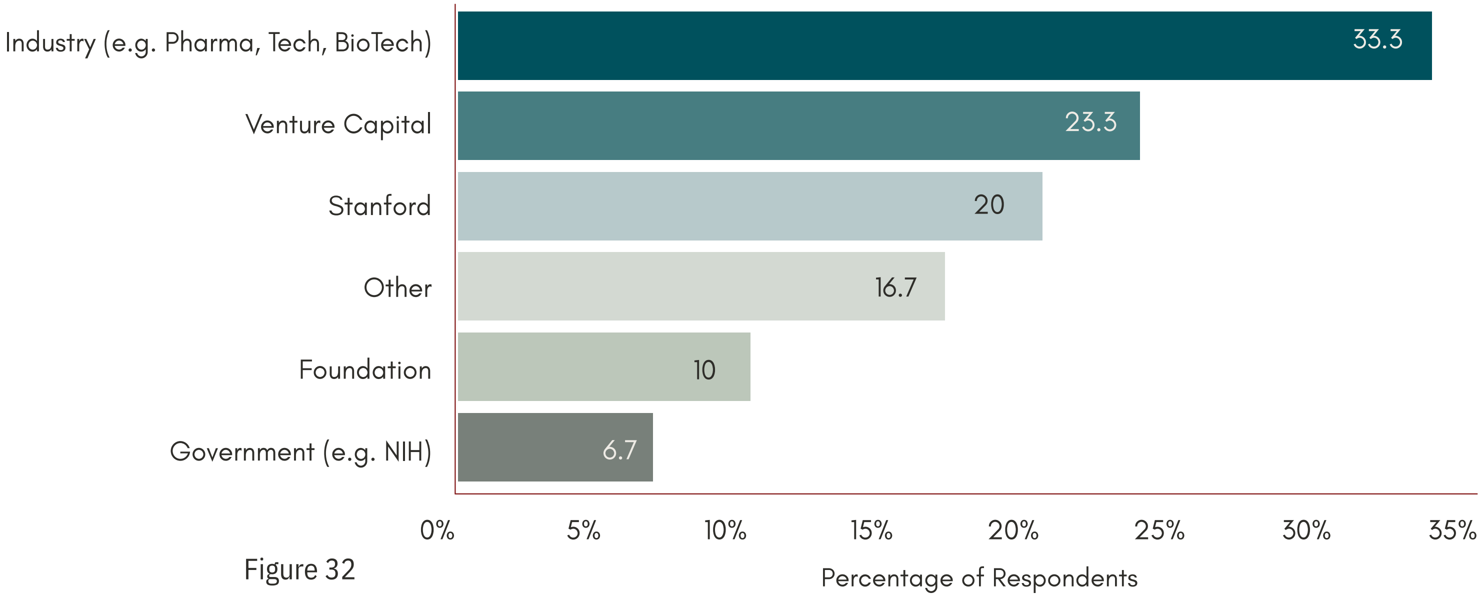


Figure 32

30 respondents reported on the status of a digital health product they were developing, almost half (45%) of whom reported a patent associated with the product. Data from the Office of Technology and Licensing supports these findings and shows a large number of patents coming from Stanford researchers and faculty with 126 patents related to digital health products, processes, and ideas specifically. While industry collaborators lead the way in co-developing and/or funding these digital health products (e.g., mobile or web applications, machine learning algorithms, wearables, other devices, etc.), almost 50% of respondents reported they were developing the tools themselves with another 23% relying on postgrads or other students to help complete their projects (Figure 31). Although a number of NIH institutes have taken an interest in digital health such as the Precision Medicine Initiative (PMI) Working Group, funding for digital health products was least likely to come from government sources, while industry and venture capital continue to dominate funding for early product development and commercialization (Figure 32). This differs quite significantly from the traditional research sector where our literature analysis showed that 77% of unique sponsors were public sources such as the United States National Library of Medicine and the National Cancer Institute.

Challenges and Areas for Improvement

Areas for improvement in Digital Health at Stanford

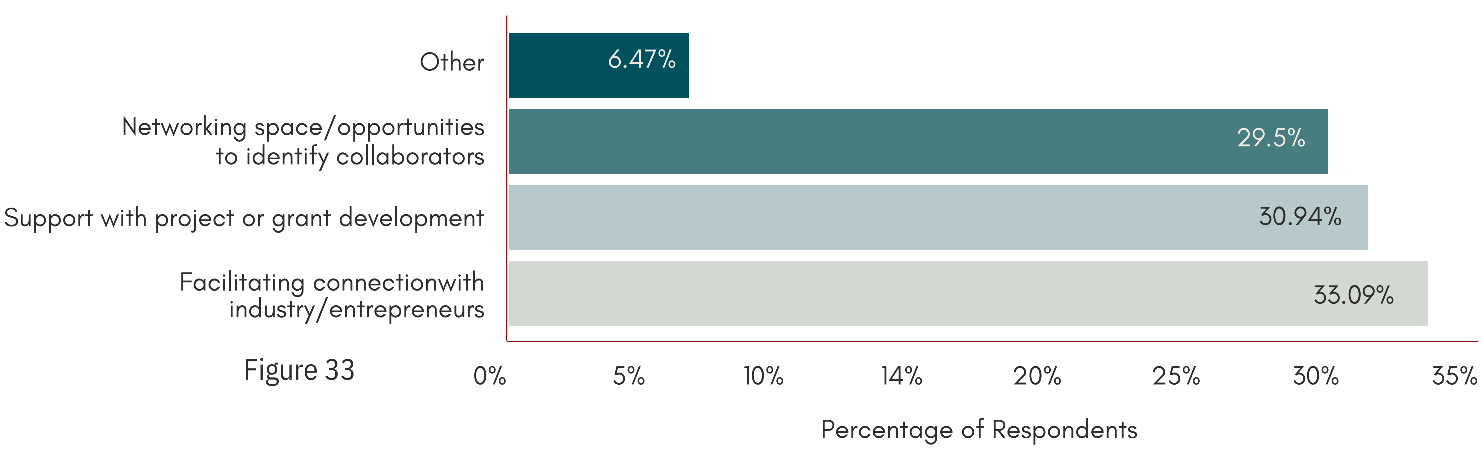


Figure 33

While the Stanford Center for Digital Health Landscape Report found a robust, diverse, and innovative digital health community at Stanford, we elicited comments from survey respondents, with the goal of catalyzing progress and providing a feedback mechanism based on the current challenges in the digital health space at Stanford. We asked respondents to suggest improvements and identify notable challenges they face as part of the Stanford digital health community.

Interestingly, respondents were distributed evenly regarding the need for facilitating connections with industry and entrepreneurs, the creation of networking opportunities to identify collaborators, and support with projects or grant development (Figure 33). Notable write in responses centered around the lack of centralized resources with guidance for funding resources, limited access to high-quality annotated datasets, and the existence of multiple digital health strategies across the Stanford ecosystem. The Center for Digital Health is committed to addressing these pain points and reducing the friction our community may experience while working in the digital health space. To achieve this aim, we've started by publishing this report and performing a needs assessment to better understand where we can assist and promote collaboration across the broader Stanford and external digital health community.

DIGITAL HEALTH COMMUNITY AT STANFORD

Student Community

Stanford is one of only a few elite universities in which all schools and departments are located on a single, contiguous campus. Such proximity brings about numerous benefits and greatly enhances innovative, interdisciplinary collaboration.

Digital health brings together students from virtually every school. Students from the School of Medicine, Graduate School of Business (GSB), and School of Engineering are constantly conducting research, planning new startups, taking courses, attending special events, and seeking internships in the digital health industry. While many successful projects are completed by medical students, MBA students, and engineering PhD or MS students (especially those studying computer science, bioengineering, chemical engineering, biomedical engineering, management science and engineering, electrical engineering, and materials science), there are also a number of students who study law, physics, biological sciences, economics, design, public policy, and more who actively pursue professional interests in digital health. Of course, not only graduate students have taken note of the recent digital health revolution. Increasingly, undergraduate students (particularly those who study computer science, and not as much those who study biology or more traditional premedical disciplines) have become involved both inside and outside the classroom.

With over 130 courses on a variety of digital health topics to choose from, Stanford students are able to explore the landscape of digital health and learn from some of the brightest minds in the field. Courses like epidemic intelligence, machine learning approaches for data fusion in biomedicine, and global leaders and innovators in human and planetary health are just a few examples of the curriculum students are offered at Stanford.

For example, the Byers Center for Biodesign offers Biodesign for Digital Health, in which students learn about digital health as an industry and design an entrepreneurial solution to an unmet problem in care. This popular course draws medical students, engineering MS and PhD students, and many undergraduate students. The teaching staff, led by vascular surgeon and digital health inventor Dr. Oliver Aalami, organizes student teams to ensure a diversity of academic backgrounds in each group– a microcosm of the unique way digital health brings together students from all over campus.

Dr. Aalami also teaches another Biodesign course, Building for Digital Health, which draws mostly computer science undergraduate and graduate students who learn about digital health frameworks such as Apple's ResearchKit and HealthKit, HIPAA and security implementation requirements, digital decentralized clinical trials, and patient engagement tools. The course is spinning out an open-source project, CardinalKit, that creates a software development kit for research study apps combining front-end (Apple HealthKit/ResearchKit) framework with back-end (Google Cloud Platform Services) to simplify implementation.

Other popular courses include Dr. Kevin Schulman's course Health IT and Strategy, which draws MBA students as well as medical students, residents, and physicians; Dr. Nigam Shah's Informatics in Industry, focusing on healthcare and biopharma; Dr. Atul J Butte's Translational Bioinformatics; the Stanford Machine Learning Group's AI for Healthcare Bootcamp; and numerous courses on artificial intelligence, informatics, and computation for healthcare across various departments.

In addition to courses, students engage in digital health work through events. The annual GSB Healthcare Conference, hosted by the GSB Healthcare Club, features well-known experts and executives in industry and has a digital health focus. Health++ is an annual health hackathon attracting 200-300 students from all over the country, and includes Stanford students from various schools and programs. TreeHacks Health is the health vertical of TreeHacks, Stanford's main hackathon that draws over 1,000 students from nearly 100 universities. The majority of projects that are produced at both hackathons are digital health projects, and many students continue pursuing and developing these projects after the hackathon. SHIFT, the undergraduate student group that organizes Health++ and TreeHacks Health, aims to cultivate a student ecosystem for digital health innovation.

Although Stanford students participate in digital health courses and events, the real defining factor for digital health on campus is the robust entrepreneurship milieu–students are constantly working on projects and startup ideas. Many digital health projects that have gained traction have come from Stanford medical students or MBA students. Many students have used the School of Medicine's Discovery Curriculum to start companies in the digital health space. Two venture-backed digital health companies to come from medical students include Augmedix, which provides a tech-enabled service that transcribes natural doctor-patient conversation into medical notes in real time and Ferrum Health, which aims to decrease medical errors with quality assurance algorithms that run on patient data across a health system.

TreeHacks Health is the health vertical of TreeHacks, Stanford's main hackathon that draws over 1,000 students from nearly 100 universities.

There are many entrepreneurial students hoping to make an impact in digital health. For instance, a Stanford student started Guardiome, which offers private sequencing services and develops open-source software for patients to analyze their own data. Engineering students from Stanford founded Wearlinq, which is developing a platform for cardiac health management enabled by the first stretchable, multi-lead ECG wearable with reduced size and weight from other wearable patches. Another great example is Osmind, a new clinical practice management and data analysis platform for mental health providers focusing on cutting edge psychedelic treatments, graduating with Y Combinator's latest cohort of companies.

While there is a heavy focus on entrepreneurship throughout Silicon Valley, many medical students have also worked for large tech companies on healthcare teams, consumer health companies, and major consulting firms.

Finally, a number of Stanford students work as fellows for venture capital firms. Firms such as Pear, Dorm Room Fund, Rough Draft Ventures, and Alix Ventures have students that scour campus for promising founders and ideas. The fellows have become increasingly focused on digital health, mirroring the larger venture capital community's interest in the industry. At Stanford, the fellows don't need to search too hard, since new ventures are springing alive each day. They do, however, need to look all over campus, as digital health is the hot topic across schools and departments.

Digital Health-Related Courses at Stanford

Groups that listed connections with digital health courses on their profile in response to the center outreach initiative are bolded in the boxes below. Additionally, digital health courses were sourced from the Stanford course catalog.

BIOMEDIN 201 Biomedical Informatics **HAI, DBDS, BMIR**	BIOMEDIN 206 Informatics in Industry **BMIR**	BIOMEDIN 215 Data Driven Medicine **BMIR, HAI**	BIOMEDIN 210 Modeling Biomedical Systems: Ontology, Terminology, Problem Solving **DBDS, BMIR**
BIOMEDIN 217 Translational Bioinformatics **BMIR, HAI**	BIOMEDIN 218 Translational Bioinformatics Lecture **BMIR**	BIOMEDIN 225 Data Driven Medicine: Lectures **HAI, BMIR**	BIOMEDIN 226 Digital Health Practicum in a Health Care Delivery System **BMIR, DBDS**
BIOMEDIN 254 Quality and Safety in U.S Healthcare **BMIR, HAI**	IMMUNOL 207 Essential Methods in Computational and Systems Immunology **BMIR**	IMMUNOL 310 Seminars in Computational and Systems Immunology **BMIR**	MED 277 AI-Assisted Care **BMIR**
BIOE 273, MED 273 Biodesign for Digital Health **Byers Center for Biodesign**	BIOE374 A/B Biodesign Innovation **Byers Center for Biodesign**	CS 342, MED 253 Building for Digital Health **Byers Center for Biodesign, HAI**	MED 232 Discussions in Global Health **CIGH**
HRP 237 Practical Approaches to Global Health Research **CIGH**	BIOE 390 Stanford Bioengineering **Computational Arrhythmia Lab**	BIODS 215 Topics in Biomedical Data Science: Large-scale inference **DBDS**	BIODS 48N Riding the Data Wave **DBDS**
SYMSYS 122 Artificial Intelligence: Philosophy, Ethics & Impact **HAI**	MED 232 Global Health: Scaling Health Technology Innovations in Low Resource Settings	CS 28 Artificial Intelligence, Entrepreneurship and Society in the 21st Century and Beyond **HAI**	LAW 4041 Lawyering for Innovation: Artificial Intelligence **HAI**
CME500 Departmental Seminar: Artificial Intelligence (AI) for Good **HAI**	CS 21SI AI for Social Good **HAI**	Biodesign Innovation Fellowship **Byers Center for Biodesign, HAI**	COMM 230 Digital Civil Society **HAI**

CS 22A, INTLPOL 200, LAW 4043 The Social & Economic Impact of Artificial Intelligence **HAI**	CS 106S Coding for Social Good **HAI**	CS 377E Designing Solutions to Global Grand Challenges: Designing Smart Healthcare	STATS 245 Data, Models, and Applications to Healthcare Analytics **HAI**
CS 522 Seminar in Artificial Intelligence in Healthcare **HAI**	GSBGEN 596 Designing AI to Cultivate Human Well-Being **HAI**	STRAMGT 364 Health Information Technology and Strategy	LAW 4039 Regulating Artificial Intelligence **HAI**
MED 232, BIOE 371 Global Biodesign: Medical Technology in an International Context	ANES 208A Data Science for Digital Health and Precision Medicine **HAI**	BIO 138 Ecosystem Services: Frontiers in the Science of Valuing Nature **HAI**	BIODS 210 Configuration of the US Healthcare System and the Application of Big Data/ Analytics **HAI**
INTLPOL 257 Technology & Public Purpose: Practical Solutions for Innovation's Public Dilemmas **HAI**	BIODS 232 Consulting Workshop on Biomedical Data Science **HAI**	SYMSS 208 Computer Machines and Intelligence **HAI**	BIODS 248P, BIOMEDIN 248, STATS 248 Clinical Trial Design in the Age of Precision Medicine and Health **HAI**
BIOE 103 Systems Physiology and Design **HAI**	BIOE 217, BIOMEDIN 217, CS 275, GENE 217 Translational Bioinformatics **HAI**	BIOE 221G, GENE 208, MI 221 Gut Microbiota in Health and Disease **HAI**	PSYCH 250:, CS431 High-level Vision: From Neurons to Deep Neural Networks **HAI**
MED 232 Global Health: Scaling Health Technology Innovations in Low Resource Setting **HAI**	CERC Design Fellowship	PUBLPOL 205, PUBLPOL 105 Empirical Methods in Public Policy **HAI**	CEE 70N Water, Public Health, and Engineering **HAI**
PUBLPOL 138, ECON 130 Poverty Policies: Theory, Design and Analytics **HAI**	COMM 154, COMM 254, CSRE 154T, SOC 154, SOC 254C The Politics of Algorithms **HAI**	PHIL 82, COMM 182, CS182, ETHICSOC 182, POLISCI 182, PUBLPOL 182 Ethics, Public Policy, and Technological Change **HAI**	HRP 275 Population Health Research **HAI**

CEE 275C Water, Sanitation and Health **HAI**	HRP 247, HUMBIO 57 Epidemic Intelligence: How to Identify, Investigate and Interrupt Outbreaks of Disease **HAI**	PSYC 242 Mental Health Innovation Studio: Entrepreneurship, Technology, and Policy **HAI**	GSBGEN 513 Using Technology and Market Interventions to Solve Social Problems
GSBGEN 551 Innovation and Management in Health Care **HAI**	MOOC Massive Open Online Courses for Individuals Interested in Data Science **Mobilize**	Clinical Research Operations Program **SCCR**	MOOC Massive Open Online Courses **SCCR**
Clinical Research Operations Program **SPADA**	Intensive Course in Clinical Research - ICCR- SPADA **SPADA**	MS&E 263 Healthcare Operations Management **SURF**	MS&E 463 Healthcare Systems Design **SURF**
AI for Healthcare Bootcamp	BIODS 220, BIOMEDIN 220, CS 271 Artificial Intelligence in Healthcare	MED 286 Health Information Technology and Strategy	BIOMEDIN 214, BIOE 215, CS 274, GENE 214 Representations and Algorithms for Computational Molecular Biology
CS 229 Machine Learning (Ng, Fall) [also available online on Coursera]	CS 246 Mining Massive Data Sets (Leskovec, Winter)	CS 337 AI-Assisted Health Care	CS 42 Designing AI to Cultivate Human Well-Being
SOMGEN 275 Leading Value Improvement in Health Care Delivery	EE 364,CME 364, CS 334 Convex Optimization (Boyd, Winter)	RAD 206 Mixed-Reality in Medicine	MED 272A, BIOE 374A, ME 368A Biodesign Innovation: Needs Finding and Concept Creation
MED 272B, BIOE 374B, ME 368B Biodesign Innovation: Concept Development and Implementation	MED 275B Biodesign Fundamentals	OIT 384 Biodesign Innovation: Needs Finding and Concept Creation	BIODS 231, STATS 331 Survival Analysis
MED 249, ECON 249, HRP 249 Topics in Health Economics I	BIOMEDIN 205 Precision Practice with Big Data	BIOMEDIN 217, BIOE 217, CS 275, GENE 217 Translational Bioinformatics	BMI 212, CS 272 Biomedical Informatics Project Course (Altman, Spring)
CS 145 Introduction to Databases (Re, Fall)	CS 224W Social and Information Network Analysis (Leskovec, Fall)	CS 341 Project in Mining Massive Data Sets (Leskovec, Spring)	STATS 216 Introduction to Statistical Learning (Hastie & Tibshirani, R., Winter)

INTLPOL 302 The Global Economy	HRP 261, BIOMEDIN 233, STATS 261 Intermediate Biostatistics: Analysis of Discrete Data	HRP 262, STATS 262 Intermediate Biostatistics: Regression, Prediction, Survival Analysis	HUMBIO 51 Big Data for Biologists-Decoding Genomic Function
HUMBIO 88 Introduction to Statistics for the Health Sciences	EARTHSYS 162, 262 Data for Sustainable Development	GENE 217,BIOE 217, BIOMEDIN 217, CS275 Translational Bioinformatics	HUMBIO 89 Introduction to Health Sciences Statistics
STATS 315 Modern Applied Statistics: Learning (Hastie, Winter)	BIOE 281, ME 281 Biomechanics of Movement (Delp, Winter)	HUMBIO 151R Biology, Health and Big Data	OIT267 Business Intelligence from Big Data
HRP 216 Analytical and Practical Issues in the Conduct of Clinical and Epidemiologic Research	HRP 223 Introduction to Data Management and Analysis in SAS	HRP 239, EDUC 260A, STATS 209 Statistical Methods for Group Comparisons and Causal Inference	CEE 246 Venture Creation for the Real Economy
GSBGEN 503 The Business of Healthcare	EMED 127, EMED 227, PUBLPOL PUBLPOL127, 227Health Care Leadership	GSBGEN 503, HRP 285, MED 285 Global Leaders and Innovators in Human and Planetary Health	EDUC 135, AFRICAST 135, AFRICAST 235, EDUC 225, GRP 235, HUMBIO 26, MED 235 Designing Research-Based Interventions to Solve Global Health Problems

Table 31

Enabling Digital Health at Stanford

In addition to the information from the center outreach initiative, the following groups and offices are instrumental in advancing digital health at Stanford. While the physicians, scientists, researchers, and engineers are the originators and creators of the digital health projects at Stanford, the supporting network of administrative and operational personnel help to actualize the ideas of those that innovate. While they may not be on the front lines of research, these organizations help to streamline research by reviewing processes, negotiating details, providing legal support, and providing general guidance on operational aspects of research projects.

