NYU School of Medicine
NYU LANGONE MEDICAL CENTER

2016 RESEARCH REPORT

WORLDS UNSEEN

Imaging at NYU Langone

Credits
2016 Research Report of NYU School of Medicine
Commissioned by the Office of Science and Research
Senior Vice President and Vice Dean for Science,
Chief Scientific Officer: Dafna Bar-Sagi, PhD

Produced by the Office of Communications and Marketing
Senior Vice President: Kathy Lewis
Director of Publications: Nicole Dyer
Writer: Bryn Nelson
Production Coordinator: Sherry Zucker
Design: Ideas on Purpose, www.ideasonpurpose.com
Photography: Karsten Moran; page 07-09, 11, 13, 15-17, 19-21,
Sasha Nialla; page 03, Getty Images; pages 04-06, 10, 14,
Science Photo Library; 05, 18, 22
Printing: Allied Printing Services, Inc.

Special thanks to:
Debra Bemis, PhD, Senior Director for Research Reputation & Engagement;
Laura Ahlborn, Vice President for Research Enterprise; Sadhana Chitale, PhD, Director,
Life Sciences Technology Transfer; Wendy Cunningham, HR Immigration Specialist;
Susan DiGeronimo-Wild, Senior Director and Business Partner–Research Finance;
Liz Donathan, Research Data Manager–Sponsored Programs Administration;
Mary Furcht, Communications Specialist–Office of Science & Research; Abram Goldfinger,
Executive Director–Industrial Liaison; Keith Micoli, PhD, Director of Postdoctoral Affairs;
Stuart Spore, Lead, Scholarly Output Assessment/Senior Systems Advisor–NYU Health
Sciences Library; and Susanne Tranguch, PhD, Assistant Dean for Biomedical Sciences.

Science is about seeing hidden worlds and making sense of life invisible to the naked eye. It's about solving mysteries through the power of observation:

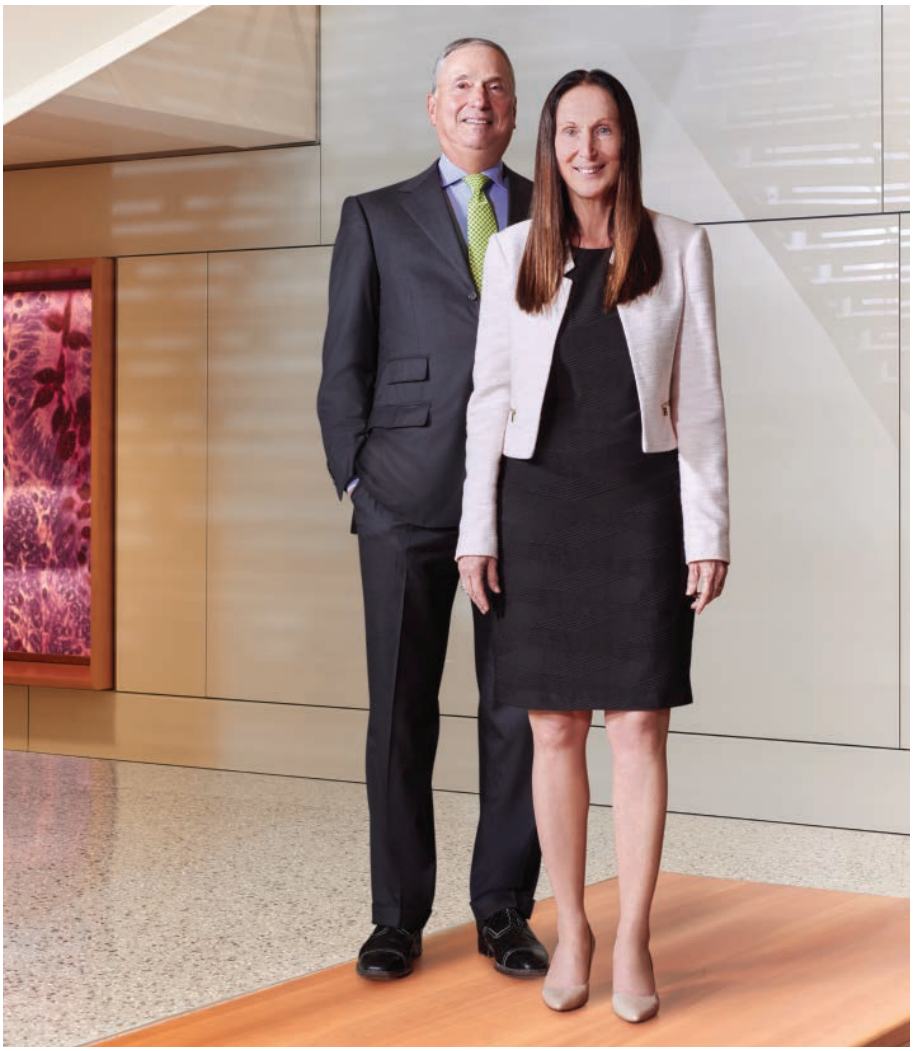
We look, we hypothesize, we experiment, and ***we look again.***

The images we create along the way can confirm or overturn assumptions, inspire new lines of inquiry, and often dazzle. Take a peek through the lens of NYU Langone biomedical research and see for yourself.

DEAR COLLEAGUES,

The striking photo that graces the cover of NYU School of Medicine's *2016 Research Report* reminds us of the power of science to inspire wonder and awe. Like the best art, its abstraction invites us to look deeper and more critically for meaning. Today, with so many advanced imaging tools at our disposal, we're doing just that with unprecedented resolution, slowly but steadily peeling back the layers of complexity that obscure the living world. Imaging, so central to biomedical research, makes a particularly rich theme for this year's report.

NYU School of Medicine's placement in *U.S. News & World Report*'s 2017 Best Graduate Schools Rankings jumped to #11, while NYU Langone placed among the top 10 hospitals nationwide in *U.S. News & World Report*'s 2017 Best Hospitals Rankings.



On the following pages, you will read about the many innovative ways in which our investigators are using optics and visualization techniques to advance our understanding of science and medicine. Their unique perspectives provide a fascinating window into a wide range of pressing health conditions, from diabetes and obesity to heart disease and autoimmune disease.

The research showcased here also reflects our continued success in attracting funding when more and more investigators nationwide continue to compete for fewer and fewer dollars. Our grant revenue totaled $328 million in 2016. As our funding grows, so does our community of leading investigators. We plan to double our research capacity over the next five years. Accordingly, we will open an expansive biomedical research building next year that will provide 10 floors of state-of-the-art laboratory space. Central to the building's design is a bridge that connects it to existing research facilities and Tisch Hospital, promoting communication between clinicians, researchers, and students.

The connection is a physical reminder of our trifold mission, which—in addition to biomedical research—embraces medical education and patient care. Last year brought exciting news in these areas. NYU School of Medicine's placement in *U.S. News & World Report*'s 2017 Best Graduate Schools Rankings jumped to #11, up from #14 the year before. In addition, for the first time in its history, NYU Langone placed among the top 10 hospitals nationwide in *U.S. News & World Report*'s 2017 Best Hospitals Rankings, coming in at #10 after ranking #12 last year.

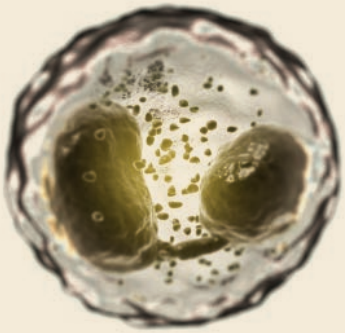
Our continued success as a leading academic medical center depends, in large part, on our team of gifted, enterprising scientists, some of whom you will meet in these pages. Their interests and insights in basic, translational, and clinical research vary widely, but all of them share the same noble goals: to improve the way disease is diagnosed and treated, to shorten the distance from the research bench to the patient bedside, and to alleviate human suffering.

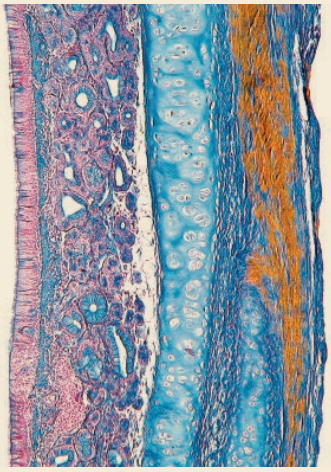
ROBERT I. GROSSMAN, MD
THE SAUL J. FARBER DEAN
AND CHIEF EXECUTIVE OFFICER

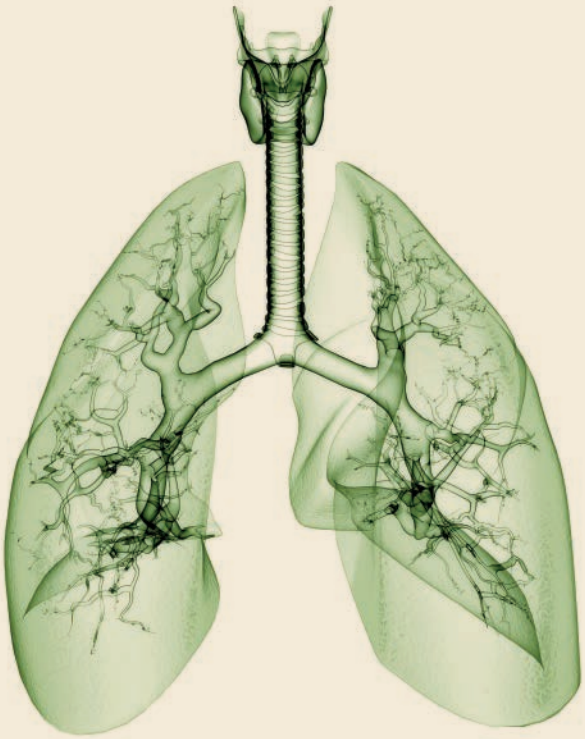
DAFNA BAR-SAGI, PhD
SENIOR VICE PRESIDENT AND
VICE DEAN FOR SCIENCE,
CHIEF SCIENTIFIC OFFICER

CONTENTS

Imaging is a natural bridge between basic and clinical research. At NYU Langone, we visualize disease across all scales, from molecules to organs, and everything in between. And because biological systems never work in isolation, neither do our researchers. Only by working together can we see the big picture and, in turn, find the big solutions.







TISSUE: A SYMPHONY OF CELLS

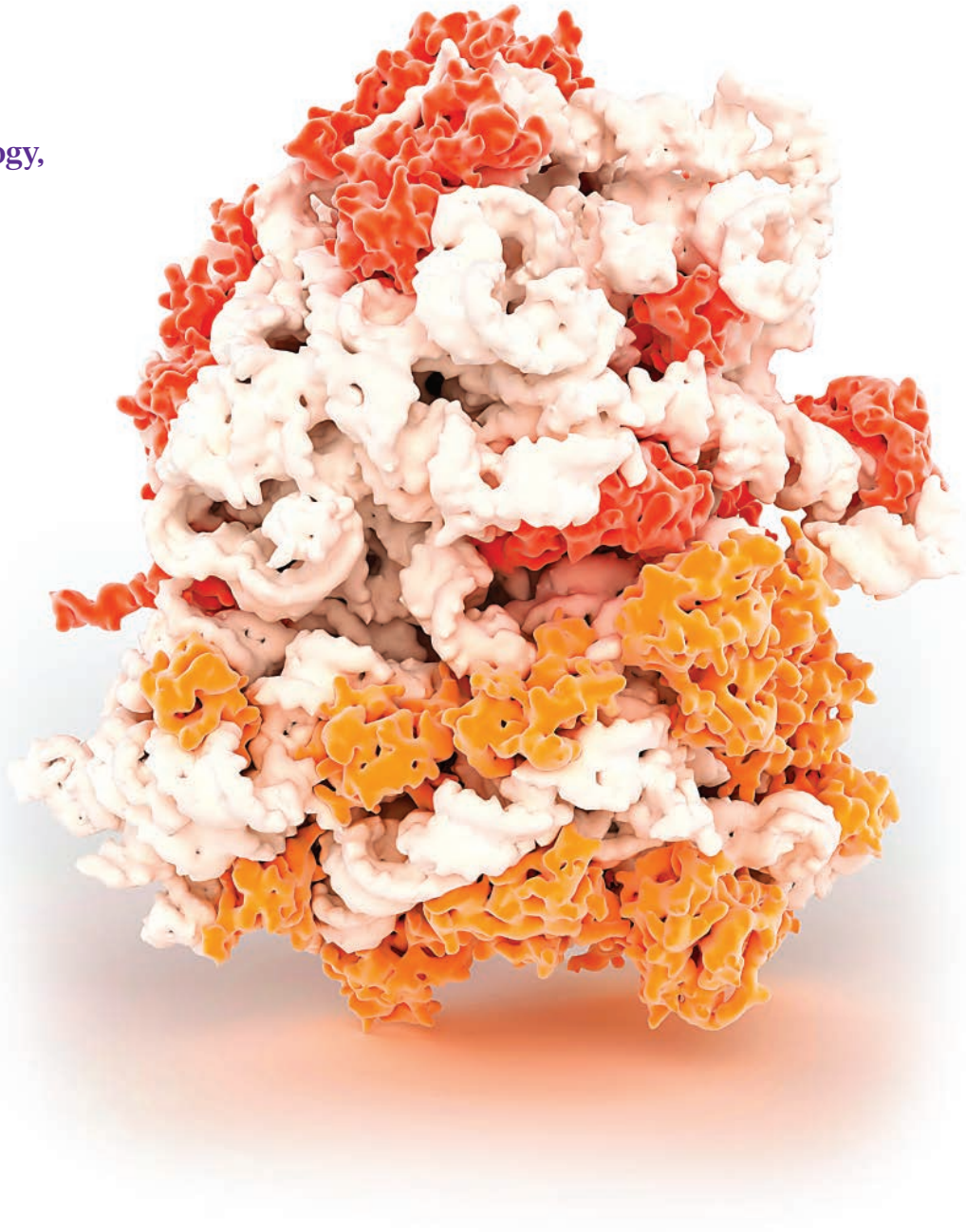
pg 14

ORGANS AS NEVER SEEN BEFORE

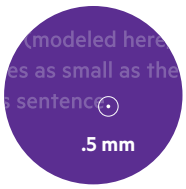
pg 18

THE HIDDEN WORLD OF MOLECULES

In the world of molecular biology, sophisticated imaging can present a paradox: the deeper scientists peer beneath the surface, the more complicated the picture often gets.



A ribosome (modeled here) is roughly 15,500 times as small as the period at the end of this sentence.



Today, we know that even the most rudimentary bacterial cell houses a universe of RNA, DNA, proteins, enzymes, and other essential cellular constituents. At NYU Langone, researchers are constantly innovating tools and techniques to visualize this cauldron of molecules to better understand how it animates life or unleashes disease.

→ **Jane Skok, PhD,** professor of pathology at NYU Langone, studies the highly organized structure of DNA and its elaborate rearrangements inside the nucleus of a cell. In doing so, she hopes to help unravel the complicated mechanism by which the immune system adapts to a constant onslaught of pathogens.

Adaptive immunity employs a reshuffling process that mixes and matches gene segments to generate a virtually endless assortment of antibodies. To visualize this process, Dr. Skok's team combines two powerful imaging techniques. One, called single-cell fluorescent in situ hybridization, or FISH, employs colorful fluorescent probes to label and track multiple points along a gene or chromosome. Another, known as chromosome conformation capture, is a population-derived approach that analyzes the organization of chromatin, a complex formed from DNA and proteins.

Using these techniques, Dr. Skok and her colleagues are documenting in high-resolution detail how chromosomes fold into loops, bringing distant genes into contact with each other and creating conformational changes that ultimately yield different antibodies for different invaders. Critically, her lab has discovered the molecule that jump-starts these changes.

"We want to understand the architecture of DNA in great detail to determine what impact it has on gene regulation," Dr. Skok says. "To do this, we're using genetic approaches to identify the sequences and binding factors involved in chromosome folding. We can then examine the influence of conformational changes on function."

In another project, recently published in *Nature Communications*, Dr. Skok and her team are developing a new four-dimensional imaging system, also based on fluorescent tagging, that can record videos of DNA moving inside a cell. "The live imaging is really cool because now we can start looking beyond

Jane Skok, PhD
Professor of pathology

"We want to understand the architecture of DNA in great detail to determine what impact it has on gene regulation," says Dr. Skok.

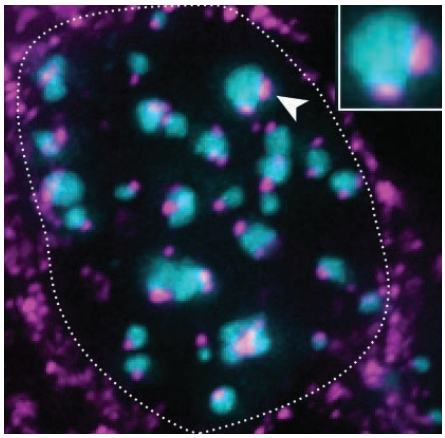


Image courtesy of the Skok Lab

Fluorescently labeled structures on a mouse chromosome illustrate a new technique developed by the Skok Lab called dual-color live imaging. The fluorescent blue tag is marking a larger region near the chromosome's midsection, or centromere, while the magenta tags are labeling two smaller regions of repetitive DNA sequences. Using fluorescent labels, this method allows researchers to track separate portions of the genome as they move inside living cells.

Da-Neng Wang, PhD
Professor of cell biology at the Skirball Institute of Biomolecular Medicine

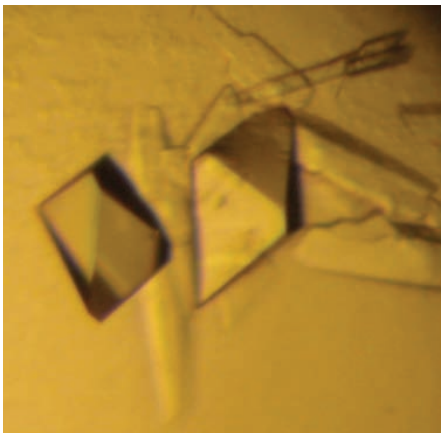


Image courtesy of the Wang Lab

These crystals of a membrane-spanning protein potentially linked to obesity, diabetes, and longevity helped the Wang lab solve the protein's atomic structure and clarify how it carries the building blocks of fatty acids and cholesterols into a cell.

Dr. Wang's lab has elucidated the structure of a protein critical for fat production. "If we can block it," says Dr. Wang, "we can potentially develop an anti-obesity drug."

snapshots of fixed cells," she says.

→ Like Dr. Skok, **Da-Neng Wang, PhD,** professor of cell biology at NYU Langone, explores the intersection of form and function at the molecular level. He and his team are using an imaging technique called X-ray crystallography to visualize the structure of a class of proteins—known as transporters—that carry molecules in and out of cells and that may play an important role in obesity, diabetes, and longevity. X-ray crystallography provides indirect physical and mathematical data about protein structure based on the precise ways in which a high-intensity X-ray beam bends around crystals.

One protein under investigation in Dr. Wang's lab is the sodium-coupled citrate transporter. It carries the main building blocks of fatty acid and cholesterol molecules from the blood into cells for the eventual production of body fat. Intriguingly, mice lacking this protein are leaner and live significantly longer than mice with it.

By repeating the X-ray crystallography technique at different moments during the transport process, Dr. Wang and his team have created a series of sequential images that clarifies how the protein sends its cargo into the cell, and reveals points in the process that could be disrupted to slow fat production. "If we can block the sodium-coupled citrate transporter in the membrane, we can potentially develop an anti-obesity drug," Dr. Wang says. Already, the pharmaceutical industry is using his team's structural snapshots to help design new fat-busting drugs.

→ **Alexander Serganov, PhD,** assistant professor of biochemistry and molecular pharmacology, uses X-ray crystallography to study a different protein, called the fragile X mental

MORE TO EXPLORE

→ **Karim-Jean Armache, PhD,** assistant professor of biochemistry and molecular pharmacology, uses X-ray crystallography and electron microscopy to study chromatin, a complex formed from DNA and proteins. His work is illuminating how various other proteins can modify chromatin to "silence" genes; if defective, this mechanism can lead to developmental disorders and cancer.

→ **Agnel Sfeir, DPhil,** assistant professor of cell biology, is applying immunofluorescence, confocal microscopy and other imaging tools to understand how repetitive DNA sequences called telomeres keep the ends of our chromosomes from fraying. Her research documents how dysfunctional telomeres or error-prone repairs can lead to unstable chromosomes and tumor formation.

retardation protein. FMRP, for short, is linked to fragile X syndrome, which can cause mild to severe intellectual, behavioral, and learning disabilities. "When we determine the structure of FMRP bound to other molecules with this technique, we can see FMRP's interactions, we can see them at the atomic level, and we can ultimately see what's wrong and what's right," says Dr. Serganov.

Scientists have known for more than two decades that FMRP interacts with messenger RNA molecules, templates for protein synthesis. The interaction likely helps turn protein production in brain cells on and off, thereby impacting memory and learning. "In 20-plus years, however, we still don't know exactly what this protein targets and what causes the disease when the protein is lost," Dr. Serganov says.

To help answer that question, the Serganov lab is crystallizing portions of the FMRP protein bound to pieces of RNA to determine the core patterns consistently recognized by the protein. Once identified, researchers can look for the same signature sequences in messenger RNA molecules and then identify which can bind to the protein. From Dr. Serganov's work so far, his lab has solved the first atomic-resolution structure of an RNA-binding domain of the protein bound to a piece of RNA. The study, published last year in *Proceedings of the National Academy of Sciences,* will help researchers understand how multiple protein-RNA interactions—or a lack of them—contribute to fragile X syndrome and other disorders.

TOOLS OF THE TRADE

Next year, NYU Langone will install two new state-of-the-art **cryo–electron microscopes** that operate at temperatures below –300° F to preserve proteins in a more natural state. With the molecules in deep freeze, an ultrasensitive camera captures 40 frames per second for remarkable resolution. "The image quality is so high that you can directly solve the structure of a large molecular complex without using crystals," Dr. Wang says (see "Power Tools," on page 22.)

Alexander Serganov, PhD
Assistant professor of biochemistry and molecular pharmacology

Alexander Serganov, PhD, uses X-ray crystallography to study the fragile X mental retardation protein. "When we determine the structure of FMRP bound to other molecules," he says, "we can ultimately see what's wrong and what's right."

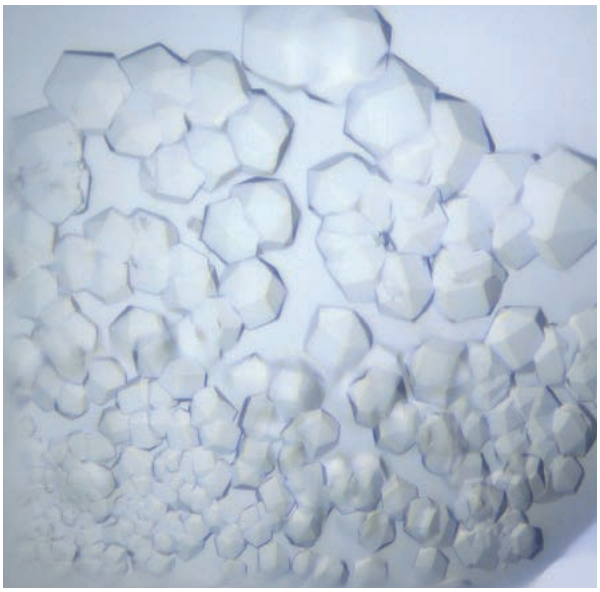
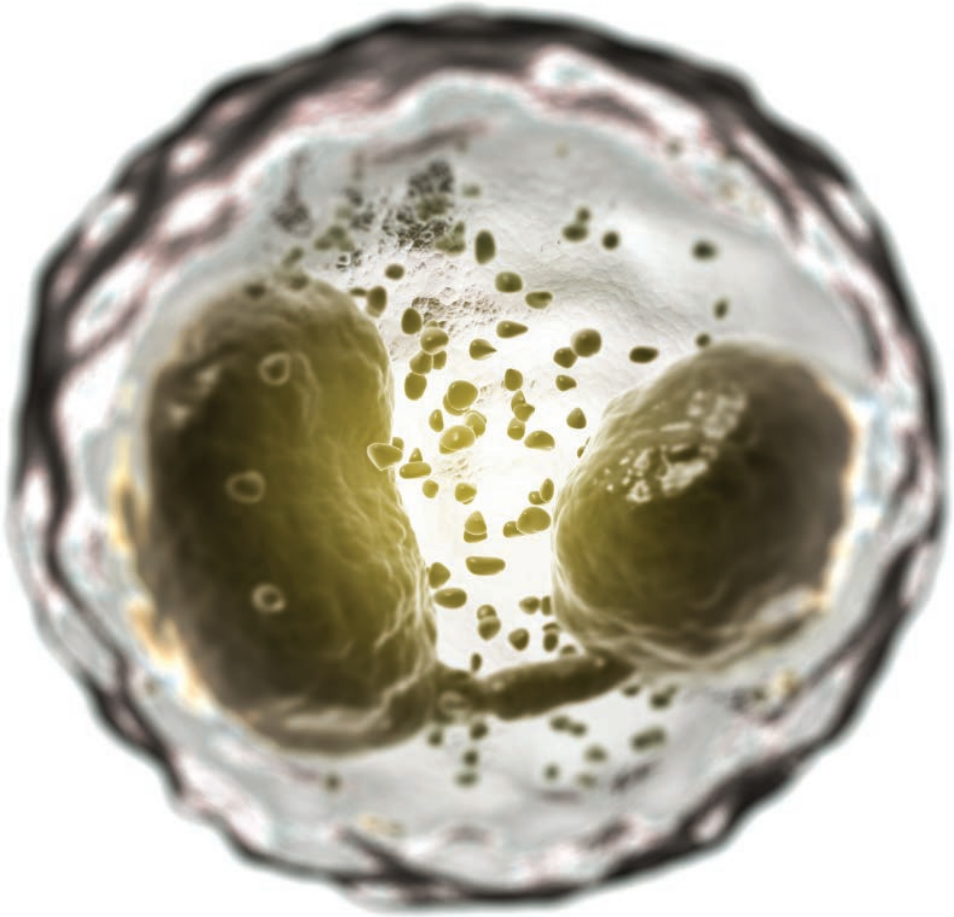


Image courtesy of the Serganov Lab

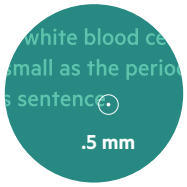
Crystals made from a fragment of the fragile X mental retardation protein bound to RNA, shown here, are helping the Serganov lab determine the signature RNA patterns recognized by this protein. A disruption in the protein-RNA interaction can cause fragile X syndrome.

CELLS IN THEIR NATURAL HABITATS

In 1653, a 26-year-old self-educated prodigy named Robert C. Hooke was studying a thin slice of cork through the lens of a homemade microscope when he was struck by an unusual pattern of compartments that he likened to misshapen honeycomb. He dubbed the structures "cells," and scientists have been using the term ever since to describe the basic building blocks of life.



The white blood cell shown here is roughly 27 times as small as the period at the end of this sentence.