Research Management Group (RMG)

Stanford MEDICINE | Research Management Group

RMG serves as the central resource, expert partner, and is responsible as the institutional official for sponsored projects and fellowships in the School of Medicine. Their services include:

Funding opportunities: identifies, manages, and distributes funding opportunity information to the School of Medicine research community.

Grants: provides guidance and oversight of proposal development including budget, and responsible for award acceptance and post award compliance as the Institutional Official.

Fellowships: provides guidance to Postdocs on proposal development, award acceptance as the Institutional Official.

Clinical Trials: negotiating clinical trial agreements, related agreements, and clinical trial budgets, specifically with industry funders.

Financial Compliance Oversight: providing financial compliance oversight of all sponsored projects in the School of Medicine.

Office of Technology Licensing (OTL)

OTL OFFICE OF TECHNOLOGY LICENSING STANFORD UNIVERSITY

OTL works with Stanford faculty, staff and students to protect and commercialize their inventions. The inventions are evaluated for their commercial potential, marketed, and, when possible, licensed to industry. Cash royalties collected by OTL after licensing provide funding to the inventors' departments and schools, as well as personal shares for the inventors themselves. OTL typically begins the collaborative process by reviewing an invention with the inventors to learn about potential commercial applications. A licensing strategy is then developed, which may include a recommendation for further maturing the invention through Stanford's network of translational programs, and the technical and market risks considered when deciding whether to patent the invention. Together with the inventors, OTL tries to find companies that might be interested in the invention and seeks a product champion within a company before negotiating a licensing agreement. Although patentable inventions constitute the majority of OTL's licensing activities, they also license out copyright (software and other content) and tangible research property, and handle outgoing Material Transfer Agreements for biological materials.

Industrial Contracts Office (ICO)

Stanford | Industrial Contracts Office

Part of OTL, ICO works in close collaboration with research and administrative offices throughout Stanford and advises other University offices on intellectual property terms and related policies. ICO negotiates agreements that balance university and industry interests. If your research will involve interactions with, or funding from, industry, or if you need research materials from labs outside Stanford, the Industrial Contracts Office (ICO) will negotiate and sign your agreements on behalf of the University. They negotiate sponsored research and other research-related agreements with industry. These agreements range from multi-year, master research collaborations to individual research projects, with companies large and small. ICO handles material transfer agreements with all types of entities: companies, government agencies and nonprofits. ICO also executes agreements for Industry Affiliates Programs.

Office of the General Counsel (OGC)

Stanford | Office of the General Counsel

OGC consists of in-house attorneys and support staff who collaborate with outside law firms to address and provide advice on the legal issues arising out of the activities of Stanford University, Stanford Health Care, Lucile Salter Packard Children's Hospital at Stanford and their affiliates.

Office of Sponsored Research (OSR)

DoResearch

OSR provides pre-award and post-award administrative services for sponsored projects. OSR collaborates with partner groups in other central and school offices to coordinate research administration services, systems, and processes. They review and endorse sponsored projects proposals, negotiate and accept awards, and issue subawards on behalf of Stanford. In addition, OSR establishes accounts in the financial system and fulfills sponsor's financial reporting requirements.

Research IT: Technology and Digital Solutions

Stanford MEDICINE | Research IT
Technology & Digital Solutions

Research IT exists to supply infrastructure, tools, and services used by researchers, patients/participants, and clinicians to collect and combine data to make discoveries and to improve human health and wellness. Research IT is a dedicated group of engineers and research support professionals with a multi-disciplinary background. Many have been with Stanford for over a decade. Research IT offers resources for COVID-19 research and can help with Stanford Hospital data and tools such as Electronic Data Capture, mHealth and secure computing platform. Read more about publications from Research IT.

FACULTY INTERVIEWS

Matthew Smuck, MD

Matthew Smuck, MD

Chief of PM&R
Associate Professor in the Department of Orthopedic Surgery at Stanford University

Medical Director of Rehabilitation Services for Stanford Healthcare

Director and Founder, Wearable Health Lab

What does digital health mean to you or how would you describe it to others? There are a lot of different definitions out there.

I think of it broadly to mean any way of making healthcare better by leveraging digital technologies. Simply put, it's the use of commonly available digital devices to make healthcare better.

As far as digital health is concerned, are the lines blurred as far as how the field is developing? Is it fairly clear to you what digital health is and isn't?

I would say the lines are somewhat blurred because I don't think anybody can accurately predict how all of this is going to evolve. I think we can look at other enterprises that have been changed by application of technology, like banking or finance, and see how human interactions change with application of digital tools. However, for healthcare this needs to be both more efficient and personalized.

Have you always been at the forefront of technology or has that been more of a recent development? If you try to trace back your entry point into the digital health space, what does that look like?

I'm not a person who has always stayed up to date on the latest technology. I've learned to do that out of necessity because of my research interests. It wasn't for a love of technology that I decided to enter digital health. It was because I saw a big problem in orthopedic and neurologic clinical care and research that can be solved through digital health tools. More specifically, early in my career, as a clinician and as a budding researcher, I became quickly frustrated with the subjectivity of the science that underpinned the treatment of people with back pain and all other kinds of orthopedics and neurologic problems. The science was built largely on outcomes from questionnaires provided to patients, our knowledge base is largely subjective. This is quite different than research and clinical care in cardiac disease or cancer, where the outcomes measures are mostly quantitative and objective. Comparing progress in these areas shows vast differences. In a few decades, cardiac care and cancer care have progressed dramatically through multiple iterations built on precise measurement of outcomes. There just has not been an ability to do this for back pain treatment, which was my primary clinical focus. The same applies to nearly all orthopedic and neurologic diseases. When I got my first iPhone I had the "aha moment" that led me to the digital health space. I thought wait a minute, this is a thing that can help us quantify the things that we care about in our research, and that the people I treat in my clinic care about. We can do it in a way that can provide objective and quantifiable measurements like those that have allowed cardiac and cancer care to advance over time. So that's what led me to first ask the question, "How can I use my iPhone to measure human function or human performance in the real-world, which is the primary measurement that researchers and clinicians look for from treatment of orthopedic problems, including low back pain? How can we use these common digital devices in order to measure the things we care about in a quantifiable way rather than in a subjective way?"

So, the "aha moment" came when you first got the iPhone for personal use?

Yes. I'm a physiatrist, also called a physical medicine and rehabilitation (PM&R) doctor, and physiatrists focus on human function. Just like a dermatologist cares about the skin, just like an orthopedist cares about the bones. We care about human function. So, I understood that an iPhone had potential to measure function in a way that was not previously possible.

What year was that? (When you got your first iPhone?)

Late 2007. This was also six months before I got a phone call from one of my former mentors at Stanford. I had trained at Stanford then took a job at the University of Michigan in 2002. I was there in 2007 when these thoughts were moving around in my head. Having done some background research I found that nobody appeared to be looking at using iPhones in this way, so I started to imagine how I would go about developing a research program focused on this opportunity. Around this time I got a call from one of my former mentors at Stanford who asked if I was interested in coming back to Stanford to help rebuild the PM&R program here at Stanford. So when I came to interview for the position, I made sure to talk to some people who were involved in research using similar digital tools. It was then clear to me that Stanford was the right place for me to develop my research ideas and I moved back to Stanford in 2008.

How does digital health contribute to your motivation to keep learning or growing and to look for new technologies that can improve those outcomes? How would you describe how digital health enables that as opposed to maybe more traditional means of providing healthcare?

Specifically to the problem I'm trying to solve, it gives us a tool where we can measure what people are doing in their daily lives, in their normal lives, and see the impact of disease on their daily lives and changes that occur due treatment. Whether we recommend physical therapy or whether we recommend surgery, whether we just recommend changes in habits, we can actually measure how people respond. We can base decisions on each individual's history since these devices can provide a historical record. It sounds fairly easy, but as it turns out the types of things I need to look at from the device are more nuanced than what the devices currently provide.

For instance, I can't just look at a person's step count or the number of exercise minutes. Those things aren't sufficient to provide the granularity of information that's needed to be meaningful for somebody with low back pain. What the people in my lab are working on is developing the algorithms that can provide the type of information we need. Ultimately the companies that make smartphones, smart watches, and other personal devices can include our algorithms to routinely measure things that have greater health implications. Our work on this is hypothesis driven. We know from clinical insights that there are certain data streams provided by the digital devices that are more likely to provide fruit and we interrogate those data streams or features or information streams that prove meaningful when compared to currently used research tools.

In terms of just your own digital health work, what would you say that you're most proud of? (A project or an initiative)

I am most proud of our work to redefine how researchers can use physical activity monitoring in populations with pain and mobility limitations. Prior to this work, physical activity monitoring had only been looked at as a means of measuring a person's energy expenditure. That's important for fitness research or work on diseases where energy expenditure impacts health, but it has very little to do with changes in behavior caused by back pain or knee arthritis. We defined the parameters that are meaningful in looking at the influence of pain on a person's physical behavior. That was an important innovation that allowed us to objectively quantify human function as it relates to pain and to learn more about orthopedics disease.

One of our publications that received a good amount of press and that provided an important insight was a study that used our new methods to demonstrate, for the first time, that physical activity is one of the important mechanisms that links obesity to low back pain. Researchers had looked at this question in the past, but only using the traditional self-reporting. By using objective and quantifiable measures we were able to show that habitual physical activity has a strong influence on the link between obesity and back pain. (Outstanding Paper: Medical and Interventional Science- Does Physical Activity Influence the Relationship Between Low Back Pain and Obesity? Matthew Smuck, MD; Ming-Chih Kao, PhD, MD; Nikhraj Brar, MD; Agnes Martinez-Ith; Jongwoo Choi; Christy Tomkins-Lane, PhD)

Do you think that outcomes will really be improved or is PM&R and orthopedic still behind the curve as far as actually improving outcomes or the standard of care?

> We defined parameters that are meaningful in looking at the influence of pain on a person's physical behavior. That was an important innovation that allowed us to apply physical activity style research to understanding more about orthopedics problems.

Outcomes will definitely be improved over time with these types of tools, not just in things like PM&R and orthopedics that need better objective outcomes, but even in things where outcomes are already objectively measured. These tools can impact many fields that currently rely largely on subjective information from questionnaires such as PM&R, orthopedics, psychiatry, and neurology. Some physicians I know fear that AI and these digital tools will replace doctors. I disagree. I think what will happen is that these tools will allow doctors to spend more time doing the things that we are uniquely trained to do.

How do you filter through the technologies that could potentially be beneficial? Is it hard to find the ones that have actual clinical efficacy or provide a benefit?

I probably approach it like the average doctor, and that is I'm not trying not to be an early adopter of these things. I wait until I see what others have experienced before making decisions. Since most physicians practice in larger systems now, instead of independently, we do not have as much control over these things as you might think. We largely use the tools provided by our institutions.

What is it about Stanford that allows for digital health initiatives, projects or ideas to flourish? What makes Stanford different, where these opportunities can really be successful?

When I arrived at Stanford, I knew about good clinical research, but I didn't really know how to approach translational research. So, one of the first people I met with once I arrived on campus was Bill Haskell, who is the director of the Stanford Prevention Center. The Prevention Center was one of the international leaders in physical activity research, and I spent some time talking to Bill about my ideas. And he was very generous with his time and also generous with some of his resources, and assigned one of his post-docs to work with me in carrying out some of the very first studies that I performed in this space. Bill has remained a mentor to me over time, even after his retirement.

From there I gathered a little bit of momentum, I started working with more people around campus and with students from different labs. Most notably, Scott Delp in Bioengineering has been very helpful. Scott established the Mobilize Center with NIH funding and got me involved with his team. Our efforts are very complementary and his insights always help make my work better. I also worked with Nigam Shah in bioinformatics to help one of his PhD candidates through his doctoral thesis on knee osteoarthritis and physical activity monitoring. These types of connections happen very naturally at Stanford through different research events and meet-ups on campus. I don't even remember how I first got linked up with Scott Delp. I think it was through the recommendation of a colleague to meet with him. Scott was very generous with his time, agreed to meet with me and saw a lot of potential and the things I was talking about which allowed us to work together. I remember I got introduced to Nigam Shah through a student who was working with me on research. He was presenting at one of the Bio-X meetings when one of the students from Nigam Shah's lab noticed his work and then brought Nigam over to talk. From there we set up a meeting, and that's how that whole collaboration started. Stanford is a very unique environment. One of the reasons I came here with the digital health idea in mind is I knew that it would be a much more fruitful environment, not just because of proximity to Silicon Valley, which has also proven useful in some interesting ways, but also because of the different types of researchers and the interdisciplinary collaborative nature of Stanford.

What do you envision are the next developments or trends over the next 5-10 years in digital health? Is there anything that specifically excites you? How do you see the field developing?

Well, video visits are already happening, and have expanded dramatically with COVID-19. This will likely trend further upward in the future. I think that barriers for people having contact with their healthcare providers are going to start to go away which will facilitate better communication. What I mean is, as you know, scheduling an appointment is a very onerous task currently and it doesn't need to be that way. I think digital tools are going to create new scheduling systems and video visits will facilitate a better, more efficient use of the health system for the patients in particular, because a digital visit can be just as useful for the clinician as an in-clinic visit. It doesn't really make a difference in many circumstances. Alongside that, I see a lot of opportunity for these new data streams to inform the clinical system: like physical behaviors and how that might influence orthopedics care. All of this can be pumped into the EMR to provide information to the clinician when needed. We currently see very little of this information, almost none it from a digital health perspective, but I think that's going to change in the next five to ten years. That type of information

"One of the reasons I came here with the digital health idea in mind is I knew that it would be a much more fruitful environment, not just because of proximity to Silicon Valley, which has also proven useful in some interesting ways, but also because of the different types of researchers and the interdisciplinary collaborative nature of Stanford."

is going to come in and inform the clinical decision making. Another thing I see happening over the next five to ten years is better use of these digital tools, not just from the things that I'm looking at, but the way that people are leveraging information from the digital tools around heart health, around mental health, and so forth. All of that is going to become very important because the health policy makers want to move the health system away from our current fee for service model and towards a value-based model of health care delivery. When that happens we will need to have systems in place to measure outcomes at scale. This is because value-based healthcare is based on outcomes over costs. The costs of care are easier to calculate while the outcomes are challenging. If we rely on patients to provide answers about their health by filling out questionnaires each time they interact with the health system, the system will fall apart due to the overwhelming responder burden placed onto the patients. If you've been to the doctor in the last couple years, you probably received a questionnaire after that visit. Hopefully you are healthy and don't get those questionnaires very often, but imagine the more typical person that comes to a physician with four or five diseases. Now imagine receiving questionnaires for each of these conditions each time you interact with the health system, not just to follow up from the most recent encounter but also from the one six weeks ago, and the one six months ago. You can see how that system falls apart. Having

" Having digital tools that can passively collect meaningful information and store it in the cloud for use when needed in the clinical environment will empower this new system of healthcare in the future. "

digital tools that can passively collect meaningful information and store it in the cloud for use when needed in the clinical environment will empower this new system of healthcare in the future.

Fatima Rodriguez, MD, MPH

Preventive and General Cardiologist in the Division of Cardiovascular Medicine at Stanford

Fatima Rodriguez, MD, MPH

What does digital health mean to you? How would you describe it?

Digital health means using everyday technology to improve health through connectivity, communication, and engagement in medical care. Within that overarching branch of digital health, there are things like mobile health, telemedicine, and remote platforms for clinical trial research. For example, most of my patients have a smartphone that can be used to better collect and track health information that can then guide shared decision making.

What was your entry point into the digital health space?

I do not necessarily consider myself a digital health expert; I am a clinician and health disparities researcher interested in getting patients to adhere to guidelines for cardiovascular care. Particularly in the space of cardiovascular prevention, we have very good data on what simple lifestyle changes and medications work to prevent heart disease. Yet, there are ongoing challenges to guideline adherence at the patient, provider, and system level. My interest in digital health was inevitable after coming to Stanford and being surrounded by innovation, technology, and industry partners in an environment that uniquely fosters collaboration.

Cardiology is also a space that welcomes digital health tools and transformations. With things like the Apple Watch and atrial fibrillation detection, many of our patients bring us data, and we need to learn how to better incorporate it in our decision-making.

Do you view digital health differently whether you are doing research or caring for patients?

Absolutely. Research requires informed consent but it is useful when we can integrate research into clinical care particularly in times of diagnostic or therapeutic uncertainty.

In clinical research, digital health tools can help us lead more efficient clinical trials, recruit diverse and engaged participants, and have them feel like they are getting value from study participation.

How is the adoption of technology playing a role in your career path?

As we are bombarded with more and more data, there's a need to leverage technology to better collect, analyze, store, and share data. Digital health approaches allow us to scale research studies and more efficiently engage with patients and study participants. As research director of a CardioClick telemedicine program, for example, we are studying how a virtual preventive cardiology program can help patients improve their cardiometabolic health. With the COVID-19 pandemic, digital health platforms have finally gained widespread adoption.

Can you talk about your involvement with Project Baseline?

I've been fortunate enough to be involved with [Project Baseline] since its inception during my cardiology fellowship. At Stanford, this project is led by Dr. Ken Mahaffey and Dr. Sam Gambir. The goal of this project is to create a modern-day cohort that tracks individuals from health to chronic disease and collects an incredible amount of participant-level data ranging from clinical, molecular, self-reported, and sensor data to deeply phenotype participants. One very interesting aspect of this project that I've been involved with is how to return results to participants without changing the course of the observational nature of the study. Nowadays, study participants expect to have their data returned to them and we need to do this in a way that balances the rights of our study participants while maintaining the integrity of the science. This has been a really amazing learning opportunity for me in the clinical research space and I look forward to the many scientific insights that will be gained from this study in the years to come.

How would you say digital health contributes to your motivation to keep learning and growing as a physician?

As seen with the COVID-19 pandemic, we need to continue to learn and adapt to meet patients and study participants where they are. The adoption of digital health will be one of the positive (and hopefully lasting) consequences of this pandemic. This will increasingly require use of digital tools such as telemedicine, sensors, and other tools in clinical care. I am hopeful that digital health will help optimize clinical workflow and minimize clinician burden.

In terms of just your digital health work overall, what would you say that you're most proud of?

The exciting thing about digital health, AI, and big data is that you get to work with so many different stakeholders; being at a place like Stanford makes that easier. I've had the privilege of working in diverse teams with clinicians, researchers, industry leaders, computer scientists, engineers, and regulators. The partnership and the understanding that not one person is going to be the expert in everything, but that together, we can inform each other and make things better for our patients, providers, and researchers – this is one of the best parts of my job and work in the digital health space.

What is it about Stanford that allows for digital health initiatives, ideas, and projects to flourish as opposed to other environments?

> "Stanford is ripe for innovation because of its geographic location and because of its committed leadership that really pushes forward innovation."

There's something in the very fabric of Stanford that promotes innovation and collaboration in the digital health space. We have amazing leaders like Dr. Bob Harrington, Ken Mahaffey, Euan Ashley, and Mintu Turakhia who are really supportive of scientific collaborations with industry and in rigorously studying new technologies and their applications to improve health. Our Biodesign program is one example of how Stanford creates leaders in health technology. When answering medical questions, we continue to maintain the rigor of the scientific method when working with industry. It's not just important to innovate quickly, but we also need to maintain very high standards. There's no substitute or shortcuts for well-conducted clinical studies.

What do you envision for the field of digital health in the next 5-10 years?

As we are seeing, companies are working with clinicians and researchers to innovate in the healthcare space. Telehealth is here to stay and I think it will not entirely replace in-person visits but will help increase our clinical and research reach. Direct to consumer products/technologies that are health-related will be more common and we will need to learn how to incorporate this data into our clinical decision making. Innovation will continue to happen at the intersection of different disciplines. That's really exciting and I'm honored to be part of this community.

Matthew Lungren, MD, MPH

Matthew Lungren, MD, MPH

Assistant Professor of Radiology (Pediatric Radiology) at the Stanford University Medical Center

What does digital health mean to you and how would you describe it to others?

To me, all healthcare is digital health. We're increasingly practicing in a healthcare system that is centered, just like our everyday lives, in the digital world. As a radiologist, my practice is quite literally digital, and that's been true for many years well before the term digital health was used in the way it is now. It seems that when we talk about digital health in the abstract it sort of becomes ephemeral, intangible. That somehow digital health is reserved only for futuristic things, ideas, or at worst implies its an app or a gimmick. But the reality is that digital health is already the foundation of what we do when we take care of patients; any practitioner who is using a risk score, calculating and leveraging data in the electronic medical record, or even trying to research a disease, relies heavily on a lot of the advancement that the digital health revolution has brought over the last few decades. So in reality even as newer digital health solutions come on line we are adding onto a strong existing foundation in our daily practice.

Do you separate different types of digital health technologies?

I think people that consider themselves in the "digital health" domain would probably separate them out, but if I'm taking a step back and looking at it from outside the healthcare system, I'm not sure they draw those distinctions quite as well. From the patient perspective I think there is some expectation that even in the course of routine care, we are also collecting data and potentially leveraging that for insights and research. So, on the outside, I wonder if maybe that has been the assumption. For example, if I told my 96-year-old grandma that we're doing a lot of things in digital health, she would probably say, "well, of course you are." I don't know if that would be a huge surprise, even as part of her regular visits to the doctor. The unique piece that Stanford brings is that we have an opportunity to help define what the field will look like, lead it, or both. I think that is an advantage of having a world class undergraduate institution so closely tied to the medical school and laser focused on applications – so far we have truly led the field.

Where was the entry point for you into digital health space?

A related quote for my approach to working in new areas is by Richard Feynman "study hard what interests you the most in the most undisciplined, irreverent, and original manner possible." I love that quote because it helps to break down some of the artificial barriers we put in front of ourselves when we want to learn about a new field that is distant from our own expertise – in other words you often hear of people worried about "staying in their lane" and focusing only on a limited area of science or, if they do find a new area of interest outside their field, they will often wait to explore, feeling as though they need to first attain additional degrees – but what I've found is that following genuine curiosity and passion with a subject, especially in research pursuits, has always led to great things, especially in cross-disciplinary pursuits. The more I got involved and learned about machine learning the more interested I became, and my interest and passion was sparked by the incredible potential for the democratization of knowledge and expertise that these technologies possess, and how powerful that could be in healthcare. The idea that you could take a complex skill that requires a decade to learn, like reading medical imaging exams, and potentially codify it in a way that allows it to be disseminated widely and made available anywhere in the world (and in particular the areas that lack subspecialized medical expertise) – well, that's an exciting proposition and a driving force in my research.

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When did you start becoming interested in AI specifically?

Well, I really began to get interested after first discovering how well these deep learning models could be applied successfully to conventional computer vision tasks and thought, "Could these models also learn medically useful imaging tasks rather than identifying a dog or a cat in an image? Could they also diagnose pneumonia on a chest x-ray?" And really at the time we started really looking into these questions and we started to see that it was possible, and of course we weren't the only ones to ask these sorts of questions and it felt like at that time there was this explosion of excitement into research for medical imaging AI applications practically overnight. While we have learned a lifetime of lessons about these technologies in healthcare in the past 2-3 years, and still have a long way to go, we are really fortunate to be a part of this amazing clinical AI global community comprised of researchers in academics, tech, and industry and we haven't looked back.

How would you say that digital health contributes to your motivation to keep growing as a physician and avoiding burnout?

I think burnout is the term that we have used to label this feeling of helplessness, feeling overwhelmed, and feeling like you're not making a difference. I think that has been pervasive in a lot of different careers, not just in medicine, but we certainly have a serious crisis in healthcare providers. There's a lot of work being done to address this and it helps that it's increasingly recognized as an epidemic that harms the healthcare system and affects patients and clinicians alike – but I will say that for me, and this is obviously a personal perspective, I find that the opportunity to engage in regular intellectual exploration has been my antidote to burnout. I truly enjoy the work that I do, in the same way some people might enjoy restoring antique cars or playing guitar. And so I'm fortunate to be at a place like Stanford where I can really lean into opportunities to explore new ideas and collaborate in an environment of like-minded curious faculty and students from all walks of life; its that very unique and special Stanford culture of chasing down interesting ideas, even if they seem a little "out there," and that to me has really been the secret sauce to help me dodge things like burnout and career dissatisfaction.

What is it about Stanford that allows digital health to really succeed?

I think about this a lot. I reflect on this because I have been at many other great world class institutions, the types of places you would probably mention in the same sentence as Stanford. But it is absolutely true that there is a cultural difference here that I have not seen anywhere else, no matter how boldly the mission statement says it, no matter how much leadership tries to encourage or manufacture a cross-disciplinary collaborative environment. But Stanford has that "it" factor, a culture that is 100% organic, and because it's not created by design, it's very hard to imagine it can be replicated. Stanford is a place that is overflowing with brilliant faculty and students filled with curiosity, an attitude of open mindedness, and an expectation of constantly learning and working together on big new ideas, even if sometimes they are considered impossible. Adding all that Stanford has to offer to the surrounding Bay Area, with Silicon Valley and an amazing legacy of entrepreneurs and self-starters, and it all comes together in an almost magical atmosphere where anything seems possible.

> “There is a cultural difference here that I have not seen anywhere else ...Stanford has that “it” factor, a culture that is 100% organic, and because it’s not created by design, it’s very hard to imagine it can be replicated.”

What do you envision for the field of digital health over the next 5-10 years?

I think we’re all trying to look into our crystal balls to see where things might head, at least as far as clinical AI is concerned. I think in the short term, we’re really happy with the progress and research we’re implementing – algorithms and clinical trials methodology etc. But I think from the longer term perspective, I think that there’s still a lot of work to be done. One, is that you do see a lot of excitement and fervor around a lot of AI, but I think we’ll hit a point where it’s going to meet some resistance – those of us working in healthcare certainly recognize that for every benefit, there are also sometimes consequences, downsides, or drawbacks, some known and some unknown. Coming to grips with that is not something that optimistic startups often do or spend a lot of time dwelling on, and I think that’s incumbent upon us in academia at a place like Stanford to lead. As we move forward we will see more groups like Stanford continuing to be the standard bearers for both moving the innovation forward, but also doing it in a way that provides a critical look at whether this is really providing value for a patient or whether this is really helping the healthcare of the population that we’re serving. So in other words I’m predicting a balance shift in the current narrative where we’ll start seeing things shift slightly more toward academic medical centers and moving into a regimented, very safe, clinical trials-based approach. Some of that will be regulatory, some of that will be finance related, but a lot of it will hopefully be driven by science. Because in the end, when all the dust settles and all the excitement for these digital health technologies goes away, no matter what you’re doing, whether it’s wearables, population health level screening, or smart home technology, it still has to show a benefit.

This domain of running clinical trials, this is in our wheelhouse, this is something that we can do. We can run large scale trials like you’ve seen with the Apple Heart Study – being able to pull together resources, but still have it in the home field of academic medicine, because we’ve done this before. So I think that’s where we’re at and where our next phase is going to be – we’ve discovered many exciting breakthroughs in new clinical technologies, but now it’s time to really show that they actually help the people that we are serving.

> “Because in the end, when all the dust settles and all the excitement for these digital health technologies goes away, no matter what you're doing, whether it's wearables, population health level screening, or smart home technology, it still has to show a benefit.”

Abby C. King, PhD

Professor of Health Research and Policy (Epidemiology) and of Medicine (Stanford Prevention Research Center)

Abby C. King, PhD

What does digital health mean to you?

My perspective comes from being a behavioral scientist. From the beginning of my career, I've been very interested in finding accessible communication pathways to diverse groups of people that can be used to promote health and wellbeing. While some of the populations I've worked with come to us through healthcare or other kinds of settings, most of the time we're reaching out to sectors and segments of the population. It's very different than having doctors sitting in a clinic and patients coming through. We're trying to seek people out in their daily lives. So, finding ways of looking for what we call mediated communication has been a hallmark of my research, pre-digital health. In other words, using the phone as a mediating communication pathway as opposed to face-to-face. That's where my research started. A lot of us have been using telehealth and other phone-based interventions for decades. When the computer really started to come of age, we were looking for ways to have people use portable and handheld audio tools and other kinds of digital devices. I was doing that back in the late 80s, early 90s with the first handheld computers where people were walking around rating their stress levels throughout different parts of their day.

I think the methods have been around for quite a while. What's happened with this acceleration and explosion of different kinds of digital health devices and platforms, is it's really been a watershed for those of us in behavioral science. What's been wonderful at Stanford is that I really feel that it has opened doors of discovery between researchers at Stanford who don't come from a behavioral science background and those of us who are in behavioral science. It's a bridge builder because physicians and other healthcare providers now realize and understand that they can capture what patients are doing out in their real world and during their day.

That's something we've always wanted to do as behavioral scientists, but we've had to rely on self-report and all the problems with that. Now we have simpler ways to capture data in a more reliable and robust manner to understand what people are doing; that has been a paradigm shift for us. At the Stanford Prevention Research Center, which has been around in some form since 1974, researchers have been doing this kind of community-based work, using media and mediated channels of communication to reach diverse groups of people where they live, learn, work, and play. However, this type of community-based work has for many decades flown in some ways "under the radar" at Stanford, not really being understood or connected with a lot of other groups. Now, I think because of this merging of interests about what people do outside of the clinic and the ways we have of measuring that, this has built this bridge, which for me is incredibly exciting.

If you think about it, the landline telephone was one of the most groundbreaking types of devices, yet we don't even think of that as digital health, because it predates the language and jargon of today. The companies and business sector are really driving a lot of this now and they are seeing what they can do with these technologies. It's really exciting to see the support in this field and how it facilitates interdisciplinary work, which many of us have been doing for many, many years. Now, with a number of different disciplines coming together, it's been a lot of fun for me to be connected with engineers, data scientists, and additional disciplines more formally.

What was your entry point into healthcare technology?

I'm a clinical psychologist by training and did my doctoral work in health fields, even though a lot of clinical psychologists don't do that. I was particularly interested in health behaviors, so my training was all about face-to-face, individual, and group instruction. As I went through my training and my clinical psychology residency, it became clear to me that this one person at a time or small group approach wasn't going to have a major impact. Trying to prevent things from happening as opposed to trying to treat them also became clearer to me. Fortunately for me, Stanford had the Stanford Heart Disease Prevention postdoctoral training program. When I was looking for a postdoctoral fellowship in the 1980s, they had one of the few postdoctoral fellowships focused on community-based interventions to prevent and control heart disease and other chronic diseases. That was before this group became the Stanford Prevention Research Center; it was a program that was well funded by the NIH and it was unique. That's how I came to Stanford. I wanted to get out of my clinical psychology "box" and really break down this silo aspect of research and learn how to do interdisciplinary research around major complex problems that require multiple frameworks and perspectives from different types of researchers and community people. My training experience as a postdoc here was wonderful. Here I was, an East Coast person, born in Buffalo, New York, and my husband and I both came to the West Coast to do our two-year postdocs. We thought we would finish and go back east.

"Well, the problem that you get when you come and stay here – we call it the Hotel California syndrome – is that you can check out any time you like, but you can never leave!"

Well, the problem that you get when you come and stay here–we call it the Hotel California syndrome–is that you can check out any time you like, but you can never leave! That's what happened to us and we really wanted to stay. It was incredible – the doors and insights that opened up to someone who's trained in one clinical type of profession and then learns about the vast amount of discovery that could be experienced through linking with other disciplines. So much of what was happening in that heart disease prevention program had to do with communication and media – not sitting with people one-on-one, but using radio, TV, newspapers – all kinds of media pathways that were open at the time, to get out messages that could help to change people's health choices, and their decisions. It just sort of rolled on from there. I connected with Barr Taylor, who is a psychiatrist, who is now emeritus. In the 1980s, Barr had been doing some of the first work with handheld computers. He was using them to help people who were having panic attacks or anxiety disorders to better capture their triggers of panic attacks in their daily lives. He loaned me some of his portable computers that I used to better capture stress responses of family caregivers, people taking care of loved ones with chronic illnesses. That was my first foray into portable, what we would now call a "digital intervention." It just went from there. I found myself seeking out colleagues, most of them not at Stanford, they were in other places (Boston, in particular), who were working with telephone-based interactive voice response systems, embodied conversational agents, and all of these electronic communication platforms that could help people change health behaviors in productive ways without having to necessarily have a heavy human touch. That has been driving a lot of what my NIH research has looked like over the past few decades.

I love pitting humans against computer programs. What we find is that a well-done, behavioral theory-based digital platform often can do about as well as a trained human in helping to change these important health behaviors – things like physical activity, for example. It's very exciting to see that. My latest passion is "citizen science," going even one step further in terms of deputizing residents to be part of the data collection solution and intervention building process; to build the interventions that are going to change their local contexts to promote their own health as well as the health of their neighbors and community.

What kind of digital health technologies are you using in your research and how is your filed evolving?

In my field and in other fields, we've always been aware of what we call the "witches conundrum", which means that there's no one size fits all intervention or treatment and you need to really tailor things to people's interests. That's always been done with a very blunt instrument in the past, based on people's self-report or observation. Because it's been very blunt, we haven't been able to get as robust a change as we would like with some of our interventions, because we really haven't had the chance to do what precision medicine is now doing. In my field I call it precision behavioral medicine; this means choosing which behavioral interventions, for which people, under which conditions. This is where this huge door has opened in my field in now being able to capture those contexts and people's behaviors in real time in ways that are not so onerous to the patients or the residents; digital devices can now replace things like keeping paper logs, etc., which many people hate to do. I think we're going to see an incredible acceleration of knowledge, insights, and solutions in a variety of health fields as part of this whole revolution in digital health.

It's really all about which type of intervention works for which type of person. In some of our research, for instance, with an interactive voice response system, which is telehealth delivered either by a human or by a human sounding computer algorithm, we found no difference overall at the end of 18 months in people's ability to increase their physical activity through either method; both worked well. We also knew that lurking under those group means, however, were subgroups, some of whom would do better or worse with a particular intervention. This is where precision behavioral medicine comes in. What we found is that for people who were a bit reluctant or a little less motivated to change their physical activity coming into our program, they did much better with the human touch and did worse with the computerized touch (even though it has a human voice). Whereas, the people who came in motivated to change did better with the computer touch and actually did worse with the human touch, because sometimes you want the humans to get out of the way and all you need is information and then you can go. But at other times you really need that human touch. Some of the areas that we need to think deeply about are how, where, and when to use the human touch, to optimize our treatments and interventions as well as resources. With the advent of COVID-19, human touch has become particularly important, and digital communication platforms provide an invaluable channel through which people from all walks of life can connect.

What is it about Stanford that allows for these digital health technology initiatives and projects to be successful and to really flourish?

Because I came from public universities, when I first came to Stanford, I was a little put off by the "Stanford, we're the best," mentality. My feeling was that every university has really smart people and that you don't have to be at Stanford or universities like Stanford to be able to do really great work. I think generally that's true, but what I've come to really appreciate is that there is a difference being at a university like Stanford. I think the difference is, it pushes people to push through boundaries, to break boundaries and to pioneer. There is a pioneering mindset that is some parts courage, some parts creativity, that I don't always see in faculty in other places; not that you can't find pockets of people, but the overall zeitgeist here is to be a pioneer. Maybe that's the "Western" way as well; I've never been at an Ivy League School, so I don't know if you'd find the same thing at Yale or Harvard, I'm sure there probably are similarities there. But there's something out here about this pioneering spirit of not being afraid of the unknown and realizing that things are not black and white, that it's a complex shades-of-gray situation. People out here are brave enough to embrace the unknown and embrace the complexity and not try to whittle down your science to a question that is inside your comfort zone. I've had to push outside my comfort zone and my colleagues do that as well, especially now more than ever. I'm not sure if it used to be that way at Stanford, but I think John Hennessy did a lot to unleash some of those forces for good throughout the university and to really try to build the interdisciplinary zeitgeist across the university, which I think has really helped the medical school in many ways.

What do you think about the relationship between Silicon Valley and Stanford?