Today, remarkable advances in microscopy afford researchers a view of these building blocks that Hooke could scarcely have imagined. At NYU Langone, such advances are helping biologists understand how a dizzying number of interactions among the body's 30 trillion cells can spark disease.

→ Cells, like the living things they occupy, respond to their environment, cueing off an invading microbe, say, or the scent of a dangerous chemical. **Susan Schwab, PhD,** associate professor of pathology, has developed an imaging technique, based on fluorescent tags, to investigate signals within the immune system that may help cells locate pathogens throughout the body. In particular, Dr. Schwab seeks to understand what happens when these cells don't do their jobs—by traveling to the wrong place and possibly triggering autoimmune diseases such as multiple sclerosis, or by abandoning their posts and leaving the body susceptible to blood-borne infections.

Recently, Dr. Schwab has zoomed in on a shadowy precursor to fats and oils—a lipid called sphingosine-1-phosphate, or S1P—that's been difficult to observe and study directly. "Signaling lipids play many, many important roles in the body," she says, "but we don't really have a good sense where they are."

Dr. Schwab's research is changing that. As described in the journal *Nature Immunology,* her imaging technique combines conventional confocal microscopy with modified green and red fluorescent labels. By attaching a bright green tag to a surface protein that binds to S1P, she can see when the signaling lipid enters the cell. Likewise, Dr. Schwab uses a red tag to label a mutated form of the binding protein. Because it can no longer recognize or internalize the S1P molecule, this mutant protein, set aglow, outlines the cell's periphery. If both the red and green-tagged proteins remain at the surface of a cell, the combined fluorescence makes the cell appear yellow and suggests that it hasn't encountered any S1P molecules.

With this labeling system, Dr. Schwab and colleagues are studying how the distribution of S1P throughout the body impacts certain immune cells. Their insights could lead to new medications for a host of autoimmune diseases. "You could develop drugs that target inflammation at the site of disease while largely leaving other systems intact," she says.

Recently, Dr. Schwab has used her tagging system to observe how cells respond to subtly different concentrations of S1P in places like the lymph nodes, small glands that can dispatch specialized cells to fight off infections. Her research suggests that S1P levels in the lymph nodes increase with proximity to the small veinlike tubes that drain the glands.

This location-dependent concentration, as she is finding, may play an important role in directing T cells to infection sites. Her research may also explain the mechanism

Susan Schwab, PhD
Assistant professor of pathology at the Skirball Institute of Biomolecular Medicine

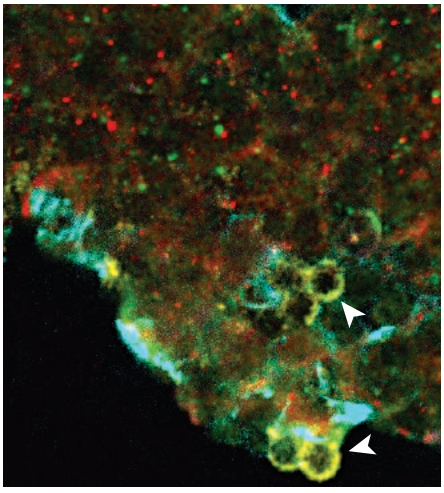


Image courtesy of the Schwab Lab

"You could develop drugs that target inflammation at the site of disease while largely leaving other systems intact," says Dr. Schwab.

This image of mouse lymph node cells shows green and red fluorescent labels used by the Schwab lab to tag a surface protein that normally binds to the S1P molecule. Tiny green dots indicate cells where the surface protein has recognized and bound to S1P, while the red label indicates a defective protein variant that no longer recognizes the molecule. A yellowish hue suggests the cell hasn't encountered S1P at all.

behind a recently developed drug for multiple sclerosis that disrupts S1P signals and effectively traps T cells in the lymph nodes, curbing some of the disease's autoimmune attacks on the brain.

Understanding the immune response is about identifying the right mix of cues that position "the right cells in the right place at the right time," Dr. Schwab says.

→ **Dmitry Rinberg, PhD,** associate professor of neuroscience and physiology, is elucidating the sprawling network of brain signals that process odor by literally opening a window on neurons in the mouse brain. "You are walking in the street, and suddenly you smell a whiff of coffee from a nearby café," he says. "How do you recognize it?"

Our sense of smell, though dull compared to canines or even mice, provides obvious advantages. With it, we can detect smoke or food past its prime. It may even help regulate mood. "We don't appreciate how important this sense is for our well-being and our everyday life," Dr. Rinberg says.

Classic odor experiments simply subject people or animals to different smells and observe their responses. Dr. Rinberg's lab was among the first in the world to instead use a light-based technique called optogenetics to manipulate genetically modified neurons that help the brain recognize different odors. In essence, he's triggering smell with laser light instead of odors. "Our animals can smell the light," he says. "We can deliver it with precise timing, and we can follow the signal in the brain to see how it propagates."

A physicist by training, Dr. Rinberg has teamed up with Shy Shoham, PhD, a bioengineering expert from Technion–Israel Institute of Technology, for a "completely new adventure" that allows him to watch signals start at one neuron and zip along to others in specific patterns. "We basically spy on the signals and try to understand how the information about odor is encoded in the activity of the cells," he says.

His chief tool is a microscope-based system that allows him to peer through a small window implanted into the head of a living mouse and see how the animal's brain cells, tagged with fluorescent proteins, respond to smell cues, either individually or collectively. "The great advantage is that I can see all of this," he says. "I can see thousands of cells simultaneously."

A recent iteration of the technique uses two-photon microscopy, in which short but powerful pulses of infrared light can travel up to tenfold farther into the brain than previous microscopy methods, allowing the researchers to observe individual cells as they fluoresce (see "Tools of the Trade" at right). "It's like a sky with many, many stars that are blinking," Dr. Rinberg says.

The eventual goal, he says, is to reproduce the same pattern of blinking cells with the laser-light switch—and ultimately determine what all of the blinking means. "If we can understand the neuronal code of odors, we can stimulate it optically," he says, "and really begin to understand how odor perception works in the brain."

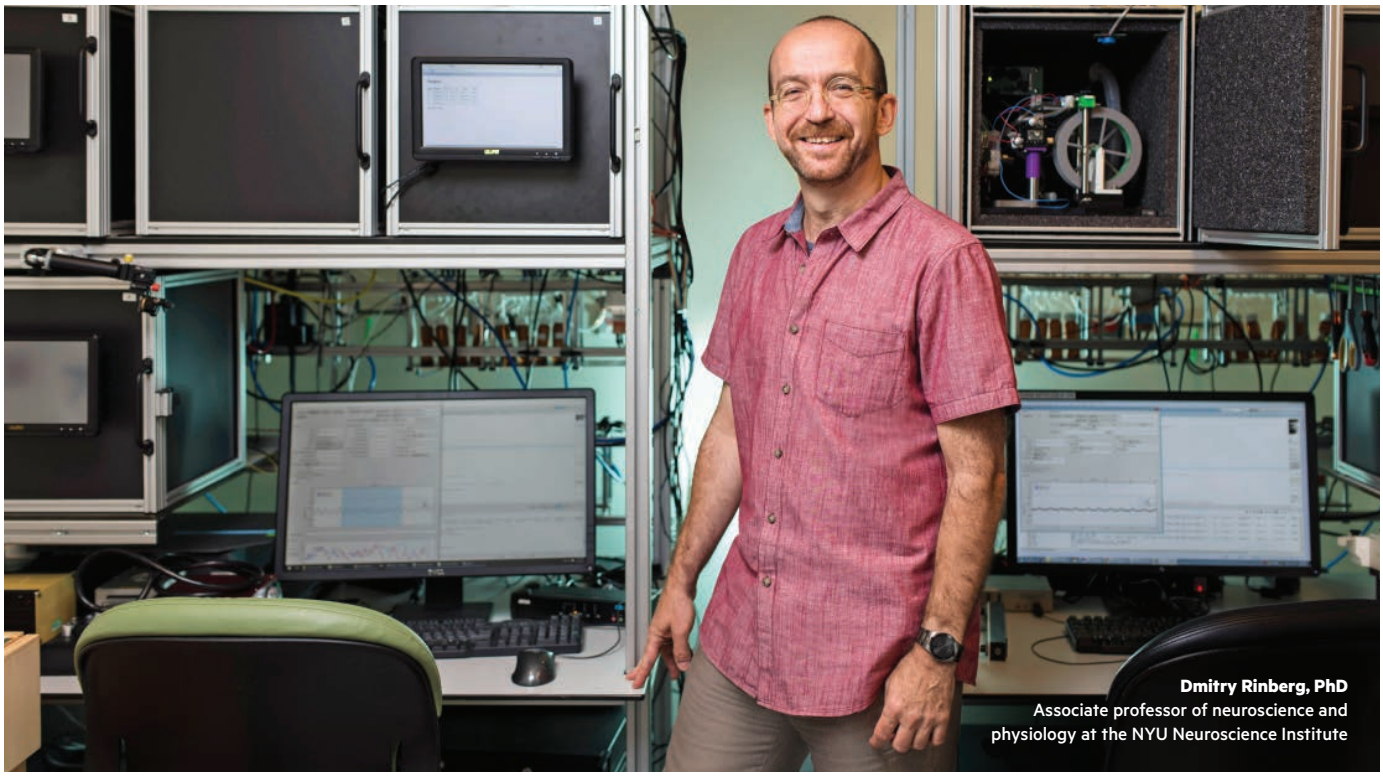
TOOLS OF THE TRADE

Neuroscientist Dmitry Rinberg, PhD, profiled on this page, and Guang Yang, PhD, assistant professor of anesthesiology, profiled on page 16, are among the NYU Langone researchers taking advantage of a powerful imaging method, called **transcranial two-photon laser scanning microscopy.** Pioneered by colleague Wenbiao Gan, PhD, professor of neuroscience and physiology at NYU Langone, the technique generates razor-sharp images of living cells, in mice, up to 1 millimeter beneath the surface of the brain—all without damaging the surrounding tissue. One way it does this is by exploiting infrared lasers and quantum mechanics to visualize fluorescently tagged brain cells.

MORE TO EXPLORE

→ **David Schoppik, PhD,** assistant professor of neuroscience and physiology, and otolaryngology, employs high-speed videography and cutting-edge optical microscopy to study how the neurons of a developing zebrafish establish its sense of balance. Understanding how these brain cells use external cues to guide reflexive behavior may help researchers treat balance-related disorders.

→ **Mario Delmar, MD, PhD,** the Patricia and Robert Martinsen Professor of Cardiology, is combining super-resolution microscopy with electron microscopy to understand how specific molecules work together as a network to help cardiac cells stick together, form interconnected channels, and transmit electrical signals. A breakdown of this complicated network can lead to heart arrhythmias that cause sudden death in young people.



Dmitry Rinberg, PhD
Associate professor of neuroscience and physiology at the NYU Neuroscience Institute

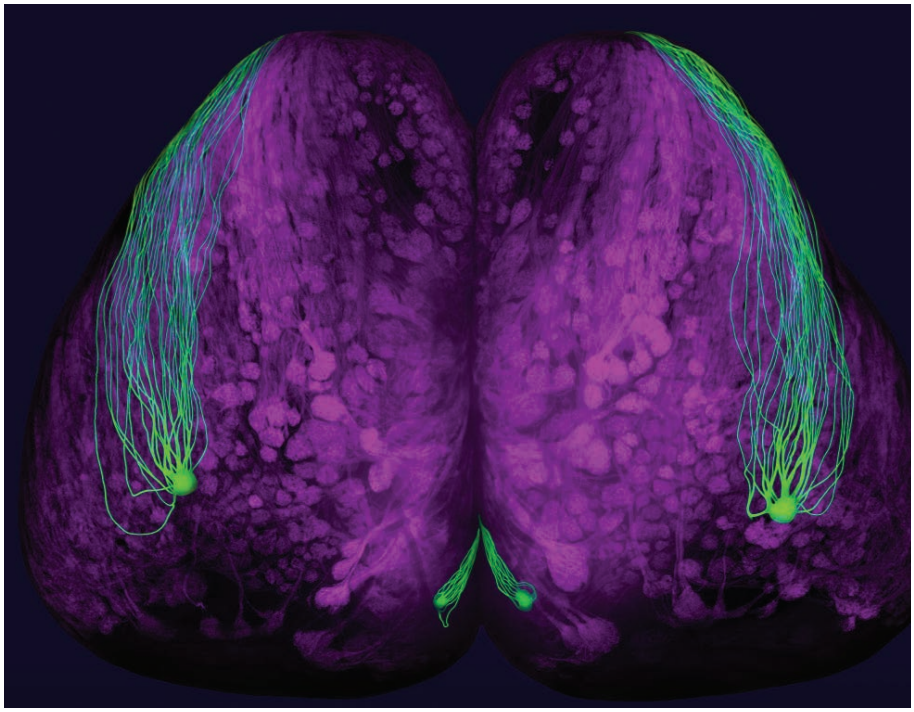
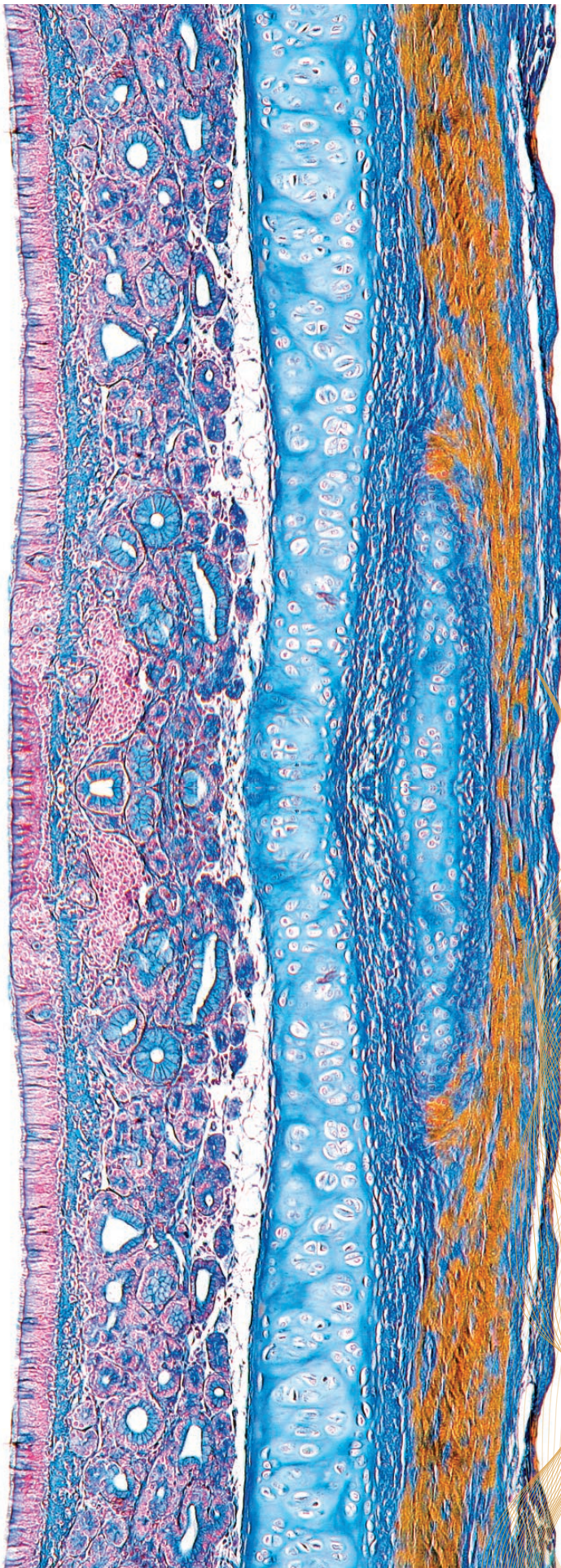


Image courtesy of the Rinberg Lab

The Rinberg lab uses a variety of odors (shown in bottles above) to understand the neural basis of olfaction in mice. The illuminated image of a mouse brain (left) demonstrates a light-based technique called optogenetics, in which the lab uses a laser to "turn on" specific sensory neurons (represented by green dots) that initiate the brain's odor recognition pathway.

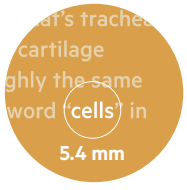
"You are walking in the street, and suddenly you smell a whiff of coffee from a nearby café," Dr. Rinberg says. "How do you recognize it?"

TISSUE: A SYMPHONY OF CELLS



In 1858, German anatomist Joseph von Gerlach soaked a few pieces of brain tissue overnight in a puddle of staining solution derived from insects. By morning, the stain had neatly outlined many of the microscopic features of the tissue, and thus began the scientific discipline of histology.

The average diameter of a cat's trachea (shown here with stained cartilage chondrocyte cells) is roughly the same size as the length of the word "cells" in this sentence.



With the aid of dyes, fluorescent stains, and better microscopes, researchers began to see a fascinating pattern. The body's trillions of cells eventually organized themselves into just one of four fundamental tissue types: muscle, nervous, connective, and epithelial.

Each tissue plays a distinct role in the body, and many can reveal telltale signs of disease. Yet most static images do little to clarify how cells receive their instructions to work and move in coordination as tissues with a common purpose, whether in assembling an organism, deriving energy from food, or allowing the brain to learn new skills.

→ **Jeremy F. Nance, PhD,** associate professor of cell biology, and other researchers at NYU Langone are focusing on the combined actions of multiple cells and cell types that often work as tissues. The process, he says, is like decoding the spirited hand gestures and facial expressions of a master orchestral conductor.

Dr. Nance uses the embryo of a small roundworm called *Caenorhabditis elegans* as a model system to understand how cells move to the right place and organize into tissues and properly shaped organs during development. "Some organs have many different cell types, so they all have to come together and function," he says. "How does that happen?"

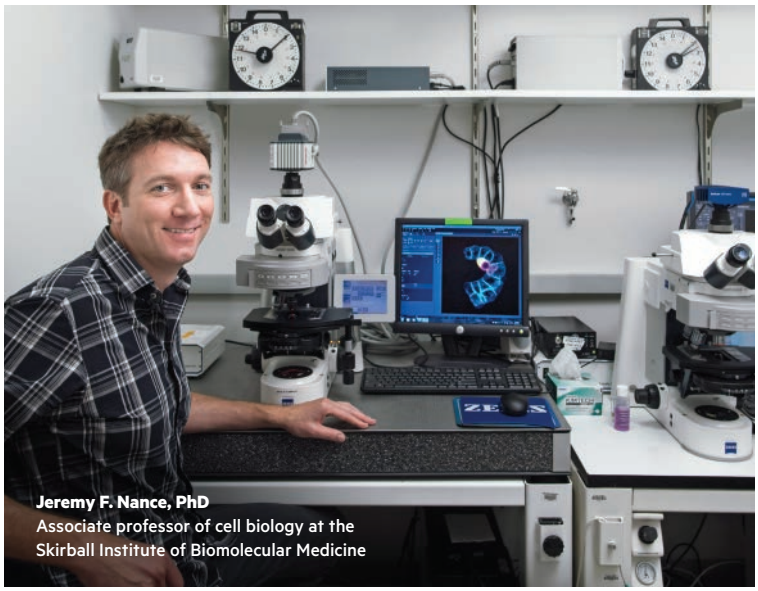
Thanks to the worm's transparency, his lab can see all of the cells in living embryos through magnification by a standard confocal microscope. Because *C. elegans* has been so well studied, researchers can kill a single precursor cell with a laser, see how that loss alters the developing body, and then deduce the role of the missing cell and its descendants.

The lab uses green, red, and other fluorescent tags to outline the magnified cells' surfaces and track their movements. A newer technique called light-sheet fluorescence microscopy (see "Tools of the Trade," on page 17) can capture an image in a fraction of the time, allowing Dr. Nance to snap pictures and make movies of the football-shaped embryo as it develops and moves around.

In one study, Dr. Nance and colleagues identified a protein that demarcates cell borders in the embryo and provides cues that help cells migrate to their final destination during development. Mutating this protein results in embryos with improperly positioned cells. Damaged proteins can also generate faulty signaling, they found, and direct cancer cells to other parts of the body during metastasis. "If you understand these basic rules, then you can apply them to different scenarios because a cell in *C. elegans* is remarkably similar to a cell in a human," Dr. Nance says.

→ **Guang Yang, PhD,** assistant professor of anesthesiology, is trying to understand how changes in cell-to-cell neural circuitry can impact thinking and memory. When mice learn a new skill, for example, how do new synapses form to connect the right neurons?

As a postdoctoral researcher



Jeremy F. Nance, PhD
Associate professor of cell biology at the Skirball Institute of Biomolecular Medicine

"Some organs have many different cell types, so they all have to come together and function," Dr. Nance says. "How does that happen?"

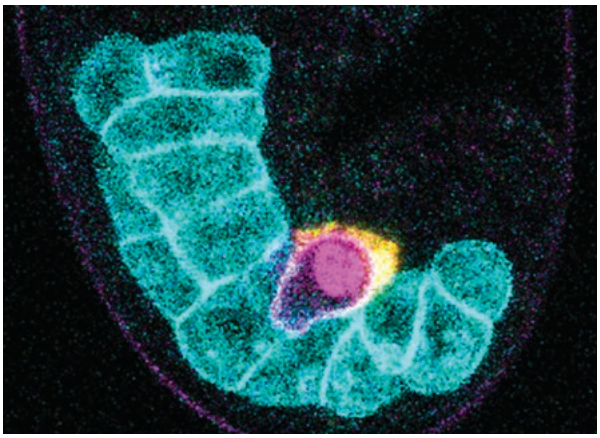
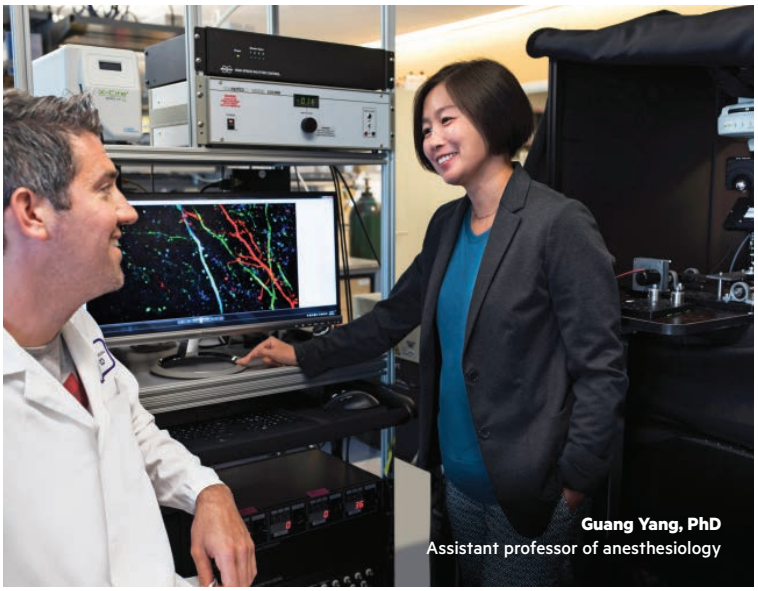


Image courtesy of the Nance Lab

This confocal microscopy image of a *C. elegans* embryo shows the three cell types needed to make the gonad, or reproductive gland. A gonadal support cell (yellow) wraps around the germ cell (magenta), which will give rise to egg or sperm. Both of these cells are held in place by intestinal cells (cyan). Each cell type has been illuminated via a differently colored fluorescent protein.



Guang Yang, PhD, and collaborator Joseph Cichon, PhD (left), review an image of active dendrites, or the information-receiving extensions of neurons, aglow in the primary motor cortex of a mouse running on a treadmill. In this time-lapse, the imaging system has successively illuminated individual dendrites, shown in blue, green, and red.

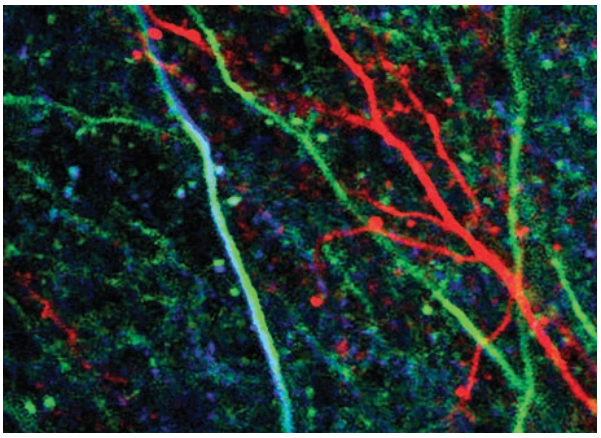


Image courtesy of Joseph Cichon, PhD, the Gan Lab

"I'm always fascinated by imaging studies," says Dr. Yang. "I want to directly observe what's really going on, to see with my own eyes what's happening within the neuronal circuits."

at NYU Langone, Dr. Yang worked with Wenbiao Gan, PhD, professor of neuroscience and physiology, on an imaging technique called in vivo transcranial two-photon imaging (see "Tools of the Trade," page 12). The technique creates a window into the brain of a living mouse and uses an infrared beam to light up cells tagged with fluorescent labels. "I'm always fascinated by imaging studies," says Dr Yang. "I want to directly observe what's really going on, to see with my own eyes what's happening within the neuronal circuits."

In a study published in *Science,* she and colleagues found that sleep promoted the formation of new brain connections in a mouse that had learned a new skill. "The animal is doing a task, and at the same time, we are collecting an image from the animal's brain so we can directly see learning-related changes in neuronal structure and function," she says.

Dr. Yang's recent work suggests that an overblown immune response—a reaction linked to conditions such as chronic pain and Alzheimer's—may instead impair the ability of the brain's neurons to link up correctly. Similarly, she and colleagues have reported recently in the journal *Anesthesiology Science Translational Medicine* that repeated exposure to anesthesia early in life impaired the ability of mice to form new neuronal connections and led to a neurodevelopmental disorder. "It's like their learning potential is limited," she says.

→ **Prodromos Parasoglou, PhD,** assistant professor of radiology, is developing an imaging technique that can accurately measure the relative concentrations of phosphorus in body tissue. Phosphorus is an important proxy for cell metabolism as a direct by-product of many basic cellular reactions, such as extracting energy from food, and one that can help pinpoint early signs of disease that

MORE TO EXPLORE

→ Collaborators **Dmitry Novikov, PhD,** and **Els Fieremans, PhD,** assistant professors of radiology, are using modeling and analytical techniques to extract additional information from MRI images of body tissue, such as the brain's white matter. Their technique could help identify disease markers and point out key differences between reversible and irreversible changes in Alzheimer's and multiple sclerosis.

→ **Bhama Ramkhelawon, PhD,** assistant professor of surgery and cell biology, is studying the mechanism underlying life-threatening abdominal aortic aneurysms, in which the artery wall balloons and can eventually rupture. Doppler imaging and fluorescence microscopy in mice are helping her track the aneurysm's development and progression, and pinpoint molecular contributors.

disrupt energy metabolism. "We believe that by using accurate imaging tools to measure changes in metabolic function, we can begin to understand diseases such as obesity, diabetes, and Alzheimer's, and hopefully delay or even reverse their effects," Dr. Parasoglou says.