I would say that when I think about the open-minded, push-the-envelope ideals that some of the leaders in Silicon Valley have come up with, I would put "ground zero" at Stanford and not necessarily Silicon Valley. I think that Silicon Valley reflects the type of brain power, openness, creativity, and courage that Stanford fosters. We see this in undergraduates here, they blow me away. It's an incredible cauldron of diverse intelligence. This fostering of innovation and fearlessness in pushing the limit, this pioneer spirit, to not stick with the status quo, is very present at Stanford. I think this is what a lot of us are running up against with the NIH and some of the current ways that science is being done in the US; there's a lot of people who don't do science this way. They stay within their training and the perspectives through which they were trained to view the world. I think it makes it very hard for innovation to get funded at the NIH these days. The people reviewing don't share that same zeitgeist or same perspective.

What are some of the exciting trends or challenges that you see in digital health over the next 5-10 years?

The thing that's so great about digital health, digital solutions, and digital assessments is that more and more, they are becoming tools that are in every resident's pocket or purse around the world. To me, the most exciting opportunities for digital health have to do with promoting health equity, looking at the digital divide, and making sure that digital health is being used to break down any divides or gaps that we may have – and I think we can do it. That's what a lot of my research has been focused on. It's not just the early adopters of every digital device that's coming down the pipeline that we want to work with. We want to work with people who could really enrich their lives and their health through these tools, and now these tools are finally becoming more and more accessible. Smartphones are the primary type of phone these days. To me, that is the most exciting opportunity. But that means that Stanford and other research groups need to push ourselves to go beyond the people who are seeking us out and already have those innate interests, and really seek out the parts of the community that we don't tend to see that could really benefit. That's what my research has focused on over the past decade. I think citizen science is part of this because residents have so much that they can bring to the table when it comes to scientific questions and advances and how contextually-relevant and action-oriented scientific inquiry can meaningfully impact people's lives – not just 20 years from now, but next week. Our citizen science research program, called the Our Voice Global Initiative aims to engage and empower residents from all walks of life to partner with researchers and local decision-makers in assessing and activating positive, health-promoting changes in their local environments. The initial gateway to this process is a mobile app, called the Discovery Tool, which is supported by an array of digital tools.

We need to look at digital health as something that can potentially improve people's health and lives both in the short term as well as in the longer term. We need to look for the short-term wins, which are one of the goals of this type of citizen science work, as well as the longer-term advances that can shape societies. And we shouldn't neglect simpler digital tools. For example, we just finished a study that looked at Latinos in the Bay Area, 350 Latino adults who were overweight and at increased risk for diabetes

We had texting programs that were tailored to them and their needs, and the texting program worked about as well as a human; people also stuck with it over the course of a year. There's a lot of behavioral science out there that Silicon Valley doesn't know about and is not using, and that is true here at Stanford as well. This mantra about "people only use devices or apps for a few months," well, it's often because there's not enough behavioral strategies built in to these devices and programs. We hear this a lot and it has been the problem that we have been facing as behavioral scientists across decades. Doctors will try something and it won't work and then they'll just summarize it by saying "the patients won't do it, they're not going to adhere," and then they close the book on it. Well, that's our challenge in behavioral science – that's our bread and butter. That's the thing that gets me up in the morning, is how can we change that trajectory.

My point about short-term wins is not just about people using digital programs. For instance, my citizen science work is really aimed at changing environmental infrastructures and policies in people's communities that can impact everybody in that community and can be done within a reasonably short period of time. There are interventions that can work in the short term, as well as those that can work in the long term, and they're not just in the smartphone app space. It's using those technologies to teach people how to get those contextual changes in their local, physical, and social environments that are much stronger predictors of whether someone's going to walk or not, the food choices they make, the stress levels they have, or whether they actually adhere to their blood pressure regimen or their diabetes regimen. Local environmental and policy impacts, which have always had a significant influence on people's health and welfare, have become acutely visible during the COVID-19 pandemic. And helping residents across the socioeconomic spectrum actively participate with researchers and local decision-makers in building livable and safe places to engage in healthy activities during these challenging times is a major focus of my current technology-informed citizen science intervention research. One of our current NIH-funded trials, for example, involves working with ethnically diverse midlife and older adults living in or around Bay Area affordable public housing sites to find safe and enjoyable places and spaces to be physically active. With the advent of the COVID-19 crisis, we were quickly able to convert our community interventions and assessments to entirely remote delivery, thanks to the latest digital communication platforms. Notably, we're finding that these older participants, some who have never used digital communication platforms before, are really enjoying connecting with other participants and our research team in this manner. We have also begun to work with Stanford and community physicians to test our Our Voice citizen science program as a means of bridging the gap between the clinic and the community, in terms of promoting safe ways to engage in healthy behaviors such as physical activity, while having residents inform their healthcare providers about the neighborhood and community barriers getting in the way of doing so.

> "I'm glad to see what appears to be Silicon Valley's increased interest in partnerships and collaborations with researchers. I think that they're increasingly seeing the advantages of bringing evidence to the table, which is good."

Do you feel like there's an unbalanced perception portrayed by the media in the digital health space between the flashy, cutting-edge technologies and the solutions that have been around for decades, like telehealth?

This is something that's really important. I would go a little farther to say that it's not just the media, but it's also been at Stanford. The Medical School has been somewhat late coming to the table when it came to something that wasn't tertiary care that was aimed at very selected populations of patients, where all the innovation was. This has been changing under Dean Minor's leadership, as interdisciplinary initiatives have been expanding here which are aimed at a broader community level and which focus on how we can harness digital health not just for individual patients, but for entire communities. I also think that we need to stay open to low-tech, low-touch as well as high-touch options; we need to come up with as many alternatives in treatment and programs as we can. Some of them are going to be low-tech/low touch, low-tech/high touch, all types of combinations, but we really need these alternatives if we want to meet the dean's goals of precision health and not just precision medicine.

We recently completed a thorough review of the field for the Department of Health and Human Services 2018 physical activity guidelines for the nation – which reflects how physical activity has really come into its own. It used to be the most understudied health behavior out there. People saw it as recreational and "light-weight." It wasn't taken as seriously as tobacco, diet, or other health behaviors, which has been problematic. The latest data show how much of an impact regular physical activity can have on people's health, function, and well-being across the age spectrum. It warms my heart to see how many of my Stanford colleagues are getting into physical activity research because of the accelerometer and similar wearable devices. Now we have a method that can be readily used to capture data around daily physical activity. I think it's going to broaden all of our horizons. In the literature review for the physical activity guidelines, there were relatively few scientific reviews that actually looked at texting, something fairly simple which virtually everybody can do. That's one of the reasons why we wrote that grant to the NIH to look at it, to put it up against the human telehealth touch, because there's been relatively little evidence and that's what we have to really hone in on – what's the evidence behind some of the products that Silicon Valley and other groups are making and how can we bring the evidence to the table?

I'm glad to see what appears to be Silicon Valley's increased interest in partnerships and collaborations with researchers. I think that they're increasingly seeing the advantages of bringing evidence to the table, which is good.

> "It warms my heart to see how many of my Stanford colleagues are getting into physical activity research because of the accelerometer and similar wearable devices. Now we have a method that can be readily used to capture data around daily physical activity. I think it's going to broaden all of our horizons."

Natalie Pageler, MD

Clinical Professor, Pediatrics Critical Care Clinical Associate Professor, Medicine - Biomedical Informatics Research

Clinical Associate Professor (By Courtesy), Pediatrics - Systems Medicine

Natalie Pageler, MD

How would you define digital health?

That's a great question and I think you can get a million different answers. It depends on the context. Digital health can encompass anything from clinic-to-clinic telehealth to virtual visits with a patient at home to asynchronous visits – either e-consults, where there is asynchronous messaging going back and forth between a primary care provider and a specialist, or e-visits, where a patient and a provider message directly. An example of an e-visit would be a patient sending a picture of a rash and asking for a diagnosis and treatment based on imaging. Remote monitoring also usually gets included in the concept of digital health. Remote monitoring may include things like continuous glucose monitoring of a teen with type-1 diabetes, at-home blood pressure checking for a pediatric renal patient, and oxygen saturation and weight monitoring for babies with congenital heart disease. Digital health may also include how we analyze and think about incorporating that data into healthcare plans.

That is what I consider in my definition of core digital health, but it sometimes also includes things like machine learning and artificial intelligence (AI). Sometimes virtual reality and augmented reality are lumped into the category of digital. It is one of those terms that is used in a variety of settings, with slightly different meanings in each setting.

Have you always been involved in technology and health? What was your entry point into digital health?

There was a bit of serendipity involved. I did my undergraduate degree in engineering physics at the University of Arizona and have always had an interest in science and technology. During my undergraduate degree, I did not predict that I would end up in the role that I'm in now. In fact, I didn't even know that it existed or what this field would be. I think the field of applied clinical informatics has evolved quickly over the last couple of decades. I came to Stanford medical school and stayed to complete my pediatric residency and pediatric critical care fellowship. I was doing a master's in medical education during my pediatric critical care fellowship and was exposed to clinical informatics during an elective. I ended up focusing my master's thesis on the application of clinical decision support in the EHR as a form of just-in-time education for providers.

That's what got me into the informatics side of my career, and it was a fascinating time to be in applied clinical informatics. Shortly after I came on board as faculty, we decided to do a major EHR conversion. I took an active role in leading that implementation. Simultaneously, applied clinical informatics became an ACGME board-certified specialty and during the implementation, our team became the first class of board-certified clinical informaticists, and started the first ACGME board-certified clinical informatics fellowship in the nation at Stanford in 2014.

There are now more than 40 fellowships across the nation, and Stanford has the largest fellowship with four new fellows starting this year.

How would you say digital health contributes to your motivation to keep learning and growing as a physician? How can digital health mitigate some of the issues with physician burnout?

There is a lot changing in the field of medicine, including the implementation of information systems. When you look at the rise of physician burnout, there are multiple different factors that impact burnout. These include changing regulatory context and the increasing amount of information physicians need to be aware of. Also, the new information systems physicians need to learn have a huge impact on people who have already been well established in their practice; suddenly they have to accommodate these new systems and it impacts everything. There are definitely opportunities to continue to improve the user interface and training on these systems.

Medicine is a rapidly evolving field and the information systems that are being implemented are significantly and quickly changing the way we practice. This rapid evolution can suddenly add another system that people need to learn and it can change the way that a health system functions, especially as some systems have shifted the burdens of work to providers – work that may have been done by other members in the past (whether or not that was appropriate). These systems also enable the enforcement of regulatory specifications or billing requirements. A lot of these individual elements that were expected to be done but not audited, became mandatory and easily audited. Additionally, there has been a great effort to standardize the practice of medicine for many good reasons. We know that one of the components of fulfillment in any career is a sense of mastery and autonomy. Some of the attempts to standardize practice through the EHR through defined order sets and pathways can have a negative impact on feelings of mastery and autonomy.

> The types of careers that physicians have in the future and the types of roles that physicians play in the future will continue to evolve. It's absolutely critical that we, especially at Stanford, continue to develop the next generation of healthcare leaders and continue to support the changing education model and model of practice in healthcare.

I think our practice is evolving quickly, our information systems are evolving quickly and having a huge impact on our practice. The types of careers that physicians have in the future and the types of roles that physicians play in the future will continue to evolve. It's absolutely critical that we, especially at Stanford, continue to develop the next generation of healthcare leaders and continue to support the changing education model and model of practice in healthcare.The amount of knowledge that a physician should know in order to optimally treat patients is growing so quickly, to a point where there is no way that any one human being can stay up to speed on all the latest information. Our information systems are going to play a more critical role. I can see the role of some physicians changing from the individual practitioner who is expected to know every piece of information and apply it directly to patients, to someone like an applied clinical informaticist who is expected to evaluate the latest literature and figure out how to incorporate it into the system to support the delivery of care by other people. There's great literature, especially in applied clinical informatics, on the unintended consequences of any implementation of an information system. The same goes for the implementation of any change in practice; we know there are going to be unintended consequences. It's critical that we study those rigorously and identify both the negative unintended consequences and the serendipitous, positive, unintended consequences, so that we can continue to optimize our information systems and the system of care delivery.

What is it about Stanford that allows for these digital health innovations to really flourish and be successful?

I'll focus on the pediatric aspects, because I think we are in a very unique situation here. To start with, looking at digital health as a whole, we are on the Stanford campus, in Silicon Valley, which affords us some incredible resources and access to incredible minds. Stanford has a long history of advanced data science, machine learning, and AI experts across the campus. The biomedical informatics program is one of the oldest in the nation and has been leading work like this for years. We are also in Silicon Valley, where you have the tech industry and folks that have come from Stanford or other excellent academic organizations and gone into industry or vice versa. The crossover between the university and the tech industry provides very rich fodder for digital health development. We also have a dedicated children's hospital, with its own foundation and board focused on elevating the quality of care for pediatrics and obstetrics. The focus, agility, and autonomy afforded to us by being a dedicated children's hospital lets us really push the boundaries in pediatric digital health. There are unique needs for children and pregnant women. Children make up only about 8% of the US spending on healthcare, but pediatric patients are about 20-25% of the population, and 100% of us were children at one time. If we make an impact in pediatric care, we can affect health for a lifetime. Because children generally are fairly healthy, you have to have access to a much larger population to support the high quality, tertiary care that we have here at the children's hospital. This means that children with chronic diseases may come from very far distances, which can be very disruptive to their development. Digital health becomes an absolute imperative in order to provide them the quality of connected care they need and minimize the disruption of their lives and otherwise normal development. Because there are fewer sick children and fewer care centers for children, children's hospitals are relatively few and far between, so learning from other pediatric hospitals can be a little bit more challenging. Some of the unique things we've done include telesurgery, where we've had experts that we were trying to learn from in Texas, connecting via telehealth (into the operating room) and guiding one of our obstetrics surgeons to do a fetal surgery. The physicians in Texas could see the surgeon, watch what they were doing, and then guide them over the speaker in the OR, helping him do his first case on his own, from a distance. Our pediatric radiologists have shown similar ingenuity in creating shared learning across children's hospitals. Safwan Halabi has worked on a bone-age AI study with six different children's hospitals to do a randomized controlled trial of a bone-age algorithm implemented in radiology practice to determine the effect on clinical care. This study was possible because of the Stanford AIMI program and our advanced informatics capabilities that facilitate integration of the algorithm into our health information systems.

What do you envision for the field of Digital Health over the next 5 years?

I think we're going to continue to see a lot more patient and family empowerment and more mobility of patients and families that we have to be ready for. We have to be able to provide them with the information and data they need about their care, so that they have it when they need it and can interact with other companies and organizations as appropriate to make sure their care is seamless. We need to also continue to optimize treatments and care delivery models at Stanford Medicine to help patients and families to achieve their healthiest possible lives. I think we're going to continue to see interoperability and empowerment of patients and families play a huge role. We need to think about how we're going to be part of that and enable our patients and families to have access to and understand information related to their healthcare journey. Especially for pediatric patients that come from distant locations and then return home, we need to ensure that we are providing streamlined care, communicating back to their primary care providers, and empowering patients/families with information that will enable them to live healthy lives wherever they go and whatever they do in the future.

CENTER OUTREACH INITIATIVE

In aggregating data from across the Stanford ecosystem, we found that a large majority of teams, centers, groups, labs, and departments were conducting research and working on projects in the field of digital health. After speaking with 32 of these groups, we also found that a number of them had been collaborating for years on projects and leveraging each other's strengths in order to expand their capabilities and explore new areas. We hope that highlighting these groups will illustrate the diverse strengths and culture of collaboration that is found throughout the broader Stanford Community. The Center Outreach Initiative is an ongoing process that will continue to expand over time. Our goal is to be as all-encompassing as possible, so if you would like to add your group to this Stanford digital health organizational database, please reach out to digitalhealth@stanford.edu.

Digital Health at Stanford: CDH Collaborator Network

1. **Precision Health and Integrated Diagnostics (PHIND)**
2. **Stanford Center for Clinical Research (SCCR)**
3. **SPARK**
4. **Population Health Sciences (PHS)**
5. **Clinical Excellence Research Center (CERC)**
6. **Mobilize**
7. **Center for Reliable Sensor Technology-Based Outcomes for Rehabilitation (Restore Center)**
8. **Stanford Center for Clinical and Translational Education and Research (Spectrum)**
9. **Stanford Byers Center for Biodesign**
10. **VA Health Economics Resource Center (HERC)**
11. **Computational Arrhythmia Research Lab**
12. **Bio-X**
13. **SHIFT**
14. **Mental Health Technology and Innovation Hub**
15. **Systems Utilization Research for Stanford Medicine (SURF)**
16. **Center for Innovation in Global Health (CIGH)**
17. **eWear**
18. **AIMI (Center for Artificial Intelligence in Medicine and Imaging)**
19. **Center for Biomedical Informatics Research (BMIR)**
20. **Wearable Health Lab**
21. **Office of Industry Relations and Digital Health (IRDH)**
22. **Human-Centered Artificial Intelligence (HAI)**
23. **Department of Biomedical Data Science (DBDS)**
24. **Institute for Economic Policy Research (SIEPR)**
25. **Quantitative Sciences Unit (QSU)**
26. **Department of Epidemiology and Population Health (E&PH)**
27. **Stanford Data Science Initiative (SDSI)**
28. **Stanford AI Lab (SAIL)**
29. **AI for Health**
30. **Research Informatics Center (RIC)**
31. **Stanford Health Care: The Digital Health Care Integrations Team (DHCI)**
32. **Stanford Children's Health Lucile Packard Children's Hospital Stanford: Digital Health Team**

Precision Health and Integrated Diagnostics (PHIND)

Description

The Precision Health and Integrated Diagnostics (PHIND) Center is the first center in the world focused on precision health and integrated diagnostics. The PHIND Center plays a critical role in mobilizing the components needed to advance this new vision of healthcare. It develops, tests, and disseminates the next generation of healthcare mechanisms for precision health. Whereas precision medicine is focused on the treatment after the manifestation of disease, precision health is focused on early prediction and prevention of disease onset.

The PHIND Center integrates diagnostic information collected from multiple sources both on the body, and in one's home. It also studies the fundamental biology underlying early transitions from health to disease and the associated biomarkers (molecules) of health and early disease.

Funding

$40M TO DATE

(Not including government funding or other funding that may have been generated by PHIND funded projects)

The Center aims to fundamentally revolutionize healthcare, leading to better and more productive lives for individuals, by integrating several key areas including:

- Risk Analytics to predict risk of specific disease(s) for a given individual
- Fundamental studies on the biology of disease initiation/progression to understand the earliest transitions from healthy humans, organs and cells to the disease state
- Biomarker research to study the molecules that indicate healthy states and early signs of disease
- Diagnostic technology and information to accurately monitor and detect health changes early, such as collecting and analyzing information from multiple sources on the body and in the home, office or wider community
- Health economic analyses for precision health strategies to show savings to the health care system for pursuing various precision health efforts

Key Stats

Established	People	Digital Health Projects	Digital Health Publications
2017	92	34	14

Key Personnel

Sanjiv Sam Gambhir, Oliver Aalami, Zhenan Bao, Garry E. Gold, Ian H. Gotlib, Michael Snyder, Pablo Paredes Castro, Russ Altman, Jan Liphardt, Christina Curtis, Scott L. Delp, Manisha Desai, Christopher Gardner, Andrew Gentles, Anthony Wagner, Trevor Hastie, Dennis Wall, Paul Yock, Anshul Kundaje, James Landay, Jamie M. Zeitzer, Robert Tibshirani, and Ryan Spitler

Key Projects

Project Baseline; Wearable Wireless Sleep Monitoring System for Precision Health; Detection and Prevention of Autism Through Wearable Artificial Intelligence and Multimodal Data Integration; Multidimensional Predictors of Major Depressive Disorder and Suicidal Behaviors In Adolescents; Precision Diets For Diabetes Prevention; Non-Invasive Cancer Detection from cfDNA via Deep Learning Analytics; Assessment of Early Knee Osteoarthritis using Low-cost, Rapid, and Multimodal Imaging and Biomechanics; Predicting Health in Aging (PHIA); A Real-Time Continuous Biochemical Sensing Platform; Novel EEG Biomarkers of Sleep Health: A Machine Learning Study; VascTrac: Passive Mobile Screening for Peripheral Artery Disease as Biomarker and Risk Assessment Tool for Cardiovascular Disease; The Smart Menstrual Pad for Precision Health Screening in Women; Mining Digital Life for Precision Prediction, Prevention & Early Detection; Precision Diagnostic and Prediction of Food Allergy; Additional AI, Sensor, Mobile App Development in the context of Precision Health.

Commercialized Projects

- Vision Article: featured on the cover of Science Translational Medicine
- The Smart Menstrual Pad for Precision Health Screening in Women: company spun-off
- Automated detection of cerebral ischemia to reduce disability and morality: patent filed

Funding

Sources: Stanford internal commitment, NIH and other related government RFAs, industry sponsorships, gifts, foundation RFAs, industry affiliates program

Collaborations

Past collaborations:

- Industry (Google, Verily, Philips, Micron, VivaLNK, GE); other universities (Duke, UK Biobank, UCSF, Harvard)
- International collaborations: Not yet, but open to this type of collaboration
- Open to exploring multiple models of collaboration with others

Grants, Courses, and Programs

- Monthly seminar series
- Annual symposium
- Industry affiliate program
- Opportunities for sponsored research and gifts to support mission

In Memoriam: Sanjiv Sam Gambhir, MD, PhD

November 23, 1962 – July 18, 2020

Professor and Chair of Radiology at the Stanford School of Medicine

Director, PHIND Center at Stanford

"Sam was a true visionary and a scientist of the highest caliber. His research and innovations have, with no uncertainty, founded modern medicine's approach to early disease diagnostics and will continue to guide the future of precision health," said Lloyd Minor, MD, dean of the School of Medicine. "Sam's contributions to Stanford, to human health, to the science of diagnostics and to the many lives he has touched and impacted throughout his career have been immeasurable."

Dr. Sanjiv Sam Gambhir was a global pioneer of technique development for molecular imaging and early cancer detection. He was admired as someone who not only had extensive expertise and dedication to his field, but showed genuine kindness to those around him. During his 17 years at Stanford, Gambhir chaired the Department of Radiology, established and directed the Precision Health and Integrated Diagnostics Center (PHIND), directed the Molecular Imaging Program at Stanford, directed the Canary Center at Stanford for Cancer Early Detection, and was involved in numerous other initiatives and projects. Dr. Gambhir also co-led the Innovative Medicines Accelerator, a program that came from Stanford's Long-Range Vision and focused on finding ways to accelerate the transformation of scientific discovery into tangible clinical progress.

Apart from his academic work at Stanford, Gambhir's focus on early cancer detection led to many great advances in healthcare. His vision that research should be proactive, rather than reactive is mirrored in many of his initiatives. Born out of this vision was the Precision Health and Integrated Diagnostics Center at Stanford, a multidisciplinary group dedicated to preventive medicine and the early detection, identification, and tracking of disease.

A direct application of PHIND's focus on passive monitoring and precision health was seen in Dr. Gambhir's most recent innovation– a "smart toilet." This novel technology monitors a user's stool and urine in an effort to detect early signs of disease. His unusual background, a physicist-mathematician turned physician-scientist, unique approach to advancing research, and passion for understanding and improving the health of the individual will continue to inspire others and live in his legacy forever.

Stanford MEDICINE | Center for Clinical Research

Stanford Center for Clinical Research (SCCR)

Description

The Stanford Center for Clinical Research's mission is to advance impactful clinical research through quality operations; this is achieved by leveraging the physical and intellectual resources of Stanford University and its affiliated teaching hospitals and clinics. SCCR partners with a broad range of faculty with expertise in diverse therapeutic areas.

Digital Health Publications

- "Rationale and Design of a Large-Scale, App-Based Study to Identify Cardiac Arrhythmias Using a Smartwatch: The Apple Heart Study"
- "Large-Scale Assessment of a Smartwatch to Identify Atrial Fibrillation"

In preparation:

- SmartAdhere
- SmartGuide

Key Projects

Project Baseline; SmartAdhere; SmartGuide; Apple Heart Study 1.0 and 1.2; DECIDE, Stanford-Taube Athletic Studies

Executive Leadership

Ken Mahaffey, Toni Nunes, Rebecca McCue, Nadia Elkarra

Collaborations

Stanford collaborations
IRT; Quantitative Sciences Unit; Center for Digital Health; SPECTRUM; IRDH, Privacy, Risk, OGC, RMG, IRB; faculty across Stanford University, including: CVMed, Radiology, GI & Hepatology, Bioengineering, ChemH, Bioinformatics, Biomedical Data Science, Neurology; industry (tech, pharma, etc.); commercial vendors; patient-advocacy groups; Community Advisory Board for Clinical Research

Domestic and international collaborations
Industry, AROs, CROs and academic institutions. Featured collaborations include: Genae; George Clinical; Duke University (DCRI); University of Colorado (CPC); Baim Institute; Canadian Vigour Centre

Funding

$110M ANNUALLY

Sources: Industry, government agencies, foundations, nonprofits and philanthropy

Key Stats

Established	People	Digital Health Projects	SCCR projects
2014	75	7	190

SPARK
AT STANFORD

SPARK

Description

The Stanford SPARK program was established to advance new biomedical research discoveries into promising new treatments and diagnostics for patients. SPARK emphasizes new ways of thinking about bridging the gap between bench and bedside, and is a unique partnership between university and industry experts.

Collaborations

- Collaborations and advisors from Industry
- International collaborations: There are ~70 SPARK Global locations in the US and across the globe (Africa, Americas, Asia, Europe, Oceania)

Grants, Courses, and Programs

Courses
CSB 240 and 242

Programs
SPARK weekly evening seminar (10months/year); Drug Discovery Innovation (Director: Rieko Yajima)

Call for proposal
Once a year for seed funding and mentoring

Key Personnel

Daria Mochly-Rosen, Kevin Grimes, Peter Santa Maria and Rieko Yajima

Key Projects

Precision Care For Autism Through Wearable Artificial Intelligence; Diagnostic For Prediction Of Severe Dengue; Novel Optical Imaging Agent of Cardiac Conduction System for Use During Heart Surgery; Platform Technology For Delivery of DNA and RNA Therapies; Platform To Enhance Therapeutic Gene Targeting; Molecular Imaging Of Bacterial Infection; Multiplexed Pathogen Detection; Small Molecule Screening For Neurodegenerative Diseases and cancer; Network analysis for discovering of novel drug targets; Using pathways to motivate drug repurposing for schizophrenia; Data driven diagnostic used in psychiatry; Empirical assessment of bias in machine learning diagnostic test accuracy studies.

Commercialized Projects

- 43 startups and 17 clinical trials
- SPARK successfully translated 61% of projects to the clinical and commercial sectors.

Key Stats

Established	People	Digital Health Projects	Digital Health Publications
2006	11	3-5	10 (Dennis Wall) 4 (Yuan Jin Tan)

Stanford | Center for Population Health Sciences
Community Engagement | Data | Education | Research

Population Health Sciences (PHS)

Description

The Center's mission is to improve the health of populations by bringing together diverse disciplines and data to understand and address social, environmental, behavioral, and biological factors on both a domestic and global scale. The overall strategy is built on four pillars: (1) collaboration and community; (2) research resources; (3) translation; (4) education and training.

Grants, Courses, and Programs

- 29 Population Health-related courses
- PhD programs
- Research training programs
- Fellowships, graduate advising faculty mentorship, pilot grants

Funding

$15M

Sources: NIH, Alfred P. Sloan Foundation, Bill & Melinda Gates Foundation, internal Stanford funding

Key Personnel

David Rehkopf, Melissa Bondy, Lesley Sept, Lorene Nelson, Lisa Chamberlain, Latha Palaniappan, Lisa Goldman Rosas, Suzanne Tamang

Key Projects

Some of our most productive projects, such as the American Family Cohort and the Danish Registers at University of Aarhus, are consortium based. Full details are available in publications from David Rehkopf and Suzanne Tamang.

Collaborations

Collaborations
Aarhus University and the Danish Registers; Avon Longitudinal Study of Parents and Children (ALSPAC); Born in Bradford; Danish National Biobank; FSRDC; INDEPTH Network; Abdul Latif Jameel Poverty Action Lab (J-PAL); Solano County Public Health Department; Research Centre for Toxic Compounds in the Environment (RECETOX), The American Board of Family Medicine

International collaborations
India; Great Britain; Denmark, Born in Bradford, Aarhus University

Key Stats

Established	People	Digital Health Projects	Digital Health Publications
2015	1650	SEVERAL HUNDRED	75

Stanford MEDICINE | Clinical Excellence Research Center

Clinical Excellence Research Center (CERC)

Description

CERC is the first university-based research center exclusively dedicated to discovering, testing, and evaluating cost-saving innovations in clinically excellent care. Their research seeks more affordable ways to deliver better care for conditions consuming the bulk of the country's healthcare spending. In collaboration with the Stanford AI Lab, CERC is using passive imaging and audio sensors to train algorithms to detect, and trigger real time correction of shortfalls in intended care and self-care for patients in fragile health states.

Key Personnel

Ehsan Adeli, Dan Azagury, William Beninati, Roger Bohn, Jill Glassman, Albert Haque, Andrea Jonas, Jeff Jopling, Kyung Mi Kim, Amit Kushal, Fei-Fei Li, Jia Li, Vincent Liu, Alan Luo, Arnold Milstein, Juan Carlos Niebles, Griffin Olsen, Mark Ott, Francesca Rinaldo, Lee Sanders, David Scheinker, Kevin Schulman, Nigam Shah, Nirav Shah, Sara Singer, Paul Tang, Vittavat Termglinchan, Jiayin Xue, Serena Yeung

Funding

$3.5M ANNUALLY

Sources: Foundation grants, Tier 2 hospital funding, private philanthropy, National Science Foundation

Grants, Courses, and Programs

- Sponsored research projects
- Education/Curriculum and Fellowship
- Affiliate program
- Hosted AI-assisted Healthcare Research Symposium in Fall 2019 with NSF, Amazon, Nature Medicine, and Moore Foundation

Key Projects

Partnership in AI-Assisted Care (PAC); Intelligent Hand Hygiene; Intensive Care Unit Clinical Pathway Support; AI-Assisted Surgical Technique; Predicting Health Crises; Computer Vision and Ambient Intelligence in Senior Care; AI in Behavioral Health Screening; AI Support in Parenting.

Collaborations

Past collaborations
Industry affiliates and collaboration; other Stanford centers (Partnership in AI-Assisted Care collaboration with Stanford Computer Science Department AI Lab)

International collaborations
Denmark; Thailand

Research sites
Palo Alto, San Francisco, Salt Lake City, and Bangkok

2 companies founded

Key Stats

Established	People	Digital Health Projects	Digital Health Publications
2011	44	7	16

Mobilize

Description

The Mobilize Center is an NIH-funded Biomedical Technology Resource Center (BTRC) whose mission is to advance the state-of-the-art in biomechanical and machine learning models for understanding human movement across a wide range of conditions. The Center's tools generate new insights from diverse datasets, including clinical notes, time-series data from smartphones and wearable sensors, medical images, and videos acquired from clinical labs as well as consumer devices.

Key Projects

Software tools, including Snorkel for machine learning of text, images, and time-series data; R tools for extracting gait events using deep neural networks; machine learning model for estimating true effect size of single event multilevel surgery in children with cerebral palsy; OpenSim for biomechanical modeling including via inertial measurement units and other wearable sensors, Video based gait analysis, Deep learning for medical images, Accurate prediction of metabolic or energetic costs from wearable sensors; Monitoring bone and muscle loads via wearable sensors, Detecting freezing of gait events in individuals with Parkinson's Disease from neural recordings and wearable sensors

Grants, Courses and, Programs

Data-sharing consortium for movement data

Key Personnel

Scott Delp, PhD, Trevor Hastie, PhD, Christopher Ré, PhD, Sreve Collins, PhD, Helen Bronte-Stewart, MD, MS, Joy Ku, PhD, Jennifer Hicks, PhD

Collaborations

Past collaborations
Industry; academia; and the general public; including: Azumio, MyFitnssPal (Under Armour), Stanford Biodesign, other NIH Big Data to Knowledge Centers of Excellence

Commercialized Projects

Projects are open-source

Funding

~$12M OVER THE PAST 5 YEARS

Sources: NIH

~$6M OVER THE NEXT 5 YEARS

Sources: National Institute of Biomedical Imaging and Bioengineering (NIBIB) and the Eunice Kennedy Shriver National Institute of Child Health and Human Development (NICHD), NIH

Key Stats

Established	People	Digital Health Projects	Digital Health Publications
2014	20+	15+	100+

Center for Reliable Sensor Technology-Based Outcomes for Rehabilitation (Restore Center)

Description

The Center for Reliable Sensor Technology-Based Outcomes for Rehabilitation (RESTORE) will establish vital research infrastructure to enable rehabilitation scientists to use mobile sensors to monitor a diverse set of real-world outcomes. The RESTORE Center integrates expertise from statistics, computer science, bioengineering, mobile health, and clinical rehabilitation. It will provide a suite of software tools and validated easy-to-use, standardized workflows for extracting meaningful metrics from mobile sensors and for analyzing large datasets within rehabilitation research. It will also provide resources, such as a pilot project program, to establish a vibrant research community.

Funding

~$4M

OVER THE NEXT 5 YEARS

Sources: Eunice Kennedy Shriver National Institute of Child Health and Human Development (NICHD) and the National Institute of Neurological Disorders and Stroke (NINDS), NIH

Key Personnel

Scott Delp, PhD, Trevor Hastie, PhD, Matthew Smuck, MD, Maarten Lansberg, MD, PhD, Joy Ku, PhD, Jennifer Hicks, PhD

Key Projects

Easy-to-use software workflows for rehabilitation researchers to estimate common real-world outcome measures; Machine learning and biomechanics model-based tools to (i) monitor and provide feedback on home-based rehabilitation and (ii) quantify rehabilitation outcomes

Grants, Courses, and Programs

- A pilot project program will provide funds to promising investigators
- A fellows program will create hubs of expertise around the country and world
- Scientific challenges will foster collaboration between rehabilitation researchers and experts from other domains, such as machine learning and robotics

Key Stats

Established	People	Digital Health Projects
2020	10+	5+

Stanford MEDICINE | Spectrum The Stanford Center for Clinical and Translational Research and Education

Stanford Center for Clinical and Translational Education and Research (Spectrum)

Description

Spectrum is a Stanford University independent research center funded in part by an NIH Clinical and Translational Science Award (CTSA). Its goal is to accelerate and enhance medical research, from basic discovery to improved patient care. Spectrum's core mission is to transform the research and educational enterprise at Stanford University in order to optimally support clinical and translational research (CTR). Spectrum uses the outstanding and diversified interdisciplinary resources of the University to streamline, accelerate, and promote the translation of basic discoveries into practical solutions that improve human health in the community, and to educate the next generation of CTR leaders to ensure more effective translation in the future. These goals are being achieved through a series of coordinated and transformative changes in our educational and mentoring programs, institutional governance structure, research support infrastructure, and the institutional culture overall. By catalyzing interdisciplinary research, developing educational programs, providing support services, and innovating methods and processes, Spectrum advances the translation of biomedical discoveries into interventions that improve health.

Key Personnel

Ruth O'Hara, Rajnesh Prasad, David Magnus, Lisa Goldman-Rosas, Rebecca Osborne, Jennier Swanton Brown, Ying Lu, Manisha Desai, David Rehkopf, Harry Greenberg, Kenneth Mahaffey, Steven Asch, Steven Goodman, Mark Pegram, Karl Sylvester, and Nigam Shah

Key Projects

Underneath the umbrella of Spectrum are SPARK (therapeutics), Stanford Biodesign (med tech), SPADA, and Population Health Sciences. SPADA has funded several digital health projects, such as: Monitoring Head Impact Exposure and Predicting Neurological Deficit using an Instrumented Mouthguard; VascTrac: A Peripheral Artery Disease Remote Monitoring Platform; Applications and Validation Assessments of Consumer Mobile & Wearable Devices and Mobile Applications for Sleep Monitoring; A Mobile Autism Initiative (AMARI) to Detect Autism Spectrum Disorder in Bangladeshi Children Under the Age of 4.

Commercialized Projects

Several, including:

- Tear Duct Stimulator for Dry Eye (TrueTear)
- Home Asthma Monitor (Tueo Health)
- Clinical Research Consent Videos (ROMP Ethics

Key Stats

Established	People	Digital Health Projects
2008	200+	100

STANFORD BYERS CENTER FOR BIODESIGN

Stanford Byers Center for Biodesign

Description

The Stanford Byers Center for Biodesign was founded to create an ecosystem of training and support for Stanford University students, fellows, and faculty with the talent and ambition to become health technology innovators. Biodesign's goal is to look beyond research and discovery to provide the knowledge, skills, mentoring, and networking required to deliver meaningful and valuable innovations to patients everywhere. When Stanford Biodesign was founded in 2000, the initial focus was on "medical technology," which was largely medical devices such as catheters and implantables. Over time that focus has expanded, and Biodesign trainees now invent a broad range of solutions to problems in care including device-based diagnostics, health information systems, traditional devices with a digital component, and pure digital health solutions. Digital health is a growing part of the solution landscape.

One of the key focus areas is bridging the gap between traditional medical device development and digital health innovation by providing expertise in the evolving regulatory landscape for digital health products, clinical evidence parameters for regulatory approval, and expertise in business model development and payment/reimbursement planning. Digital health innovation case studies can be found online. Also, an article on digital health innovation authored by Biodesign director Paul Yock appeared in Fast Company.

Key Personnel

Paul Yock, Gordon Saul, Lyn Denend, Oliver Aalami, Michelle de Haaff, Ryan Spitler, and Shiqin Xu

Funding

Sources: Corporate sponsors, foundation and philanthropic funding, and grants

Collaborations

Past collaborations
Industry professionals; Center for Excellence in Clinical Research (CERC); Center for Digital Health (CDH); the Biodesign Club; SHIFT; Health++ Hack-a-thon.