An engineer by training, Dr. Parasoglou is collaborating with Ryan Brown, PhD, assistant professor of radiology, to build hardware, software, and data analysis tools "from scratch" that can determine the location and level of phosphorous metabolites. Their main imaging tool is a variant of magnetic resonance imaging, or MRI, which uses strong magnetic fields and radio waves to pick up signals emitted by water molecules and produce detailed maps of water-bearing tissues.

The collective signal from phosphorous metabolites is 1/100,000th the strength of conventional MRI signals. As a solution, the team has precisely tuned the MRI scanner to recognize and point out phosphorous concentrations in tissues of interest. Beyond the brain, the researchers are investigating how metabolic impairment in leg muscles can lead to complications in the lower extremities of diabetic patients.

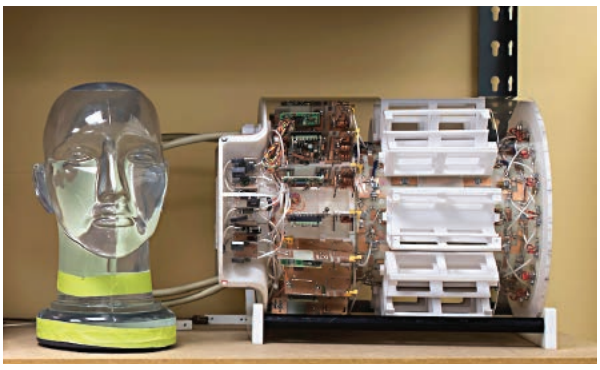
As Dr. Parasoglou and his team reported recently in the journal *NeuroImage,* they have been able to see phosphorous metabolite levels in several brain structures and regions with unprecedented clarity. "So now we're ready to acquire data and understand what part of the brain or what part of the muscle fails," he says. "If we have a quantitative tool that can pick up those changes way before they result in cognitive impairment, perhaps we can slow them down," he says. "Or even more important, we can reverse them."

TOOLS OF THE TRADE

Light-Sheet Fluorescence Microscopy

A widely used imaging method called confocal microscopy uses a laser light to scan back and forth across cells until it yields a single magnified image. This technique works well for motionless tissue but can lead to frustrating blurs when trained on more active organisms such as the wriggling embryos of a worm called *C. elegans*. A more advanced technique called **light-sheet fluorescence microscopy** illuminates the entire field of view at once, making it up to 1,000 times faster at acquiring images and a boon for mapping larger tissue structures. The newer method not only allows scientists to take clearer pictures of moving cells and tissues, but also prevents unnecessary laser damage and stress to sensitive organisms such as developing worms.

Prodromos Parasoglou, PhD
Assistant professor of radiology

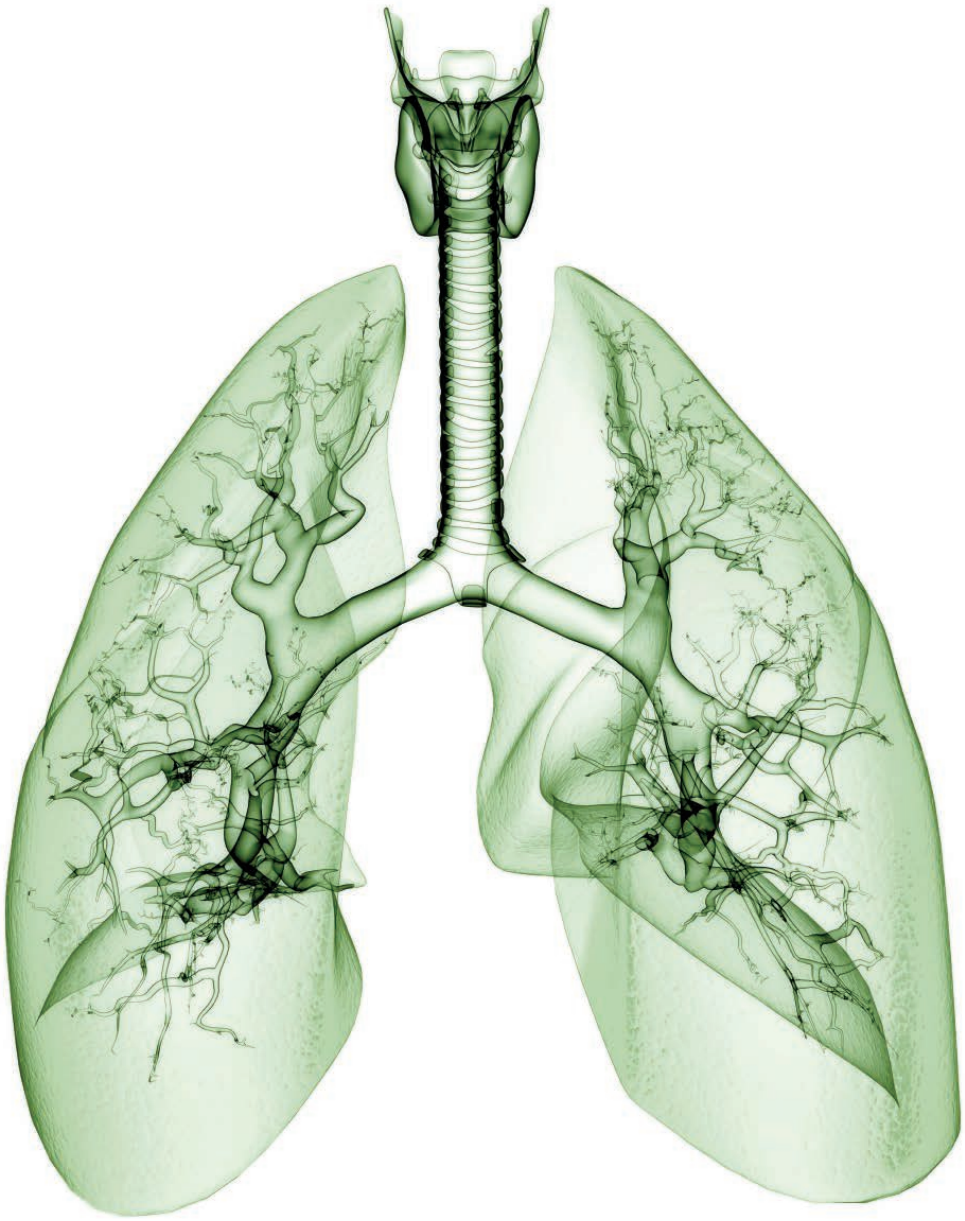


Prodromos Parasoglou (left) has collaborated with colleagues like Ryan Brown, PhD, assistant professor of radiology (right), to build and operate imaging devices such as a phosphorous/proton coil to image muscles of the lower leg (shown here with a water-filled head used to demonstrate a related brain-imaging technique).

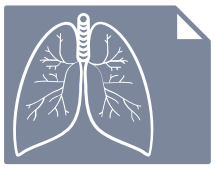
"We believe that by using accurate imaging tools to measure changes in metabolic function, we can begin to understand diseases such as obesity, diabetes, and Alzheimer's, and hopefully delay or even reverse their effects," Dr. Parasoglou says.

ORGANS AS NEVER SEEN BEFORE

The field of medical imaging has come a long way since 1895, when German physicist Wilhelm Röntgen aimed an electron beam at his wife's hand and imaged her bones and wedding ring on a photographic plate, generating what's believed to be the first X-ray.



The average height of a man's lungs (shown here) is slightly smaller than the width of this page.

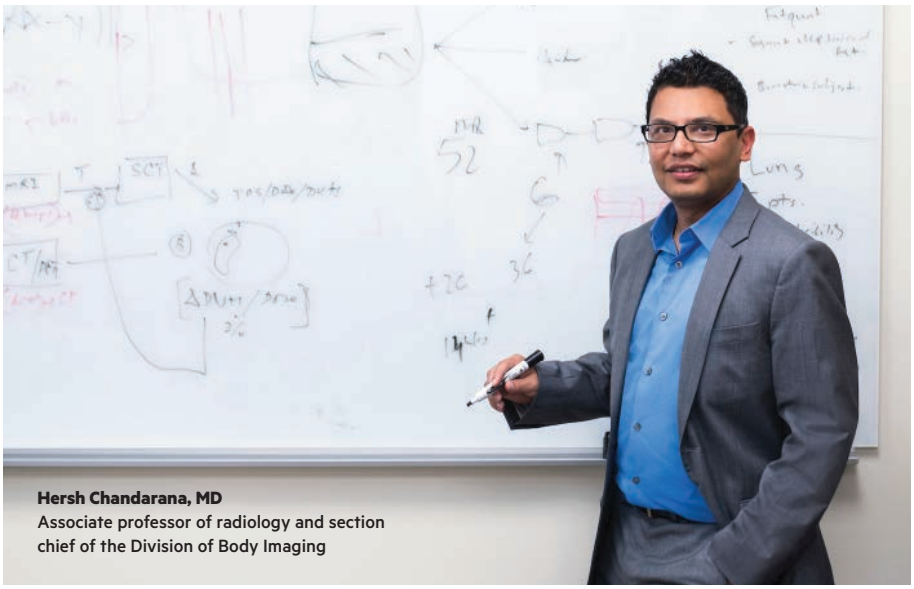


Today, millions of radiological images are created every year in the U.S., thanks to a growing suite of sophisticated tools, several of which have been advanced by researchers at NYU Langone.

→ Among these investigators is **Hersh Chandarana, MD,** an NYU Langone radiologist who's making MRIs of the liver, pancreas, kidney, and abdomen that are faster, more accurate, and far more comfortable for patients. "MRI exams can be an ordeal, especially for children, because we ask them to hold their breath and sit stock-still while we try to acquire images," he says.

Dr. Chandarana's lab is developing MRI techniques that eliminate motion from the scanning data, reconstructing an image only from data points acquired at very precise times during the procedure, such as at the very end of every exhale. "We're actually using less data to make better images," Dr. Chandarana says. As a result, patients can move and breathe normally inside the MRI tube, without sedation, while radiologists get a better view. In fact, the improved resolution has allowed his group to better detect tumors and even analyze the structure of blood vessels within the tumor—a challenging assessment with conventional MRI resolution.

Other methods are helping Dr. Chandarana distinguish between aggressive and benign kidney tumors. One technique, a type of diffusion MRI, measures how cancerous tissue restricts the motion of water molecules flowing through the body, exploiting the fact that more complex tumors and tissues restrict more water than benign ones. Combining the technique with perfusion MRI, which detects differences in the complexity of blood vessels, has shown great promise in spotting deadly kidney tumors.



Hersh Chandarana, MD
Associate professor of radiology and section chief of the Division of Body Imaging

With a conventional MRI, the borders of the large pale mass shown at right would be indistinct in this six-year-old patient. Dr. Chandarana's free-breathing-motion robust MRI shows much crisper borders and confirms that the mass is contacting but not invading the patient's heart.

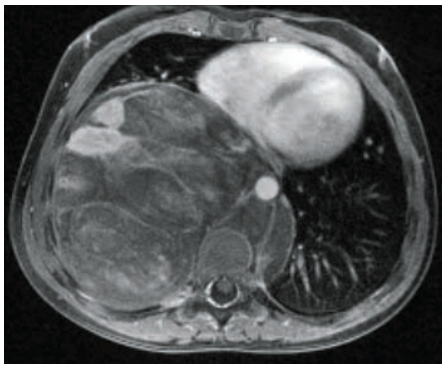


Image courtesy of the Chandarana Lab

"We're actually using less data to make better images," Dr. Chandarana says.

→ Cardiologist **Glenn Fishman, MD,** the William Goldring Professor of Medicine and director of the Leon H. Charney Division of Cardiology, meanwhile, has trained his focus on the heart. In particular, he and his team study the irregular heartbeats that can cause sudden death, a phenomenon that kills more than 300,000 nonhospitalized people in the U.S. every year. "Our team is trying to understand the underlying arrhythmia mechanisms and use that knowledge to come up with predictive tools for at-risk patients and new therapeutic strategies," Dr. Fishman says.

Among his aims is to demystify the heart's cardiac conduction system, a small but critical network of specialized heart cells, called Purkinje cells, that control the organ's electrical behavior and establish its normal rhythms. His lab's main imaging technique is based on green fluorescent tags that illuminate targeted genes. "If you looked at the inside of a mouse heart without the fluorescent color, you'd just see these nooks and crannies,"

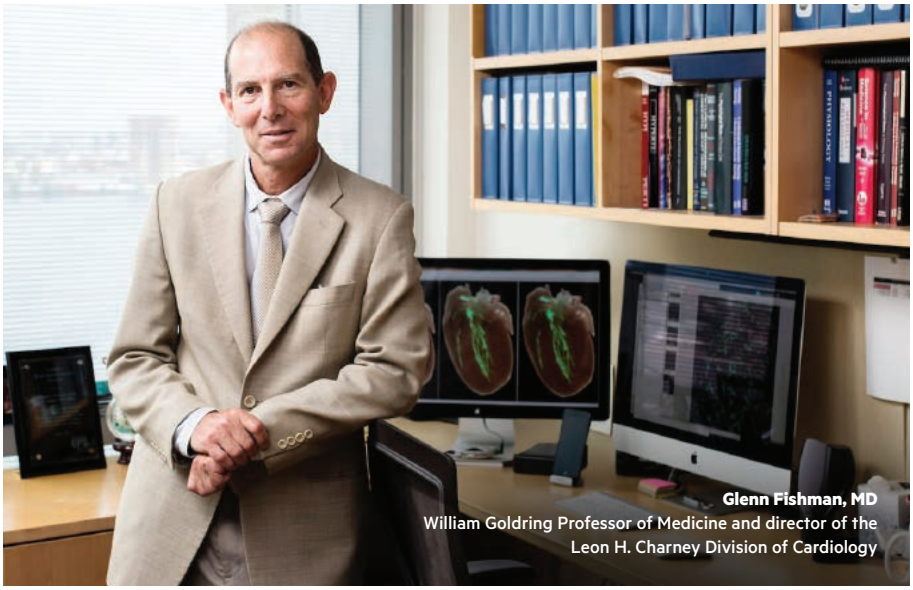
Dr. Fishman says. "Everything would look the same. Turning on the fluorescent color is like illuminating a branching tree through the organ."