International collaborations
Singapore (JagaMe); Japan (Remohab)

Key Stats

Established	People	Digital Health Publications
2000	72	1

Key Projects

Zio Patch by iRhythm, a wearable heart rhythm monitor for arrhythmia detection and diagnosis and the first solution to a problem in healthcare with a digital health component; the graduate/undergraduate course, Biodesign for Mobile Health (now called Biodesign for Digital Health), one of the first to focus on the development of digital technologies to solve important unmet medical needs; Building for Digital Health, a new course currently piloted to help researchers and physicians in the hospital advance their digital health projects; coaching and mentoring at Stanford and beyond for digital projects that come out of Biodesign. CardinalKit, an open source platform and codebase for digital health research and applications in which we provide a suite of tools to build a digital health experience from the ground up, from the app itself to storing collected data in the cloud. CardinalKit is the content for Building for Digital Health, a new course to help researchers and physicians in the hospital advance their digital health projects, as well as Biodesign's monthly workshops

Commercialized Projects

- AVA: air pollution and respiratory health
- Cala Health: wearable therapy for hand tremors
- EMME: reproductive health
- iRhythm: arrhythmia detection and diagnosis
- Lully: night terrors
- MUVR: wearable device to help knee surgery patients' complete therapy accurately and completely
- Tueo Health: pediatric asthma management
- Vynca: advance care planning

Grants, Courses, and Programs

- BIOE273 Biodesign for Digital Health
- CS253 Building for Digital Health
- BIOE374 A/B Biodesign Innovation
- Biodesign Innovation Fellowship
- Biodesign Faculty Fellowship
- Grant programs include: Spectrum Medtech Grants, Stanford-Coulter Translational Research Grants, Biodesign extension funding, Biodesign NEXT

Health Economics Resource Center

VA Health Economics Resource Center (HERC)

Description

The mission of the VA Health Economics Resource Center (HERC) is to increase the quality of VA health economics research so that the nation and the nation's veterans may get the best possible health care value from available resources.

Collaborations

Past collaborations
Department of Health Research and Policy Stanford School of Medicine; Center for Primary Care and Outcomes Research/ Center on Health Policy, Stanford University; VA Center for Innovation to Implementation; Stanford Department of Psychiatry; Stanford Department of Pediatrics; Stanford Department of Surgery, Johns Hopkins University

Funding

$4.2M

Sources: A Health Services Research & Development (HSR&D) Service, NIH, and other sponsors

Key Personnel

Todd Wagner, Ciaran Phibbs, and Yoko Ogawa

Key Projects

Telehealth Evaluation; The Economic Effects of Mobile Health on Access; Telemedicine Outreach for Patients with Chronic and Mental Illness, COVID Analysis examining whether medications that veterans are taking when admitted place them at higher or lower risk for poor outcomes while in the hospital (intubation, ventilation and death)

Grants, Courses, and Programs

Cyberclasses and cyber seminars for VA health economics researchers

Key Stats

Established	People	Digital Health Projects	Digital Health Publications
1999	23	10+	30+

COMPUTATIONAL ARRHYTHMIA
RESEARCH LABORATORY

Computational Arrhythmia Research Lab

Description

The mission of the Computational Arrhythmia Research Lab is to develop bioengineering solutions to improve the therapy and management of patients with complex heart rhythm disorders (arrhythmias) by clarifying mechanisms. Our focus has been NIH-funded and industry funded studies with the goal of bidirectional translation from basic science mechanisms to and from patients. Our disease focus is complex arrhythmias, specifically human atrial fibrillation (AF) and ventricular fibrillation (VF).

Key Personnel

Sanjiv Narayan MD PhD (Director), Kathleen Mills, BS (Lab Manager), Gerri O'Riordan, RNP (Research Coordinator), Prash Ganesan, PhD (Post-doctoral Fellow), Kian Waddell, MS (Pre-doctoral fellow/ Research Associate)

Funding

~$1M ANNUALLY

Sources: NIH

Other Funding

Typically ~$50k-$100k/year

Sources: AHA, HRS, Fulbright Foundation, Industry, Philanthropy

Key Projects

Detailed Electrophysiological Characterization of Human Atria and Ventricles; Novel Electrogram Analyses.

Grants, Courses, and Programs

- Research fellowships
- Journal clubs
- Arrhythmia Center Symposia, Annually at the time of the EP in the West Conference
- Stanford Bioengineering BIOE 390
- Stanford Medicine DOM 289
- Berkeley Bioengineering lectures BioE 290-I, 252

Collaborations

Past collaborations: Academics; clinicians

International collaborations: UK; Spain; France; Germany; Netherlands; Taiwan.

Key Stats

Established	People	Digital Health Projects	Digital Health Publications
2001	10-15	5+	100+

Patents Include

- Method and Apparatus for Classifying and Localizing Heart Arrhythmias
- System And Method For Reconstructing Cardiac Activation Information
- Methods for the Detection And/Or Diagnosis Of Biological Rhythm Disorders
- System And Method For Reconstructing Cardiac Activation Information
- Machine and Process for Treating Heart Instability
- Methods, System and Apparatus for the Detection, Diagnosis and Treatment of Biological Rhythm Disorders
- Method for Treating Complex Rhythm Disorders
- Method for Analyzing Complex Rhythm Disorders
- Method and System for Detection of Biological Rhythm Disorders
- System and Method for Diagnosing and Treating Heart Rhythm Disorders Using Shaped Ablation
- System and Method for Identifying Sources for Biological Rhythms

Bio-X

Description

Since its establishment in 1998, Stanford Bio-X has grown into one of the largest interdisciplinary institutes at Stanford University. The mission of Bio-X is to catalyze discovery by crossing the boundaries between disciplines, to bring interdisciplinary solutions and to create new knowledge of biological systems, in benefit of human health. Bio-X supports, organizes, and facilitates interdisciplinary research connected to biology and medicine, and ideas and methods embodied in engineering, computer science, physics, chemistry, and other fields are being brought to bear upon important challenges in bioscience. In turn, bioscience creates new opportunities in other fields. Significant discoveries and creative inventions are accelerated through the formation of new collaborative teams.

While the James H. Clark Center is the hub for Stanford Bio-X, providing the resources, space, and environment so that boundaries are dissolved for researchers of all fields to collaborate together, the Bio-X community extends across Stanford campus and beyond. The community spans across all 7 schools of Stanford University with our Executive Committee, approximately 1,000 Bio-X affiliated faculty members, 336 Fellows, 708 Undergraduate Summer Research Program participants, over 630 Travel Award recipients, and the Bio-X/Clark Center Team. The Bio-X research programs are platforms that have brought the Bio-X community closer together, and the collaborative enthusiasm to conduct interdisciplinary research thrives in programs such as the Bio-X Interdisciplinary Initiatives Seed Grants Program, which has inspired 941 Bio-X affiliated faculty members to propose projects together over the history of the Seed Grants. Alumni of Bio-X programs are also sharing and disseminating its interdisciplinary spirit throughout the world. Through numerous symposiums, seminars, educational events, and collaborations with corporations, Bio-X continues to build interdisciplinary collaborations and spearhead impactful life bioscience research at Stanford.

Digital Health Projects

(Please note that Bio-X has funded over 1,000 life bioscience research projects in total, so these are a handful of digital health-related projects) A machine learning approach to automated detection and characterization of dendritic spines in the mammalian brain; Wireless wearable electroencephalography (EEG) device for sleep monitoring ; A novel approach towards drug screening using single cell experiments, isolated heart preparations, multiscale modeling and machine learning; Computational methods for characterizing children’s first-person social experiences; Decoding tumor initiating cells in breast cancer by digital cytometry; Mapping microbiome-directed immunity using single cell sequencing; Predicting seizures via intracortical brain-machine interfaces; Miniaturized RFID cell-tags for wireless cell monitoring; Neural control of a robotic arm using an adaptive brain-machine interface enabled by error detection feedback; Open, configurable high-throughput imaging platform for diagnostics and research; A compact optical sensor for parallel analysis of blood components

Key Programs

The major research programs at the heart of Stanford Bio-X include the Interdisciplinary Initiatives Seed Grants Program (IIPs), the PhD Fellowship Program, and the Undergraduate Summer Research Program (USRP). Since 2000, Bio-X has funded 212 IIP projects from proposals submitted by 941 Bio-X affiliated faculty members: the funded research has resulted in an over 10-fold return on investment to Stanford University, hundreds of papers published and researchers supported, and over 100 inventions and patents developed. Over 200 of the 318 Stanford Bio-X PhD Fellows have graduated and are pursuing exemplary careers in industry and academia, with 6 at Stanford as faculty members. 708 Stanford undergraduates have trained with our affiliated faculty members through the Bio-X USRP, resulting in alums pursuing doctorates and medical degrees; establishing successful industry careers; and founding innovative start-ups at the intersection of science, technology, and health. All of Bio-X's programs promote and enhance interdisciplinary collaboration by facilitating cross-talk across research disciplines, connecting the entire university and supporting groundbreaking research on many levels. In 2014, faculty at the Stanford School of Education analyzed the effect of Bio-X's programs and interdisciplinary community-building and determined that Bio-X had united faculty in medicine and engineering at Stanford with unprecedented success bridging the gaps between the disciplines.

SHIFT

Description

SHIFT is a student group at Stanford that empowers students to move healthcare forward. SHIFT aims to promote and cultivate health innovation on campus by creating a forum for developers, entrepreneurs, and pre-health students to collaborate. As a student initiative, SHIFT wants to create an environment to equip students for the growing intersection of healthcare and technology.

Grants, Courses, and Programs

- Health++
- TreeHacks Health
- Seminar in AI in Healthcare
- ThinkTank
- Blueprint
- Expo

Funding

$25K

ANNUALLY

Sources: Stanford departments, health tech companies, and ASSU grants

Key Personnel

Andy Jin, Marc Huo, Anoop Rao, and Oliver Aalami

Key Projects

Health++, an annual two-day hackathon that attracts 200-300 students from all over the country; workshops, panels, speakers, and mentor booths to help interdisciplinary teams practice tackling challenging questions in healthcare; TreeHacks Health, Stanford's main hackathon that attracts over 1,000 students from ~100 universities.

Collaborations

Past collaborations
health++; TreeHacks Health; Seminar in AI in Healthcare; ThinkTank; Blueprint; Expo

Key Stats

Established	People	Digital Health Projects
2014	25	80

Stanford University
Mental Health Technology + Innovation Hub

Mental Health Technology and Innovation Hub

Description

The mission of the Mental Health Technology and Innovation Hub (The Tech Hub) is to foster well-being and ease the burden of mental illness worldwide by employing cutting-edge technology and scientific methodology to produce, evaluate, disseminate, and appropriately apply accessible, person-centered digital health innovations to empower individuals, communities, and healthcare providers to advance these goals. The Tech Hub is a Special Initiative of the Chair of the Department of Psychiatry and Behavioral Sciences that is still forming, but planned activities include a conference on ethics in digital mental health and development of education opportunities in digital mental health (e.g.,, training experiences for residents), a repository of documents and resources to support grant and IRB submissions, and opportunities for cross-disciplinary/cross-department collaborations. Longer-term plans include integration of mHealth technology with EHRs and guidance on industry partnerships (through BrainStorm, an affiliated Special Initiative).

Collaborations

Past collaborations: Local community groups; national programs; academics (internal and external to Stanford)

International collaborations: Cambodia; India; Australia; UK

Key Personnel

David S. Hong, Eric Kuhn, Shannon Wiltsey Stirman, Laura Roberts, Max Kasun, and Kyle McKinley

Key Projects

VA Mobile Apps development and research; studies on digital mental health interventions for eating disorders, bipolar disorders, and other mental health problems; virtual reality projects, NLP, ML, AI and telehealth, COVID-19 Resources in collaboration with the American Psychiatric and Psychological Association for telepsychiatry and the psychological impact of quarantine

Grants, Courses, and Programs

- Precision Psychiatry
- allcove
- Brainstorm Lab
- Virtual Reality and Immersive Technology Program
- Stanford Mental Health Technology and Innovation Group
- VA National Center for PTSD Mobile Apps Tech Into Care Initiative

Funding

Sources: NIH, foundations, internal funding

Key Stats

Established	People	Digital Health Projects	Digital Health Publications
2017	65	20+	30+

SURF Stanford Medicine
Systems Utilization Research For Stanford Medicine

Systems Utilization Research for Stanford Medicine (SURF)

Description

SURF aims to facilitate the delivery of world class advances in medical care through world class advances in hospital operations; improve the quality of patient care; educate students, doctors, nurses, and hospital leaders; and share knowledge with the medical and academic communities. SURF uses machine learning, mathematical optimization, simulation, and a variety of statistical, probabilistic, and computational tools.

Collaborations

Past collaborations
Professors and students from the Lucile Packard Children's Hospital, the School of Medicine, the School of Engineering, and the Graduate School of Business

Funding

$250-350K

ANNUALLY

Sources: Lucile Packard Children's Hospital, Stanford School of Medicine

Commercialized Projects

Carta Healthcare

Key Personnel

David Schneiker, Kristin Petersen, Andy Shin, Lane Donnelly, Margaret Brandeau, Nicholas Bambos, David Maahs, Fatima Rodriguez, Peter Glynn, David Rosenthal, Kelly Johnson, Samuel Rodriguez, Tom Caruso, Francesca Pei, Shannon Feehan, Ellen Wang, Carey Phelps, and Henry Hopkins

Key Projects

Patient Flow and Planning Capacity for Stanford Medicine; Improving Surgical Value; Personalized Type 1 Diabetes Care with the Analysis of Data from Continuous Glucose Monitors; PeriOp Resource Usage and Analytics; Data-Driven Tools for CLABSI Reduction; Telemedicine; Imaging Services; CV Tap List; Surgical Resources; Non-Accidental Trauma; Patient Acuity; Emergency Accommodation; OR Supplies; Surgeon Schedules; Acute Kidney Injury; Physiological Waveform Analysis; Crisis Event Prediction; Planning a Major Hospital Expansion; Predictive Model of Patient Flow; Surgical Case Length; Automating Target Based Care.

Grants, Courses, and Programs

- MS&E 263 Healthcare Operations Management
- MS&E 463 Healthcare Systems Design

Key Stats

Established	People	Digital health Projects	Digital health Publications
2015	18	12	26

Center for Innovation in Global Health (CIGH)

Description

CIGH creates partnered programs in global health, both overseas and in the United States, in underserved, low resource communities to inspire a new generation of global health leaders; supports research, education, and mentorship opportunities in global health; and serves as a resource to connect interested global health scholars to opportunities at Stanford and beyond.

Key Personnel

Dean Michele Barry (Director) and Allison Phillips (Executive Director)

Collaborations

Bay Area Global Health Alliance: CIGH has partnered to produce the annual Bay Area Global Health Innovation Challenge (of which some participants specialize in the digital health field).

Bay Area Global Health Challenge

Grants, Courses, and Programs

MED 232: Scaling Health Technology Innovations in Low Resource Settings

MED 232 Description: Recent advances in health technologies – incorporating innovations like robotics, cloud computing, artificial intelligence, and smart sensors – have raised expectations of a dramatic impact on health outcomes across the world. However, bringing innovative technologies to low resource settings has proven challenging, limiting their impact. This course explores critical questions regarding the implementation and impact of technological innovations in low resource settings. The course will feature thought leaders from the health technology community, who will explore examples of technologies that have been successful in low resource communities, as well as those that have failed. Students will think critically to consider conditions under which technologies reach scale and have positive impact in the global health field. This course is open to undergraduate students, graduate students, and medical students. Undergraduates can take this course for a letter grade and 3 units. Graduate students and MD students can enroll for 2 units. Students enrolling in the course for a third unit will also work on group projects, each of which will focus on the potential opportunity for a health technology in a low resource setting and consider approaches to ensure its impact at scale. Students enrolled in the class for three units will also have additional assignments, including weekly discussion posts. Students must submit an application and be selected to receive an enrollment code. Please contact Olivia Paige to receive an application or for any additional questions: olivia.paige@stanford.edu. Professors inclue Dr. Anurag Mairal and Dr. Michele Barry, Senior Associate Dean for Global Health.

Established

2010

Stanford eWear

Description

Stanford eWear is a university-wide initiative to solve research challenges for future wearable solutions. eWear encourages collaborations across academic disciplines and with corporate members in the affiliates program. eWear has the goals to (1) bring together Stanford expertise in materials, electronics, systems, data, and clinical science; (2) provide a forum for discussing and setting future directions of wearable electronics; (3) foster collaborations between Stanford researchers and industry; (4) provide a forum for the early communication of published results; (5) foster communication between industrial sectors; (6) push the forefront of wearable technologies; and (7) provide multi-dimensional training for students and postdocs.

Commercialized Projects

Most of the work done in eWear is proof of concept

Collaborations

Past collaborations: Stanford labs; industry affiliates

Funding

$500K+

Sources: Corporate affiliate members

Key Personnel

Zhenan Bao (Faculty Director) and Angela McIntyre (Executive Director)

Grants, Courses, and Programs

- Seed funding opportunities
- Seminar series

Key Projects

How to perform accurate measurements; how to design and fabricate flexible and stretchable electronics to provide comfortable wearing and low cost production; how to handle large amounts of data; how to use effective algorithms to reduce artifacts from variables; how to combine information from multiple types of measurements to get meaningful information; how to keep data secure; clinical significance of measured information; how doctors handle vast amounts of information from patients; proper clinical and user measurement protocols; new medical devices for clinical needs; flexible and stretchable electronic materials; flexible circuit and system design; wearable energy harvesting and storage devices; wearable sensors; wireless communication; data analysis and algorithm development; wearable applications in aerospace and structural monitoring; robotics; health monitoring; virtual reality; robotics; automobiles; medical diagnosis; neuroprostheses.

Key Stats

Established	People
2016	50

Stanford | Center for Artificial Intelligence in Medicine and Imaging

Center for Artificial Intelligence and Medical Imaging (AIMI)

Description

The Stanford Center for Artificial Intelligence in Medicine and Imaging (AIMI) was established with the primary mission to develop, evaluate, and disseminate artificial intelligence (AI) systems to benefit patients. AIMI conducts research that solves clinically important imaging problems using machine learning and other AI techniques, and empowers outstanding interdisciplinary AI research that optimizes how clinical images are used to promote health.

Collaborations

Past collaborations: School of Medicine (17 departments); School of Engineering; AI in Healthcare Bootcamp; companies/industries that provide the opportunity for model development; global health initiatives; teleradiology

International collaborations: Australia; South Africa; Malaysia; Vietnam

Funding

Sources: Industry affiliates program, sponsored research funding, philanthropy, internal

Key Personnel

Curtis Langlotz, Matthew Lungren, and Johanna Kim

Key Projects

Artificial Intelligence IT Infrastructure Development; Deep Learning for Computer Vision Research; Imaging Labeling and Natural Language Processing Research; Clinical Validation of AI Algorithms; Upstream AI systems that enhance early detection, reduce diagnostic errors, select appropriate treatment, or improve the quality and efficiency of medical imaging

Commercialized Projects

Bunkerhill, Inc

Grants, Courses, and Programs

- AIMI Seed Grant Program
- AI for Healthcare Bootcamp
- Affiliated faculty program
- AIMI-Google Cloud Credit Call for Proposals
- AIMI-GE Call for Proposals
- AIMI Symposium
- AIMI Office hours (1:1 AI Consultations)

Key Stats

Established	People	Digital Health Projects	Digital Health Publications
2018	115	62	MANY

Center for Biomedical Informatics Research (BMIR)

Description

The mission of the Stanford Center for Biomedical Informatics Research is to improve health and wellness through biomedical discovery and clinical care, governed by data, information, and computation. In order to handle the ever-increasing amounts of data in healthcare and biomedical research, the faculty, students, and staff investigate and create novel computational, statistical, organizational, and decision-making methods. Their research advances the state of the art in semantic technology, biostatistics, and the modeling of biomedical systems to benefit clinical and translational research, as well as patient care.

Key Projects

The Cancer Genome Atlas (TCGA) PanCan Effort; ONCOCIN; Protégé; TOPAZ; Center for Advanced Medica; Informatics at Stanford (CAMIS); Chronus; Résumé; EON; ATHENA; Nation Center for Biomedical Ontology (NCBO)/Bio Portal; Center for Expanded Data Annotation Retrieval (CEDAR); Program for Artificial Intelligence in Healthcare; Green Button - Clinical Informatics Consult Service; Opioid Abuse And Poisoning; Apple Heart Study; Radiogenomics/Imaging Genomics; immunoStates; EpiTOF - Epigenetic profiling using Cytometry Time of Flight; MetaIntegrator; Interactive Antibiogram; Acid-Base Analyzer; MDCalc Version; Opioid Equivalent Dosing; Medicine Assessment and Plan Templates.

Key Personnel

Mark Musen, Manisha Desai, Nigam Shah, Lance Downing, Andrew Gentles, Olivier Gevaert, Tina Hernandez-Boussard, Purvesh Khatri, Jonathan Chen, Deendayal Dinakarpandian, Russ Altman, Daniel Rubin, Summer Han, Zihaui He, Jonathan Palma, Natalie Pageler, Teri Klein, Elsie Ross, Curtis Langlotz, Douglas Brutlag, Matthew Eisenberg, Sandy Napel, Michael Tierney, Carol Cain, Michael Higgins, Daniel Riskin, and Albert Chan

Key Stats

Established	People	Digital Health Projects	Digital Health Publications
1979	100+	65+	500+

Commercialized Projects

- Cardinal Analytics
- Kyron
- Inflammatix, Inc.
- CEDAR
- BioPortal
- Protege
- ATHENA

Funding

$8M+

Sources: NIH, industry sponsored grants and contracts, foundations, internal seed grants, gifts, and endowments, School of Medicine

Collaborations

Past collaborations
Duke; Oxford; Yale; UC Berkeley; UCSF; University of Colorado; Harvard; Stanford (Biomedical Data Science, Bio-X, Surgery, Radiology, Cancer Center, Neurosciences, Pathology, Cardiology, Anesthesiology); University of Bologna (Italy); University of Lorraine (France); Corporate Affiliates Program; Google; IBM; Apple; AstraZeneca; Northrop Grumman; American Heart Association; Moore Foundation; Bill and Melinda Gates Foundation; Lucence Diagnostics; Janssen Research and Development; IQUVIA; Leidos; Pinterest; Vir Bio; Genentech; Roche; National Cancer Institute; National Library of Medicine; National Heart, Lung, and Blood Institute; National Institute of General Medicine Sciences; Department of Defense; FDA; WHO

International collaborations
Belgium; China; UK; France; India; Italy; Netherlands; Switzerland; South Africa

Grants, Courses, and Programs

- Colloquium research talk series
- Biomedical Informatics Graduate Program
- Biomedin 201 Biomedical Informatics
- Biomedin 206 Informatics in Industry
- Biomedin 210 Modeling Biomedical Systems
- Biomedin 215 Data Driven Medicine
- Biomedin 217 Translational Bioinformatics
- Biomedin 218 Translational Bioinformatics Lectures
- Biomedin 225 Data Driven Medicine: Lectures
- Biomedin 226 Digital Health Practicum in a Health Care Delivery System
- Biomedin 254 Quality and Safety in U.S. Healthcare
- Immunol 207 Essential Methods in Computational and Systems Immunology
- Immunol 310 Seminars in Computational and Systems Immunology
- Med 277 AI-Assisted Care

Stanford MEDICINE | Physical Medicine and Rehabilitation

Wearable Health Lab

Description

The Wearable Health Lab harnesses the power of wearable biosensor data to span the gap between a qualitative approach toward a quantitative approach in research, prevention, and treatment of orthopedic and neurological disease.

Commercialized Projects

Vivametrica

Grants, Courses, and Programs

1-year Research Fellowship for International Fellows

Collaborations

US Collaborations
Stanford Mobilize Center; Stanford Bioinformatics Shah Lab; UCSF Core Center for Chronic Low Back Pain; the NSF Center for Disruptive Musculoskeletal Innovations, The NIH Center for Reliable Sensor Technology-Based Outcomes for Rehabilitation

International collaborations
Machine Learning and Data Analytics Lab at Friedrich-Alexander University (FAU); Laboratory of Movement Analysis and Measurement at Ecole Polytechnique Fédérale de Lausanne (EPFL)

Key Personnel

Matthew Smuck, Agnes Martinez-Ith, and Ruopeng (Robin) Sun

Key Projects

Use of wearable biosensors in musculoskeletal and neurologic disease monitoring, treatment and prevention including low back pain, osteoarthritis, lumbar spinal stenosis, and stroke; co-development of the largest known databases of accelerometer data for individuals with lumbar stenosis; empirical derivation of novel intervals to evaluate routine daily physical performance of people limited by musculoskeletal pain; establishment of guideposts for targeted exercise interventions for low back pain prevention through discovery of how physical activity mitigates the relationship between low back pain and obesity; development of an mHealth-based lifestyle modification app for self-management of low back pain; digital biomarkers of knee osteoarthritis and lumbar spinal stenosis.

Funding

$750K

Sources: National and Society grants, gifts

Key Stats

Established	People	Digital Health Projects	Digital Health Publications
2014	11	20+	30+

Stanford MEDICINE | Industry Relations & Digital Health
Office of the Dean

Office of Industry Relations and Digital Health (IRDH)

Description

Technology is advancing at an exponential pace. From gene editing to artificial intelligence, developments that were once considered science fiction are now knocking on health care's door. To effectively respond to this opportunity, academic medicine needs a new process for innovation—one that embraces industry collaboration. The mission of IRDH is to foster relationships that will promote discovery, accelerate the use of technologies that advance human health, and translate today's breakthroughs into tomorrow's standard of care. The IRDH was created to serve as the primary home for developing strategic industry collaborations with Stanford Medicine and to support faculty in these endeavors. The IRDH partners with a broad array of departments and industry entities that align with key initiatives under the Integrated Strategic Plan. The Stanford Medicine Catalyst program is housed in IRDH. The Catalyst program was established as a result of a joint strategic effort between the School of Medicine, Stanford Health Care, and Stanford Children's Health to bolster breakthrough innovations from faculty, staff, and students seeking validation in the real-world setting. Propelling research and clinical innovations beyond the initial grant stage is difficult. The Catalyst program aims to solve that by offering a variety of resources, including access to industry experts, to fund, validate, and bring promising research and solutions to the next step. While Stanford Medicine is well-known for innovation, the Catalyst program seeks to contribute critical resources for health innovations to mature internally. Whether validating an idea, determining the appropriate market application, or finding the best strategic partner, Catalyst exists to help our innovators and their ideas make a global impact.

Key Personnel

Michael Halaas (Associate Dean), Reed Sprague (Operations Lead), Kyle Asay, Austin Aker, Jessica Kennedy, Michael Paschke, Jared Roberts, Ana Sandoval, Kelsey Sobomehin, and Courtney Schmit.

Collaborations

Past collaborations
Corporate and Foundation Relations; School of Engineering (SoE); Corporate and Foundation Relations and Development Office, SoM; Development Office at LPCH; Industry Contracts Office (ICO); Industrial Affiliates Program (under the purview of ICO); Information Security Office (ISO); Office of General Counsel; Office of Technology Licensing (OTL); Privacy Office; Research Compliance Office (RCO) and Institutional Review Board (IRB); Research Management Group (RMG); Stanford Health Care Compliance Office and Privacy Office; Stanford University Office of Development

Key Stats

Established	Digital Health Projects
2018	~50

Human-Centered Artificial Intelligence (HAI)

Description

The Stanford Institute for Human-Centered Artificial Intelligence (HAI) is dedicated to guiding and building the future of artificial intelligence (AI) with a mission of advancing AI research, education, policy and practice to improve the human condition. The institute focuses on developing AI technologies inspired by human intelligence; guiding, forecasting and studying the human and societal impact of AI; and designing and creating AI applications that augment human capabilities.

Key Personnel

John Etchemendy, Fei-Fei Li, Russ Altman, Susan Athey, Michele Elam, Surya Ganguli, Daniel E. Ho, James Landay, Christopher Manning, and Rob Reich

Key Projects

COVID-19 + AI; Collective and Augmented Intelligence Against COVID-19 (CAIAC initiative); Correcting Gender and Ethnic Biases in AI Algorithms; The Impact of Artificial Intelligence on Perceptions of Humanhood; AI 100; AI Index; AI4ALL; How to Grow a Mind; Machine Learning; Inspirations from Neuroscience for Better Models of Human-like Intelligence; Toward AI Models of Reasoning and Language Understanding; Legal and Regulatory Implications of a World with Artificial Intelligence; Understanding and Shaping the Economic Implications of Artificial Intelligence; Artificial Intelligence and Trust; The Ethical, Political, and Social Dimensions of AI; AI in Education; Improving Health Care Delivery through the use of Artificial Intelligence; Smart Government; Designing AI-Based Human Augmentation; Facial Recognition Technology, Measurement, and Regulation (white paper and workshop); HAI AI and Labor Markets (Affinity Group); AI and Climate (Affinity Group).

Key Stats

Established	People
2019	300+

Collaborations

Past collaborations
Multiple Stanford departments; Stanford Center for Comparative Studies in Race; Stanford Center for AI in Medical Imaging; Stanford Regulation, Evaluation, and Governance Lab (RegLab); Stanford Center for Continuing Medical Education; Stanford GSB Executive Education; Stanford Pre-Collegiate Studies; Stanford Center for Professional Development; Stanford Office of the Vice President for the Arts; Stanford Cyber Policy Center; Stanford Hoover Institution; Stanford Freeman Spogli Institute for International Studies; Federal Judicial Center; Sundance Institute; Stanford Center on AI Safety; McCoy Family Center for Ethics in Society; Stanford Center for International Security and Cooperation; Stanford Center for the Study of Language and Information; Stanford Data Analytics for What's Next; Stanford John S. Knight Journalism Fellowships; Stanford Open Virtual Assistant Lab; Stanford Institute for Economic Policy Research; AI4ALL; CAIAC; Bloomberg Beta; Allen Institute for AI; Carnegie Mellon AI; Facebook AI Research; Google/DeepMind; Harvard University (Berkman Klein Center, Kennedy School); Massachusetts Institute of Technology (Computer Science and AI Laboratory; Initiative on the Digital Economy; J-PAL; Quest for Intelligence; Microsoft Research; New York University (AI Now Institute); OpenAI; Tsinghua Institute for AI; University of California, Berkeley (AI Research Lab, Center for HumanCompatible AI); University of Toronto Vector Institute; Center for Advanced Study in the Behavioral Sciences; Digital Civil Society Lab; Initiative for Shared Prosperity and Innovation; McCoy Family Center for Ethics in Society; Project on Democracy and the Internet; Stanford AI Lab (SAIL); Stanford Artificial Intelligence & Law Society (SAILS); Stanford Center for Blockchain Research; Stanford Center for Mind, Brain, Computation and Technology; Stanford Center on Philanthropy and Civil Society; Stanford Center on Poverty and Inequality; Stanford Data Analysis for What's Next (DAWN) Project; Stanford Data Science Initiative; Stanford Humanities Center; Stanford Institute for Economic Policy Research; Stanford Natural Language Processing Group; Stanford Program for AI Health Care; Stanford Robotics Lab; Stanford Vision and Learning Lab (SVL); Stanford Woods Institute for the Environment; Wu Tsai Neurosciences Institute

International collaborations: Several, including China and Canada

Grants, Courses, and Programs

Grants

- HAI seed grants
- Hoffman-Yee Grants
- Cloud credit program

HAI seeks to both serve as a clearinghouse/ entry-point for the study of Human-Centered AI at Stanford and to support the success of courses in this area. The following list includes both courses actively supported by HAI and those which touch on the core clearinghouse mission of the Institute related to AI (including Data Science and Machine Learning) and Health, within both traditional disciplinary and interdisciplinary contexts. It is not presumed to be exhaustive.

Grants, Courses, and Programs Continued

- SYMSYS 122 Artificial Intelligence: Philosophy, Ethics & Impact
- CS 28 Artificial Intelligence, Entrepreneurship and Society in the 21st Century and Beyond
- LAW 4041 Lawyering for Innovation: Artificial Intelligence
- CME500 Departmental Seminar: Artificial Intelligence (AI) for Good
- CS 21SI AI for Social Good
- COMM 230 Digital Civil Society
- CS 22A, INTLPOL 200, LAW 4043 The Social & Economic Impact of Artificial Intelligence
- STATS 245 Data, Models, and Applications to Healthcare Analytic
- CS 522 Seminar in Artificial Intelligence in Healthcare
- GSBGEN 596 Designing AI to Cultivate Human Well-Being
- ANES 208A Data Science for Digital Health and Precision Medicine
- BIODS 210 Configuration of the US Healthcare System and the Application of Big Data/Analytics
- MED 232 Global Health: Scaling Health Technology Innovations in Low Resource Setting
- HRP 275 Population Health Research
- CEE 70N Water, Public Health, and Engineering
- HRP 247, HUMBIO 57 Epidemic Intelligence: How to Identify, Investigate and Interrupt Outbreaks of Disease
- Seminars, Workshops, Talks (Stanford-only)
- Embedded Ethics Modules in Multiple Core Computer Science Courses

Stanford MEDICINE | Biomedical Data Science

Department of Biomedical Data Science (DBDS)

Description

The Department of Biomedical Data Science (DBDS) is an academic research community comprised of faculty, students, and staff who are pursuing collaborative and interdisciplinary data science research at the intersections of biostatistics, biomedical informatics, and biomedical computation.

Key Personnel

DBDS Leadership includes Sylvia Plevritis as Chair, Chiara Sabatti as Associate Chair for Education and Training, Lu Tian as Associate Chair for Faculty Affairs, Jaap Suermondt as Executive Director of the Biomedical Informatics Graduate Program, and Michael Negrette as Director of Finance and Administration.

Primary faculty include Carlos Bustamante, Bradley Efron, Trevor Hastie, Iain Johnstone, Teri Klein, Ying Lu, Aaron Newman, Julia Palacios, Manuel Rivas, Daniel Rubin, Robert Tibshirani, Wing Hung Wong, Serena Yeung, and James Zou. Our secondary faculty include Russ Altman, Euan Ashley, Mark Cullen, Manisha Desai, Olivier Gevaert, Tina Hernandez-Boussard, Purvesh Khatri, Laura Lazzeroni, Mark Musen, Julia Salzman, Nigam Shah, Dennis Wall, and Alice Whittemore.

Collaborations

Past collaborations
Numerous clinical divisions and basic science departments in the School of Medicine; Schools of Education, Humanities and Sciences, Law

Key Projects

Research Informatics Center; Data Studio; The Cancer Genome Atlas (TCGA) PanCan Effort; Determining Cell Type Abundance and Expression from Bulk Tissues with Digital Cytometry; An Open Resource for Accurately Benchmarking Small Variant and Reference Calls; Opportunities and Challenges for Transcriptome-Wide Association Studies; Effect of Wearable Digital Intervention for Improving Socialization in Children With Autism Spectrum Disorder; Mitogenomes Illuminate the Origin and Migration Patterns of the Indigenous People of the Canary Islands; Benchmarking Germline Small-Variant Calls in Human Genomics; Covidcast: A map of Real-time COVID-19 Indicators; Analysis of human genome/phenome data, including host genetics of COVID-19; Analysis of risk factors and cost of 100k COVID-19 patients; Precise RNA variant in SARS-CoV-2; Stumbling around in the United States of Data: A COVID-19 study; Integrating spatial gene expression and breast tumour morphology via deep learning; FasTag: Automatic text classification of unstructured medical narratives; Clinical genetics lacks standard definitions and protocols for the collection and use of diversity measures; Rare protein-altering variants in ANGPTL7 lower intraocular pressure and protect against glaucoma.

Key Stats

Established	People
2015	50-100

Key Projects Continued

A machine learning approach to identifying changes in suicidal language;A human lung tumor microenvironment interactome identifies clinically relevant cell-type cross-talk; Common microdeletions in SARS-CoV-2 sequences;Specific splice junction detection in single cells with SICILIAN;Why do young, healthy people die from COVID-19?; Assessing digital phenotyping to enhance genetic studies of human diseases;Video-based AI for beat-to-beat assessment of cardiac function; Initial review and analysis of COVID-19 host genetics and associated phenotypes; Healthcare worker absenteeism, child care costs, and COVID-19 school closures: a simulation analysis

Grants, Courses, and Programs

- BIODS 48N Riding the Data Wave
- BIODS 215 Topics in Biomedical Data Science: Large-Scale Inference
- BIODS 220: Artificial Intelligence for Healthcare
- BIODS 232 Consulting Workshop on Biomedical Data Science
- BIODS 237 Deep Learning in Genomics and Biomedicine
- BIODS 260A/B/C Workshop in Biostatistics
- BIODS 299 Directed Reading and Research
- BIOMEDIN 201 Biomedical Informatics Student Seminar
- BIOMEDIN 205 Precision Practice with Big Data
- BIOMEDIN 208 Clinical Informatics Literature Review Seminar
- BIOMEDIN 304 Clinical Experience Seminar for Students in Biomedical Informatics
- BIOMEDIN 290 Biomedical Informatics Teaching Methods
- BIOMEDIN 299 Directed Reading and Research
- BIOMEDIN 370 Medical Scholars Research
- BIOMEDIN 390A/B/C Curricular Practical Training
- BIOMEDIN 801 TGR Master's Project
- BIOMEDIN 802 TGR PhD Dissertation
- BIOMEDIN 210: Modeling Biomedical Systems: Ontology, Terminology, Problem Solving
- BIOMEDIN 212: Introduction to Biomedical Informatics Research Methodology
- BIOMEDIN 214: Representations and Algorithms for Computational Molecular Biology
- BIOMEDIN 215: Data Driven Medicine
- BIOMEDIN 217: Translational Bioinformatics
- BIOMEDIN 219: Mathematical Models and Medical Decisions
- BIOMEDIN 221: Machine Learning Approaches for Data Fusion in Biomedicine
- BIOMEDIN 222: Cloud Computing for Biology and Healthcare
- BIOMEDIN 224: Principles of Pharmacogenomics
- BIOMEDIN 226: Digital Health Practicum in a Health Care Delivery System
- BIOMEDIN 251: Outcomes Analysis
- BIOMEDIN 256: Economics of Health and Medical Care
- BIOMEDIN 260: Computational Methods for Biomedical Image Analysis and Interpretation
- BIOMEDIN 273A: The Human Genome Source Code
- BIOMEDIN 279: Computational Biology: Structure and Organization of Biomolecules and Cells
- BIOMEDIN 432: Analysis of Costs, Risks, and Benefits of Health Care
- BIOMEDIN 472: Data science and AI for COVID-19

Programs

- Biomedical Informatics (BMI) Training Program
- Data Studio
- Workshops in Biostatistics
- Clinical Science Data Fellowship
- DBDS Seminar Series (Fall 2020)

Stanford | Institute for Economic Policy Research (SIEPR)

Institute for Economic Policy Research (SIEPR)

Description

The mission of SIEPR is to catalyze and promote evidence-based knowledge about pressing economic issues, leading to better-informed policy solutions for generations to come. SIEPR envisions a future where policies are underpinned by sound economic principles and generate measurable improvements in the lives of all people.