Molecular studies of the glowing Purkinje cells can reveal their most active genes, while electrode-based tests help measure their electrical activity. "Imaging helps us find the needle in the haystack of these very rare cells," notes Dr. Fishman. He and his team have also identified multiple genes that act like master programmers to coax stem cells into Purkinje cells. Some factors "prime the pump" of stem cell development, they've found, while others turn on specific genes that guide the cells' behavior. By knowing the genes involved in the process, Dr. Fishman can begin to ask whether some are mutated or abnormally active or inactive in human diseases. "I think we're starting to understand the blueprint," he says.

→ **Biyu Jade He, PhD,** assistant professor of neurology, neuroscience and physiology, and radiology, is using cutting-edge imaging techniques to understand conscious awareness. In other words, she says, "How do the two pounds of meat between our ears generate this rich experience that defines us?"

Understanding the basis of the brain signals necessary for consciousness could help researchers intervene in cases of distorted perception, a hallmark of psychiatric disorders like schizophrenia. "We could be perceiving what comes out of our own brain as if it is coming from the external world," Dr. He says. "Those are the cases where you have hallucinations." Another condition, called alien hand syndrome, distorts free will, preventing a stroke patient from controlling the movements of one hand. For instance, the left hand may be unbuttoning a shirt while the right hand buttons it.

To get at the basis of consciousness, Dr. He's group is using high-field functional magnetic resonance imaging, or fMRI, to measure brain activity based on changes in blood flow. Other techniques, including electroencephalography and magnetoencephalography, record the electric and magnetic fields generated by neurons. "There is a unique opportunity to understand how a healthy human brain functions," Dr. He says. "In turn, our insights can



Glenn Fishman, MD
William Goldring Professor of Medicine and director of the Leon H. Charney Division of Cardiology

"Imaging helps us find the needle in the haystack of these very rare cells," notes Dr. Fishman.

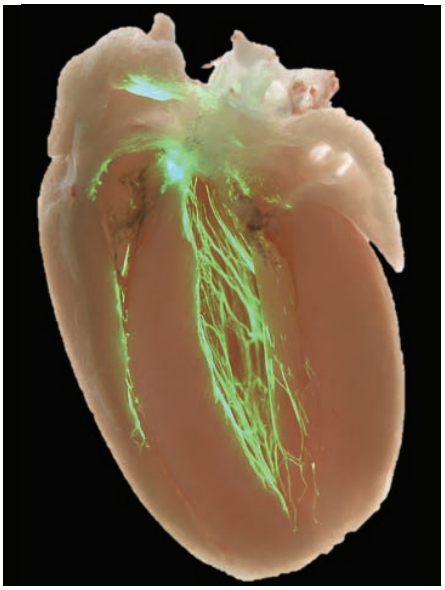
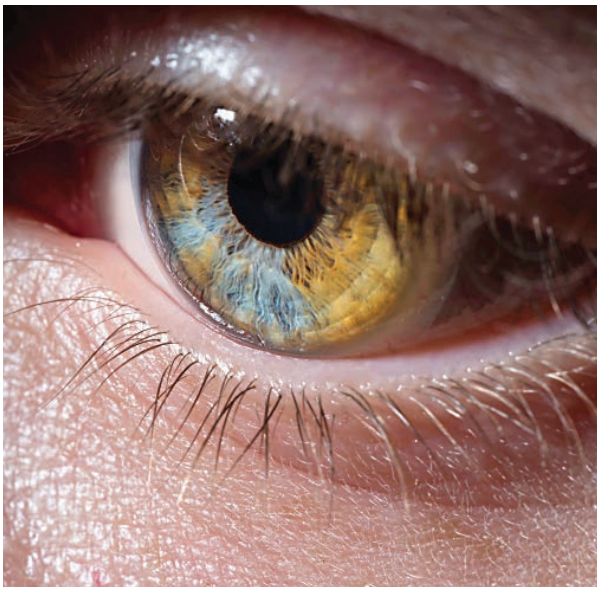


Image courtesy of the Fishman Lab

Specialized heart cells called Purkinje cells are shown here within a mouse heart as a fluorescent green treelike network that forms the cardiac conduction system.

Biyu Jade He, PhD
Assistant professor of neurology, neuroscience and physiology, and radiology



When we perceive our surroundings, that conscious awareness is generated by the brain through an unknown process. The He lab is using cutting-edge imaging techniques and studying brain activity patterns in human volunteers to better understand how varying brain activity gives rise to different conscious experiences.

"There is a unique opportunity to understand how a healthy human brain functions," Dr. He says. "In turn, our insights can translate back to clinical care."

translate back to clinical care." Through a collaboration with neurosurgery, Dr. He is also using electrocorticography, a technique in which surgeons place a sheet of electrodes on the brain's surface to directly record the neural activity in patients with epilepsy.

From her studies so far, Dr. He has learned that conscious awareness is not concentrated in one region of the brain but generated by large-scale networks distributed across different parts of the organ. The decentralized web of connections means that a relatively isolated injury would be unlikely to prompt a complete breakdown of awareness. However, diffuse damage throughout the brain or an injury to a location that connects to many others, such as the thalamus, could prompt a total loss of awareness. "It's a bit like you turn off the switch to the brain," Dr. He says.

MORE TO EXPLORE

→ **Ricardo Otazo, PhD,** associate professor of radiology, is developing new imaging methods based on a mathematical technique called "compressed sensing" to glean the most information from the least amount of data. His research may speed up MRI scans, reduce the radiation dose needed for CT scans, and improve image resolution by accounting for normal movements of the heart and lungs.

→ **Kai Tobias Block, PhD**, assistant professor of radiology, is likewise working to improve MRIs, especially for children and other patients who cannot remain still during an exam. Beyond using compressed sensing to accelerate the scans, he has focused on a technique called radial sampling that gleans accurate imaging data despite patient movements; so far, the technique has been applied to more than 13,000 abdominal, brain and prostate scans.

TOOLS OF THE TRADE

Magnetic Resonance Imaging, Big and Small

NYU Langone's Siemens 7 Tesla whole body MRI in the Department of Radiology's Bernard and Irene Schwartz Center for Biomedical Imaging stands as the most powerful MRI machine in the New York metropolitan area. The 30-ton scanner features more than 200 miles of superconducting wire, delivering enough resolution to visualize even the smallest metabolic pathways of the brain. Meanwhile, in laboratories at NYU Langone's Center for Advanced Imaging Innovation and Research, investigators are working to shrink the footprint of MRIs' gargantuan magnets, laying the groundwork for handheld MRI scanners and tabletop machines that boast the same resolution as their bulkier counterparts.

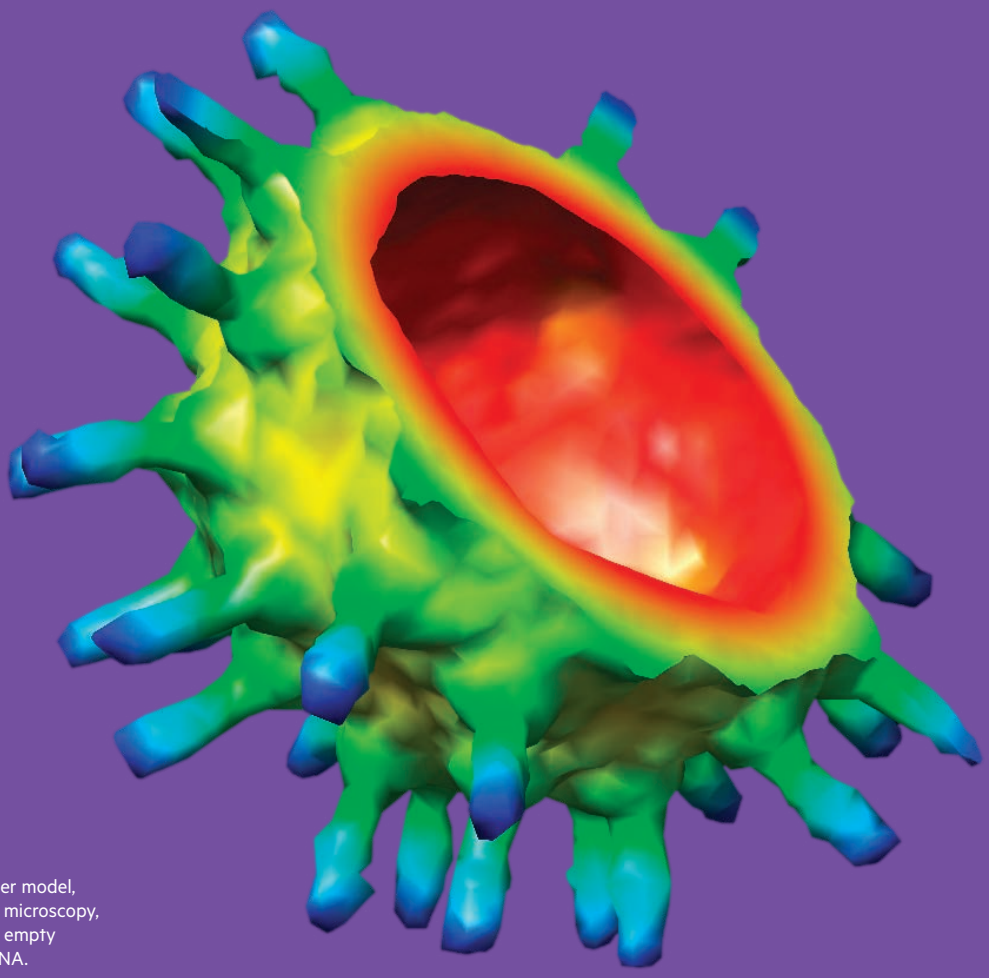
POWER TOOLS

A suite of new instruments, techniques and services at NYU Langone takes imaging to the next level.

CRYO-ELECTRON MICROSCOPY

Extreme cold, extreme resolution

To discern the bewilderingly complex shape of proteins—among the most elaborate molecules known to science—researchers historically have turned to a technique known as X-ray crystallography. This tried-and-true method assembles the three-dimensional structure of a protein from a blueprint of mathematical and physical calculations based on how a high-intensity X-ray beam scatters when it hits a crystallized form of the molecule. Each saltlike crystal might contain a billion or more neatly ordered copies of the protein, helping to amplify the signal. But it's notoriously easy to grow an impure or flawed crystal that distorts the



SUPER COOL: This detailed 3-D computer model, developed with the aid of cryo–electron microscopy, shows a cross-sectional view of a virus's empty protein shell, which normally contains DNA.

Image courtesy of Science Photo Library

X-ray beams and yields an unusable blueprint. Getting the process right can take many years, or not work at all, especially for large, complex protein assemblies that carry out many important cellular processes.

Researchers at NYU Langone will soon have access to a powerful alternative called cryo–electron microscopy (cryo–EM) that could dramatically improve our understanding of protein structure. "This technology has exceeded even the most optimistic expectations," says **David Stokes, PhD,** professor of cell biology and scientific lead of the collaborative effort to bring cryo–EM to the Medical Center. "So now it's in real competition with X-ray crystallography because it can produce the same level of detail—atomic resolution—and you don't have to make crystals."

Descendants of the electron microscopes first developed in the 1960s, cryo–EM machines fire a volley of high-energy electrons at a carefully preserved sample—such as a protein or virus particle—that has been flash-frozen in a tiny pool of liquid ethane kept at more than –300º F. Cryo–EM's deep freeze keeps proteins in a natural state and preserves features down to the atomic level. Enough electrons are deflected by the sample to create two-dimensional images that can be merged into a single 3-D picture.

Previous electron microscopes tended to yield blurry and grainy images due to shifting samples and damage inflicted by the electron beam. The latest cameras, however, have "totally revolutionized the electron microscopy world," Dr. Stokes says. The cameras, known as direct detectors, can create a panoramic image by taking a movie of the target molecule and automatically stitching that movie into a single sweeping image. "We record the movie at many frames per second, and then we analyze the frames and look for movement in the sample," Dr. Stokes says. "The sample is still moving, but we can track it and compensate for that motion and create a summed image where the blur has been effectively eliminated." The cameras also reduce noise levels by efficiently collecting the deflected electrons, yielding up to 1,000 superresolution composite images during each 24-hour automated photo shoot.

Two new cryo–electron microscopes will be available through NYU Langone's Imaging Core by the end of 2017. That expanded access, Dr. Stokes says, will likely foster new collaborations with cryo–EM experts and will help many researchers decipher the fine structural details of molecules that have long seemed just out of reach.

"This technology has exceeded even the most optimistic expectations," says David Stokes, PhD, professor of cell biology and scientific lead of the collaborative effort to bring cryo–EM to the Medical Center. "So now it's in real competition with X-ray crystallography because it can produce the same level of detail—atomic resolution—and you don't have to make crystals."

BIOINFORMATICS

Finding meaning in images

Today, even a casual photographer can amass a photo collection that rivals the Library of Congress. Organizing it can be a daunting task. Researchers face a similar problem, and while supercomputers can solve the storage woes, scientists are still left to manually sift through countless images for relevant and meaningful information.

At NYU Langone, help is on the way. After a successful pilot phase, a new bioinformatics laboratory will soon begin to help researchers glean information from their images. **David Fenyö, PhD,** professor of biochemistry and molecular pharmacology, and **Itai Yanai, PhD,** professor of biochemistry and molecular pharmacology, and pathology, and director of the new Institute for

Computational Medicine, will provide the scientific oversight.

An immediate priority for Drs. Fenyö and Yanai is to automate the data-extraction process, as Dr. Fenyö has done for **Eli Rothenberg, PhD,** associate professor of biochemistry and molecular pharmacology. Dr. Rothenberg is using superresolution microscopy and fluorescent labels to study the interactions of proteins that detect and repair DNA damage. Because the lab generates so many complex images, Dr. Fenyö's group developed a simulation-based method to automatically assess whether any single image is likely depicting the random distribution of two proteins or a meaningful interaction between them.

Other algorithms under development may help scientists image, follow, and measure live cells as they move—a task also made easier by fluorescently tagged cells. At first, Dr. Fenyö says, the laboratory will likely create the software on demand or string together existing algorithms developed by others. Over time, NYU Langone can build up its own library and reuse or adapt software for new projects.

The new capability will likewise emphasize machine learning, which refers to sophisticated programs that allow a computer to gradually improve its performance based on new information. "Facebook and Google use it to recognize faces in photos on the Internet, as well as other objects," says Dr. Fenyö. In the same way, the bioinformatics service will apply deep learning to research images to automatically identify biological features such as subcellular structures and tumors.

"One of the biggest opportunities in pathology and radiology is to automate diagnoses and hopefully increase the accuracy of diagnosis," Dr. Fenyö says. The goal is to sort out the images that clearly belong in one group or another—a normal versus abnormal cell, for example—so that pathologists can focus on more difficult cases.

Eventually, the technology could look at skin biopsies and point out a melanoma, determine the type, and then assess which treatment might be best. Says Dr. Fenyö, "Now is the right time to really invest in bioinformatics."

THE CYCLOTRON

An on-campus atom smasher boosts state-of-the-art imaging

This winter, the Department of Radiology flips the switch on a 200-ton cyclotron and a new radiochemistry laboratory, both located at 660 First

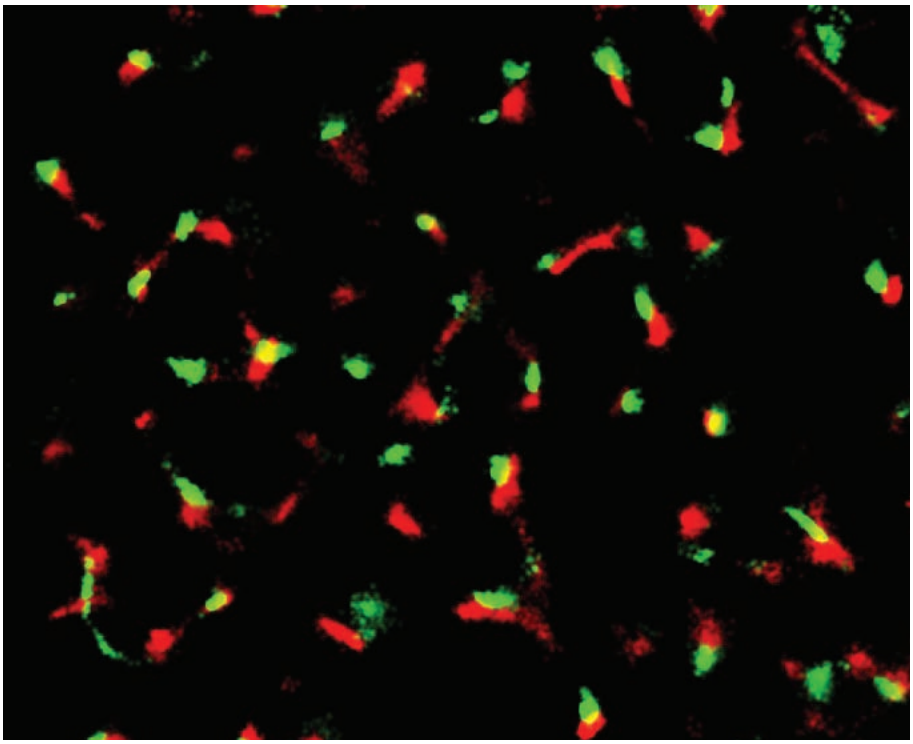


Image courtesy of Yandong Yin and Eli Rothenberg

"One of the biggest opportunities in pathology and radiology is to automate diagnoses and hopefully increase the accuracy of diagnosis," Dr. Fenyö says.

BIOINFORMATICS AT WORK: This image, generated by superresolution fluorescence microscopy, shows DNA (red) and a binding protein (green) clustering within the nucleus of a cell. A bioinformatics algorithm developed at NYU Langone helped the researchers determine the degree to which the DNA and protein molecules overlap, which can help distinguish true interactions from random occurrences.

Avenue, that together will enable technicians to create custom-made radioactive tracers for positron emission tomography (PET) scanners throughout the Medical Center.

Radiotracers, once injected into the body, attach to designated molecules where they can illuminate physiological processes such as changes in blood flow, oxygen levels, or glucose metabolism, all of which can indicate disease. Common tracers can be purchased off the shelf, but some of the most exciting and powerful labels decay too quickly for shipping. The radioisotope carbon-11, for example, used in tracers that can track neuropsychiatric and neurodegenerative disorders, loses half of its signal strength every 20 minutes, leaving precious little time for preparation.

"When you want to do this interesting new science, you need a cyclotron on site," says **Fernando Boada, PhD,** professor of radiology, neurosurgery, and psychiatry, and director of the Center for Advanced Imaging Innovation and Research.

The new cyclotron, shielded by lead and buttressed by massive structural reinforcements, whips beams of charged particles around a circular, vacuum-sealed metal track and then smashes the particles into elements, such as carbon or fluorine, to create tracers that glow inside the body. "It's a miniature particle accelerator," says **Daniel K. Sodickson, MD, PhD,** vice chair for research in the Department of Radiology and director of the Bernard & Irene Schwartz Center for Biomedical Imaging.

The radiochemistry laboratory, built alongside the cyclotron, will allow technicians to quickly affix the radioisotopes to chemical tracers as needed, so researchers can immediately put them to use.

While cyclotrons are not new to academic medicine, NYU Langone will be among only a handful of medical centers in the world to pair the machine with an MR-PET scanner, which combines magnetic resonance (MR) imaging and PET to capture both anatomy and metabolic activity in a single scan. The combined setup will allow researchers to precisely measure tiny amounts of molecules and accurately establish their anatomical location and physiological context. As a result, the invaluable new tool could aid in the detection of often hard-to-diagnose diseases such as lung cancer, brain tumors known as neurofibromas, epilepsy, and Alzheimer's disease.

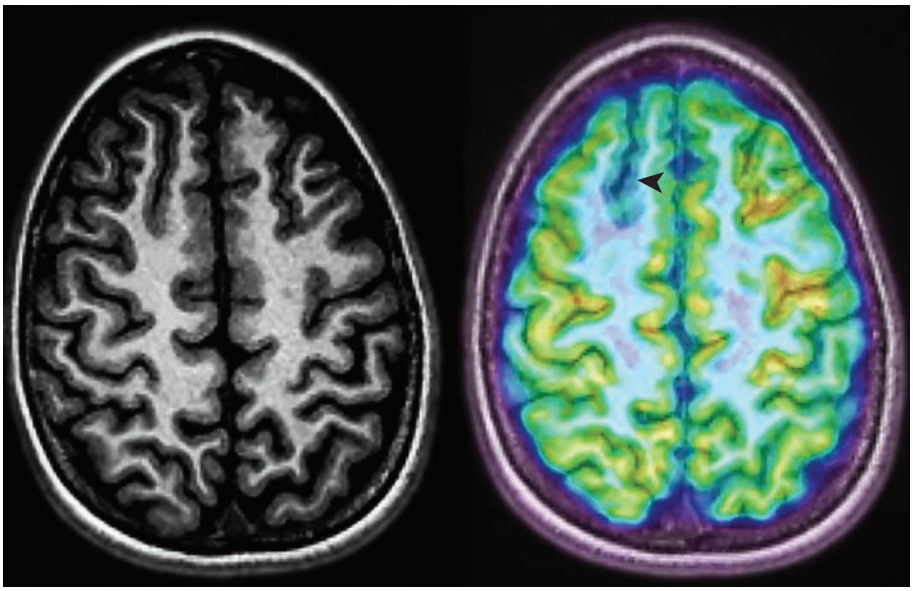


Image courtesy of Timothy Shepherd, MD, PhD, assistant professor of radiology

CYCLOTRON BOOSTS DIAGNOSTIC POWER: These images show the brain of a child diagnosed with nocturnal seizures. The black-and-white MRI (left) shows a subtle irregularity in the gray matter. Superimposing a color PET scan onto the MRI (right) more clearly reveals the problem through low uptake of radioisotope-labeled glucose (arrow), helping doctors confirm a diagnosis of epilepsy and perform an effective surgery.

"When you want to do this interesting new science, you need a cyclotron on site," says Fernando Boada, PhD, professor of radiology, neurosurgery, and psychiatry, and director of the Center for Advanced Imaging Innovation and Research.

THE MICROSCOPY CORE

Bringing deep expertise and the latest microscopy technology to NYU Langone

NYU Langone's Microscopy Core boasts an impressive suite of state-of-the-art imaging equipment, including two electron microscopes, a new light-sheet microscope (see "Tools of the Trade," page 17), three live-cell imaging systems, and four newly upgraded confocal light microscopes. The service offers far more than just high-powered gear, however. The unusually deep expertise of the scientists who operate and maintain it has opened up new collaboration and training opportunities for students and researchers throughout the Medical Center.

"Our philosophy as a microscopy core is a little different than most," says director **Feng-Xia "Alice" Liang, PhD,** who started the core a decade ago. "We don't just help take images. We partner in the science, help design experiments, and solve problems. Every cell, every tissue sample is different. There's no single protocol."

In June, as part of an ongoing effort to offer NYU School of Medicine investigators the latest microscopy tools, Dr. Liang's team helped secure a $1.14 million grant from the National Institutes of Health for a 3-D scanning electron microscope. When installed this February, the instrument will be among the first of its kind in New York City and one of only 50 in the world.

The advanced microscope will allow researchers to visualize biological structures as small as synaptic vesicles in three dimensions, and even trace the 3-D structures of neural circuits. Like a conventional electron microscope, a 3-D scanning electron microscope emits a concentrated beam of electrons, not light, to visualize the surface of a biological specimen. To achieve a 3-D view with finer resolution, it uses a diamond knife to slice a sample into nanometer-thin layers, exposing and imaging one layer after another. Computer software reconstructs the composite view in three dimensions.

Researchers can correlate these 3-D images with views obtained from NYU Langone's superresolution light microscopes, says collaborator **Mario Delmar, MD, PhD,** the Patricia and Robert Martinsen Professor of Cardiology in the Department of Medicine's Leon H. Charney Division of Cardiology. "You're able to localize, with great precision, a molecule that you detect by light microscopy on the landscape that you've obtained with the electron microscope." The image assembled with this "extremely critical" technology, he says, could provide an unprecedented look at key drivers of disease.

Adds **David E. Levy, PhD,** professor of molecular pathology and microbiology at NYU School of Medicine, "the Microscopy Core is truly a nexus of image-based analysis and biomedical problem solving for our research community.

"Our philosophy as a microscopy core is a little different than most," says director Feng-Xia "Alice" Liang, PhD, who started the core a decade ago. "We don't just help take images, we partner in the science, help design experiments, and solve problems. Every cell, every tissue sample is different. There's no single protocol."

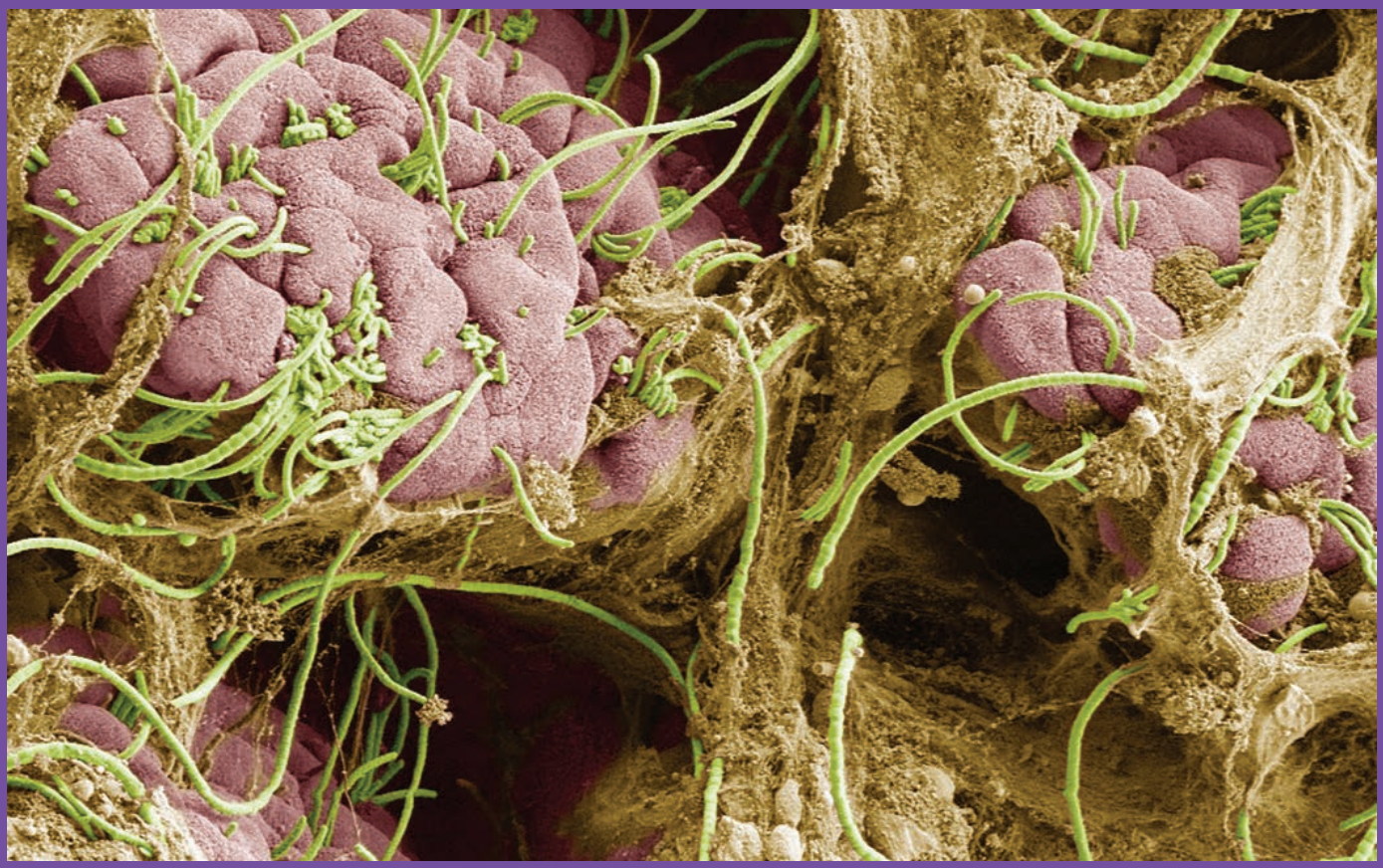


Image courtesy of the Litman Lab

GUT CHECK: A color-enhanced scanning electron microscopy image shows beneficial gut microbes, known as segmented filamentous bacteria, or SFB (green), dwelling in the intestinal epithelial cells of a rodent. Recent studies by the Litmann Lab at NYU Langone have shown that SFB can activate specialized immune cells and trigger the release of infection-fighting molecules.