Key Personnel

Gopi Shah Goda, SIEPR Deputy Director and Senior Fellow; Vivienne Fong, Director of Programs and Faculty Affairs; Sammantha Gembala, Program and Faculty Affairs Coordinator; Lisa Gounod, Program Manager for Student Programs

Key Projects

SIEPR Senior Fellows, Faculty Fellows and Visitors focus their research on a wide range of economic policy issues. Several are specifically focused on health and health care and innovation and technology. In addition to drawing faculty from Stanford School of Medicine (as well as from each of the university's other schools,) SIEPR collaborates very closely with the other policy-oriented institutes reporting to the Dean of Research, including the Stanford Institute for Human-Centered Artificial Intelligence (HAI).
A few recent examples of Digital Health-oriented research:

Senior Fellow Matthew Gentzkow and Faculty Fellow David Chan working paper: Selection with Variation in Diagnostic Skill: Evidence from Radiologists. Physicians, judges, teachers, and agents in many other settings differ systematically in the decisions they make when faced with similar cases. Standard approaches to interpreting and exploiting such differences assume they arise solely from variation in preferences. We develop an alternative framework that allows variation in both preferences and diagnostic skill, and show that both dimensions are identified in standard settings under quasi-random assignment. We apply this framework to study pneumonia diagnoses by radiologists. Diagnosis rates vary widely among radiologists, and descriptive evidence suggests that a large component of this variation is due to differences in diagnostic skill. Our estimated model suggests that radiologists view failing to diagnose a patient with pneumonia as more costly than incorrectly diagnosing one without, and that this leads less-skilled radiologists to optimally choose lower diagnosis thresholds. Variation in skill can explain 44 percent of the variation in diagnostic decisions, and policies that improve skill perform better than uniform decision guidelines. Failing to account for skill variation can lead to highly misleading results in research designs that use agent assignments as instruments.

Faculty Fellow David Chan working paper: Mastering The Art Of Cookbook Medicine: Machine Learning, Randomized Trials, And Misallocation. The application of machine learning (ML) to randomized controlled trials (RCTs) can quantify and improve misallocation in healthcare. We study the decision to prescribe anticoagulants for atrial fibrillation patients; anticoagulation reduces stroke risk but increases hemorrhage risk. We combine observational data on treatment choice and guideline use with ML estimates of heterogeneous treatment effects from eight RCTs. When physicians adopt a clinical guideline, treatment decisions shift towards the recommendation but adherence remains far from perfect. Improving guideline adherence would produce larger gains than informing physicians about guidelines. Adherence to an optimal rule would prevent 47% more strokes without increasing hemorrhages.

Stanford MEDICINE | Quantitative Sciences Unit

Quantitative Sciences Unit (QSU)

Description

The Quantitative Sciences Unit (QSU) is a collaborative statistics unit in the Biomedical Informatics Research (BMIR) Division in the Department of Medicine (DOM). The mission of the QSU is to facilitate cutting-edge scientific studies initiated by Stanford investigators by providing expertise in biostatistics and informatics, to mentor and educate clinical investigators in research methods, and to mentor data scientists so that they can reach their full potential. The QSU achieves its mission through an interdisciplinary collaborative approach where QSU members become fully integrated into individual research teams.

Funding

$1M+

Sources: Internal, industry, NIH, and foundations

Grants, Courses, and Programs

- QSU Research Methods Seminars
- QSU Clinical Trial Program

Key Personnel

Manisha Desai and Mary Boulos

Key Projects

Apple Health Study; Stanford GOALS RCT; other studies include physical activity RCTs, one migraine study, and diabetes-related trials.

Collaborations

Past collaborations: Stanford affiliates

International collaborations: Swedish School of Sports and Health Sciences

Key Stats

Established	People	Digital Health Projects	Digital Health Publications
2009	27	15	10+

Stanford MEDICINE | Epidemiology and Population Health

Department of Epidemiology and Population Health (E&PH)

Description

The Department of Epidemiology and Population Health (E&PH) is Stanford's academic and organizational home for such activities, offering expertise, research, and training on study design, data collection, analysis and proper interpretation of scientific evidence to improve human health in the clinic and in the field.

Key Personnel

Laurence Baker, M. Kate Bundorf, Mark Cullen, Lisa Goldman Rosas, Steven Goodman, Victor Henderson, Mark Hlatky, John Ioannidis, Abby King, Allison Kurian, Yvonne "Bonnie" Maldonado, Michelle Mello, Lorene Nelson, Michelle Odden, Julie Parsonnet, Maria Polyakova, Rita Popat, Maya Rossin-Slater, Kristin Sainani, Julia Simard.

Collaborations

Past collaborations: Many departments all across campus; industry; government; clinicians; academics.

International collaborations: At least 5 countries.

Key Stats

Established	People
1992	40

Stanford | Stanford Data Science Initiative

Stanford Data Science Initiative (SDSI)

Description

The Stanford Data Science Initiative (SDSI) aims to make Stanford a data enabled university. The Initiative advances data science methods and tools, and weaves them into the fabric of the university, to effectively respond to our most pressing societal and scientific challenges.

Commercialized Projects

Contributions to open source software packages: Deep Dive; Snorkel; Fonduer; SNAP

Funding

$14.7M

Sources: Industry

Grants, Courses, and Programs

Bi-annual workshop, HealthAI working group including Hackathon

Key Personnel

Jure Leskovec, Euan Ashley, and Erika Strandberg

Key Projects

Privacy Preserving Internet of Things - Analytics for Human Behavior Interventions; Mapping the "Social Genome"; Data Science for Personalized Medicine; DeepDive – a High-Performance Interference and Learning Engine; Use of Electronic Phenotyping and Machine Learning Algorithms to Identify Familial Hypercholesterolemia Patients in Electronic Health Records; Real-Time Large-Scale Neural Identification; MyHeart Counts.

Collaborations

Past collaborations

Industry members, including: Accenture; American Family; BASF; Docomo; Farmers Zurich; GE; Google; Hitachi; HTC; Huawei; Hyundai Card; Intel; Juniper; Keysight; Lightspeed Venture Partners; Microsoft; MUFG; Northrup Grumman; Orange; RWE; Siemens; State Farm; Swiss Re; Takaful Emarat; Toshiba; Tyco Sensormatic; Veritas; Western Digital, Amazon

Key Stats

Established	People
2014	83

Stanford AI Lab (SAIL)

Description

The Stanford Artificial Intelligence Laboratory (SAIL) is a center of excellence for Artificial Intelligence research, teaching, theory, and practice. The affiliates program represents a new era of close engagement with a small number of major companies. It supports corporate interaction through organized retreats, an Advisory Board, and informal interactions. The goal is bidirectional transfer of knowledge and excitement.

Key Personnel

Chris Manning and Erika Standberg

Commercialized Projects

Supported research includes developing Stanford NLP Bio; DeepDive; Snorkel; Fonduer; SNAP

Funding

$5.7M

Sources: Industry

Key Projects

Computer Vision for Health Applications (including surveillance and hand washing); Natural Language Processing for Biological Language; DeepDive, Snorkel and Fonduer for extracting and creating training data from unstructured dark data; genomics; other research areas unrelated to digital health.

Collaborations

Past collaborations
Corporate affiliates, including: DiDi; Google; Huawei; Lam Research; OPPO; Panasonic; Prudential UK; Samsung; SDIT AI (Serba Dinamik); SK Telecom; Tencent; Toyota; UST Global; Virtusa, Total

International collaborations
China; Korea; UK; Japan

Grants, Courses, and Programs

Annual workshop for industry members and guests.

Key Stats

Established	People
2016	40

Stanford ENGINEERING | AI for Health

AI for Health

Description

The mission of AI for Health is to develop unbiased, explainable AI algorithms to better understand health and wellness, to improve the efficiency, value and delivery of healthcare, and to improve patient experience and outcomes.

Key Personnel

James Zou, Erika Strandberg, Russ Altman, Jure Leskovec, Christopher Re, Daniel Rubin, and Nigam Shah

Key Projects

ALTE: AI for Literacy, Transparency and Engagement: the goal of this flagship project is to advance patient literacy, engagement and healthcare transparency through natural language processing of medical text and general jargon or layperson descriptions of medical conditions. Success of this flagship will enable patients to be better informed in making healthcare decisions, decrease call center and provider time in translating medical terminologies, and ultimately provide better care outcomes and value.

Funding

$700K

Sources: Industry

Collaborations

Past collaborations: Anthem; Genentech

Key Stats

Established	People	Digital Health Projects
2018	7	3

Stanford MEDICINE | Research Informatics Center

Research Informatics Center (RIC)

Description

The Research Informatics Center helps to advance data-driven clinical research by offering clinical informatics services to Stanford University and Stanford Medicine researchers on topics related to clinical data access for research purposes. RIC consultants review the clinical data needs of your research project, provide advice on requesting IRB and Privacy Office approval to obtain clinical data from the STARR Clinical Data Warehouse, and discuss options for clinical data abstraction, reporting, and storage to meet your research needs. In 2018, the Data Coordinating Center (DCC) was integrated into the RIC. The data coordination team specializes in the planning, development, management, and secure implementation of data systems for biomedical research and works with investigators to enable subject curation and apply advanced statistical and bioinformatics tools to achieve project goals in a technologically modern environment. In collaboration with the Stanford Cancer Institute (SCI), the data coordination team created, maintain, and support the Stanford Cancer Institute Research Database (SCIRDB). SCIRDB has a rich set of data and integrates many sources including Epic EHR, STARR, specialized databases in surgical pathology and radiation oncology, and the Stanford Cancer Registry.

Funding

$2.7M OVER THE PAST 2 YEARS

(FY20 spending + FY21 estimates)

Key Personnel

- Daniel Rubin, Director of the Research Informatics Center
- Balasubramanian Narasimhan, Director of the Data Coordinating Center
- Yelena Nazarenko, Informatics Consultation Service Manager
- Eileen Kiamanesh, Research Data Analyst
- Mina Liu, Research Data Analyst
- Archana Bhat, Research Data Analyst
- Solomon Henry, Data Integration Architect
- Douglas Wood, Senior Software Developer
- Yulin Chien, Software Developer

Key Projects

- Stanford Cancer Institute Research Database (SCIRDB)
- Curation Application for Disease Database (CADD)
- Bone Marrow Transplant (BMT) Database
- Center for Cancer Cell Therapy (CCT) program
- The Oncoshare Project
- Department of Cardiothoracic Surgery's database
- Department of Ophthalmology's American Academy

Collaborations

Large initiatives such as SCIRDB, BMT Database, and The Oncoshare Project, in addition to considerable funding provided by the SoM Dean's Office in support of a clinical data consultation service available to all University, SHC, and LPCH researchers; External collaborators have included Bayer AG

Key Stats

Established	People	Digital Health Projects	Digital Health Publications
2018	10	136 (Over the past 2 years)	27 (Over the past 2 years)

Stanford HEALTH CARE

Stanford Health Care: Digital Health Care Integrations Team (DHCI)

Description

Stanford Health Care seeks to provide patients with the very best in diagnosis and treatment, with outstanding quality, compassion and coordination. With an unmatched track record of scientific discovery, technological innovation and translational medicine, Stanford Medicine physicians are pioneering leading edge therapies today that will change the way health care is delivered tomorrow. The Digital Health Care Integration team identifies and enables digital health programs and initiatives to align with the Integrated Strategic Plan for Stanford Medicine. This team is immediately focusing on launching and scaling foundational virtual health capabilities, including video visits, eConsults and the Second Opinion Program. Looking forward, the team will focus on scoping and deploying supplementary programs, like remote patient monitoring and an Emergency Medicine Virtual Care program, as well as expanding reach to deliver services via network providers, employers and beyond. Ultimately, the team aims to use Digital Health tools to improve and personalize access, connect networks, transform value and empower care teams at Stanford Health Care.

Key Personnel

Christopher “Topher” Sharp, Lawrence “Rusty” Hofmann, Chris O’Dell, Leah Rosengaus and Leslie Haas

Key Projects

The Digital Health Care Integrations team launched a video visit program in September of 2018. This program continues to scale and is currently offered across all outpatient services. Two years post-launch, the program delivers greater than 60,000 video visits per month. The DHCI team also developed a second opinion offering, which went live in November 2018. Patients from across the globe can request an online review of medical records and will receive recommendations from a specialist for treatment options. In less than a year, Stanford Health Care providers have delivered over 2,000 second opinions.

Piloted since 2015, the DHCI team officially launched and expanded the eConsults program to new providers and specialties in 2019. Through this program, over 150 patients monthly receive recommendations from a specialist via an asynchronous provider-to-provider consult initiated by a PCP. This program is available in 10 specialties. Additional opportunities with the program are being assessed, including layering AI on top of submitted eConsults to provide initial

Key Stats

Established	People	Digital Health Projects	Digital Health Publications
2018	13	10+	2

Key Projects Continued

recommendations. Outcomes from the eConsults pilot have been published: https://www.ncbi.nlm.nih.gov/pubmed/30301409

The Stanford Health Care Digital Health Care Integrations has established a collaborative of providers, including 25 C-Suite and VP level leaders from leading health systems, including Sutter, Intermountain, Ochsner, Cleveland Clinic, Providence, Kaiser, Geisinger, and more. This group meets monthly and convenes in person annually for a Digital Health Symposium, during which executives discuss best practices, learnings, risks and priorities across digital health.

In 2019, the DHCI team completed a strategic planning process, through which strategic objectives were outlined and a three-year roadmap was developed. Out of this process, additional opportunities were identified, including to deploy a virtual triage program to help decant the ED. Remote patient monitoring and on demand video visits have also been prioritized and these programs are in development. Stanford Health Care, more broadly, launched the MyHealth app, which is regarded as an industry leader for its advanced capabilities, deep integration and convenient patient navigation and experience. Stanford Health Care continues to layer new functionality into the MyHealth app, such as adding video capability. Stanford Health also has a successful Telestroke program.

Stanford Children's Health

Stanford Children's Health Lucile Packard Children's Hospital Stanford Digital Health Team

Description

Stanford Children's Health is the only health care system in the San Francisco Bay Area – and one of the few in the country – exclusively dedicated to pediatric and obstetric care. The physicians and health care teams offer comprehensive clinical services, from treatments for rare and complex conditions to well-child care. Their digital health goal: Digital Health Program, In our Care Anywhere, seeks to transform healthcare for mothers and children worldwide through technology, by making it faster, safer, and easier.

Key Personnel

Denny Lund, Cameron D'Alpe, Natalie Pageler, Ed Kopetsky, and Lee Kwiatkowski

Key Projects

Stanford Children's Digital Health has been developing an integrated Virtual Care Platform to support Stanford Children's Health Vision 2025. In 2014, Stanford Children's Health initially launched clinic to clinic telehealth between the main campus and multi-specialty clinics across the Bay Area from Monterey to San Francisco, with Dr. Bill Kennedy serving as a pioneer and champion for the initial efforts. This model helped improve access, saved provider driving time, and increased patient satisfaction.

In December 2017, Stanford Children's Health launched an integrated virtual visit program allowing patients to be remote (e.g., in their homes) and providers in dedicated telehealth clinic rooms. With the COVID-19 pandemic, this program saw an explosion in virtual visit numbers, from approximately 20 visits per day before the pandemic to more than 800 visits a day several weeks later. Virtual visits offered a way for children to continue to receive the vital health care they needed, while minimizing risk to patients, families and providers. During the pandemic, providers and patients / families realized several previously unrecognized benefits of telehealth, such as enhanced

Key Stats

Established	People	Digital Health Projects	Digital Health Publications
1991	10+	MANY	MANY In collaboration with faculty

ability to assess child development when they are comfortably playing in their own home. While many types of health care will appropriately return to in-person visits when the pandemic subsides, telehealth will continue to play a major role in comprehensive health care going forward.

Stanford Children's Health began tracking metrics of telehealth quality and value early in the program, and with the significant growth of telehealth during the COVID-19 pandemic, analytics has become a major focus to support continued development. Early successes of the program include improved utilization of same-day cancellation slots, improved patient satisfaction and increased provider wellness. Even prior to the pandemic, certain services integrated telehealth into their clinic flows and saw an estimated 20% of total follow-up visits being completed via telehealth. Those numbers are certain to remain much higher post-pandemic, and active research is ongoing to determine the right mix of virtual and in-person services for specific patients.

With the proliferation of virtual visits related to COVID-19, Stanford Children's Health is doing timely work on enabling the transfer of vital signs and other clinical data from home directly into the electronic health record (EHR). This data pipeline was established as part of a pilot project that automated the collection of weight and oxygen saturation by our home monitoring program for infants following cardiac surgery. Vital signs data are entered in Link, a mobile app developed at Stanford Children's Health, making them available in the EHR for review, documentation, and population-level analytics. The app is currently being enhanced to allow for the collection of all vital signs and a patient's height and weight, so it can be extended to additional patient populations and supplement our virtual visits.

Additionally, as part of the comprehensive diabetes digital health program led by Dr. Priya Prahalad, every new onset type 1 diabetic is provided with an iPad and a Bluetooth enabled continuous glucose monitor. These data are also uploaded directly through the patient portal to the EHR, where physicians can view the information in a custom decision support tool to help guide better treatment plans.

At Stanford Children's Health, the digital health program has also focused on creating a digital front door to help patients and families reach the services they need. This strategy aims to convert many of the traditional interactions between patients and the organization into a digital experience to facilitate access and improve ease and efficiency for patients and families. These programs include: online appointment scheduling for new and existing patients, second opinions (in collaboration with Stanford Health Care), and providing an interactive experience through the Stanford Children's Mobile App. Stanford Children's Health launched ZocDoc in FY19 to offer new patients a method to schedule visits with the Packard Community Healthcare Alliance (PCHA), bringing in over 570 visits through the program. Through Second Opinions, Stanford Children's Health opened 5 services globally for anyone to request a second opinion through one of Stanford Children's Health's experts. All of these programs help each child and family get the right care at the right time, wherever they may be.

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Disclaimers and Limitations

In building the Stanford Center for Digital Health Landscape Report, we discovered some limitations that affected how data was presented in this report. Because the literature review was conducted in a single database (PubMed), our analysis cohort may not include the totality of digital health literature at Stanford. Due to the broad and interdisciplinary scope of digital health, our chosen search queries might have unknowingly omitted relevant results. Further limitations include the subjectivity of the manual screening process and associated data categorization process described in the methodology.

As digital health is a relatively new term in the lexicon of medical terminology, without an agreed-upon universal definition, there are some inherent limitations to categorization and characterization of digital health as the field is still radpily evolving. Additionally, because Stanford is such a large organization, there are thousands of projects, publications, teams, groups, and individuals that are working in the field of digital health in some capacity. While we tried to be as inclusive and comprehensive as possible, we realize that due to the vast scope of this report, there are some inherent limitations in reporting, namely the inadvertent omission of faculty, groups, and other initiatives that play a role in digital health at Stanford. If you would like to inform us of your work and be included in future versions of the report, contact us at digital health@stanford.edu.