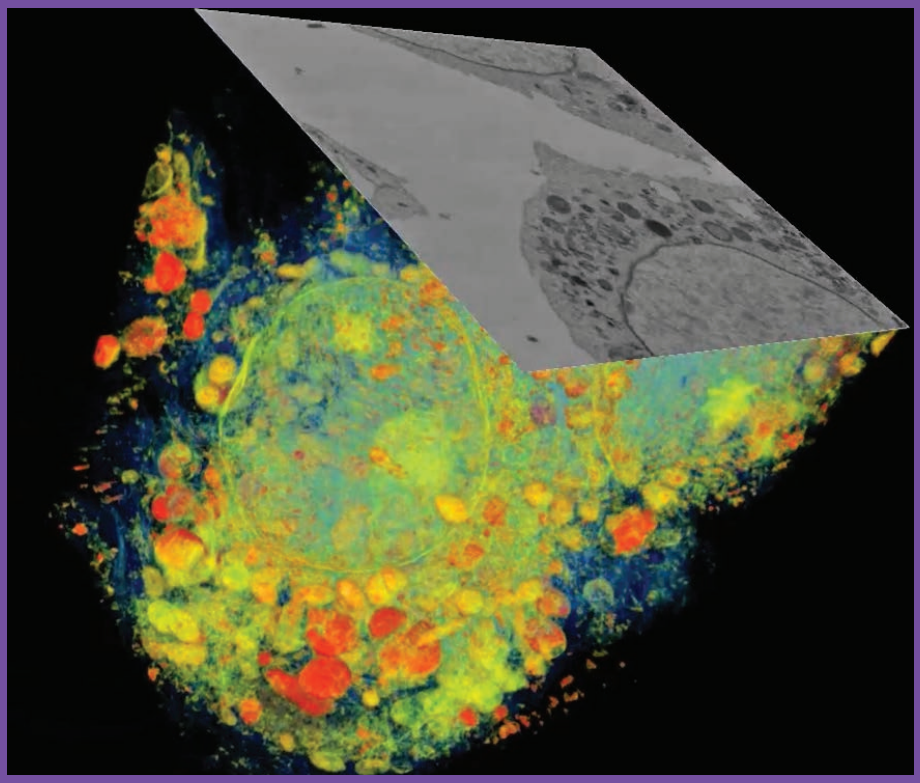
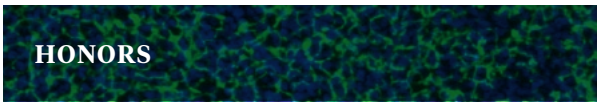


Image courtesy of the Lehmann Lab

3-D MICROSCOPY: An image generated with a three-dimensional scanning electron microscope shows a Wolbachia bacterium invading the embryonic cell of a fruit fly. Wolbachia bacteria, found in 60% of insect species, can inhibit the growth of viruses that cause Dengue and Zika infections.

FACTS AND FIGURES



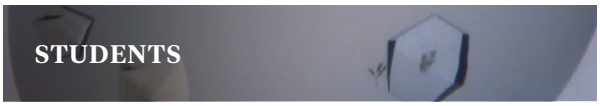
5
Howard Hughes Medical Institute
Investigators

9
Health and Medicine Division of the National Academies of Sciences, Engineering, and Medicine
(Formerly Institute of Medicine)
Members

11
National Academy of Sciences
Members

11
American Academy of Arts & Sciences
Members

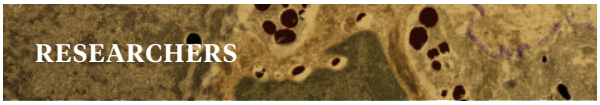
13
American Association for the Advancement of Science
Fellows



80
MD/PhD

243
PhD

49
PhD Recipients



435
Research Faculty

38
New Research-Focused Faculty

390
Postdoctoral Fellows

FACILITIES

550,500
Square Feet
of Research Space

220
Laboratories

53
Countries
Represented in Labs

PUBLISHED RESEARCH

4,381
Original Research Papers
That Appeared in Science and Medical Literature in Calendar Year 2015

367
Publications
That Had an Impact Factor of at Least 10

OFFICES OF INDUSTRIAL LIAISON *NYU School of Medicine Figures**

+$1B
Total Amount Raised by Startups

58
Startups Formed

729
Patents Issued

#1
in License Income over the Past 10 Years

24
Biomedical Products Brought to Market

80%
Increase in NYU School of Medicine Licenses over the Past Three Years

*These numbers are cumulative and do not include activities from other NYU schools.

FUNDING

FY2016 Total Grant Revenue

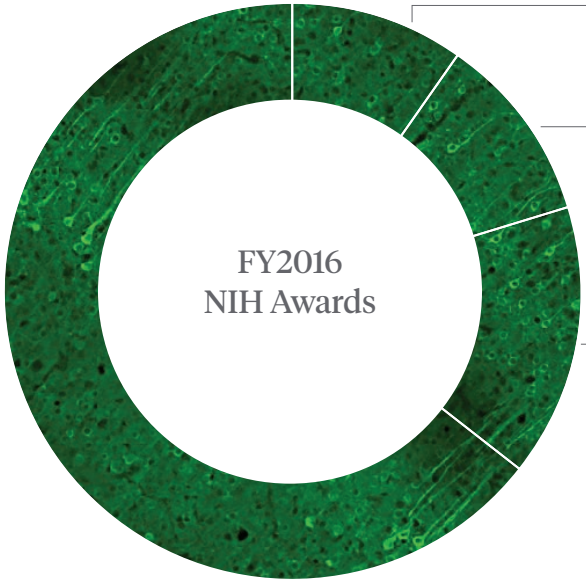
$328,000,000

1,268
TOTAL NUMBER OF AWARDS

- 65.48% NIH
- 1.73% INDUSTRY/FOR-PROFIT
- 14.00% FOUNDATION/NOT-FOR-PROFIT
- 2.03% STATE/LOCAL GOVERNMENT
- 1.09% NONFEDERAL: SUBCONTRACT
- 1.11% FEDERAL NON-NIH: SUBCONTRACT
- 9.27% FEDERAL: NON-NIH
- 5.29% NIH: SUBCONTRACT

Percentages by dollar amounts

495
TOTAL NUMBER OF NIH AWARDS



- 64.21% RESEARCH PROJECTS
- 9.81% TRAINING AND OTHER RESEARCH-RELATED PROGRAMS
- 10.66% RESEARCH PROGRAM PROJECTS AND CENTERS
- 15.32% COOPERATIVE AGREEMENTS

Percentages by dollar amounts

PHILANTHROPY

Nonfederal funding above $100,000 made or pledged between September 1, 2014 to August 31, 2015

Philanthropic support plays a vital role in biomedical research. Major gifts can inspire new projects, encourage investigators to take risks, facilitate collaboration and accelerate advances. We wish to extend a special thank-you to Judith and Stewart Colton, Alexandra and Steven Cohen, Fiona and Stanley Druckenmiller, Paolo and Marlene Fresco, Helen L. Kimmel, Laura and Isaac Perlmutter, The Skirball Foundation, Joan and Joel Smilow, Marica Vilcek, Jan Vilcek, MD, PhD, and Hansjörg Wyss for their ongoing commitment to research at NYU Langone.

Above and Beyond LLC
The ALS Association
American Heart Association
amfAR
Anonymous
Timur Artemev
Arthritis Foundation
Arthritis National Research Foundation
Associazione Italiana per la Ricerca
Avon Foundation for Women
Dawn and Leonard Berkeley
The Antoinette E. & Herman Boehm Foundation
Breast Cancer Research Foundation
BrightFocus Foundation
Burroughs Wellcome Fund
Cancer Research Institute
Steven & Alexandra Cohen Foundation
Cohen Veterans Bioscience
Lauren Tessler Corrigan and Patton R. Corrigan
Crohn's & Colitis Foundation of America
Dysautonomia Foundation, Inc.
Peter Emch
Blanche T. Enders Charitable Trust
Gertrude and Louis Feil Family
Carol J. Feinberg
The Fisher Center for Alzheimer's Research Foundation
Ralph S. French Charitable Foundation in Memory of Ralph S. French and Louis and Herbert French
Mr. Paolo and Mrs. Marlene Fresco
Heffter Research Institute
The Irma T. Hirschl Trust
The Holliday Foundation
Hudson River Foundation for Science and Environmental Research, Inc.
Human Frontier Science Program
Ionis Pharmaceuticals, Inc.
Marc Jacobs International, LLC
Jacobson Family Charitable Foundation
The Eva Kahn 2002 Rev. Trust
Judith and Irwin Kallman
Norman Katz Trust
Esther A & Joseph Klingenstein Fund Inc.
Rita and Sheldon Kwiat
Estate of Pauline Kyle
Estate of Emma Landau
Diane E. Lederman and Arthur G. Levin
A. L. Levine Family Foundation
The Lourie Foundation Inc.
Barbara and Robert Luciano
The W. Bruce Lunsford Foundation, Inc.
Lupus Foundation of America, Inc.
Macro Risk Advisors LLC
Making Headway Foundation, Inc.
Estate of Estelle A. Manning
March of Dimes Foundation
Ilse Melamid
Melanoma Research Alliance
Merck & Co., Inc.
Musculoskeletal Transplant Foundation
myFace
The New York Community Trust
The David and Lucile Packard Foundation
The Laura and Isaac Perlmutter Foundation
Susan and Lewis Rapaport
Rheumatology Research Foundation
James P. Riley, Jr.
Florence and Joseph P. Ritorto
Edward John & Patricia Rosenwald Foundation
Damon Runyon Cancer Research Foundation
St. Baldrick's Foundation
Elana S. Siegel
Simons Foundation
Alfred P. Sloan Foundation
Beryl Lynn Snyder
The Stringer Foundation
Tomorrow Foundation, Inc.
The V Foundation for Cancer Research
Marica and Jan Vilcek
The Warner Foundation, Inc.
WCG Foundation, Inc.
J. Weinstein Foundation Inc.
The Zimin Foundation

LEADERSHIP

New York University

William R. Berkley
Chairman, Board of Trustees

Andrew D. Hamilton
President

Robert Berne, PhD
Executive Vice President for Health

NYU Langone Medical Center

Kenneth G. Langone
Chairman, Board of Trustees

Robert I. Grossman, MD
The Saul J. Farber Dean and Chief Executive Officer

Executive Leadership Team

Steven B. Abramson, MD
Senior Vice President and Vice Dean for Education, Faculty, and Academic Affairs

Dafna Bar-Sagi, PhD
Senior Vice President and Vice Dean for Science, Chief Scientific Officer

Andrew W. Brotman, MD
Senior Vice President and Vice Dean for Clinical Affairs and Strategy, Chief Clinical Officer

Michael T. Burke
Senior Vice President and Vice Dean, Corporate Chief Financial Officer

Richard Donoghue
Senior Vice President for Strategy, Planning, and Business Development

Annette Johnson, JD, PhD
Senior Vice President and Vice Dean, General Counsel

Grace Y. Ko
Senior Vice President for Development and Alumni Affairs

Kathy Lewis
Senior Vice President for Communications and Marketing

Joseph Lhota
Senior Vice President and Vice Dean, Chief of Staff

Vicki Match Suna, AIA
Senior Vice President and Vice Dean for Real Estate Development and Facilities

Nader Mherabi
Senior Vice President and Vice Dean, Chief Information Officer

Robert A. Press, MD, PhD
Senior Vice President and Vice Dean, Chief of Hospital Operations

Nancy Sanchez
Senior Vice President and Vice Dean for Human Resources and Organizational Development and Learning

Science and Research Administration

Laura Ahlborn
Vice President for Research Enterprise

Bruce Cronstein, MD
Codirector, NYU-HHC Clinical and Translational Science Institute

Anny Fernández
Senior Director for Financial Affairs and Administration

Judith Hochman, MD
Senior Associate Dean for Clinical Sciences
Codirector, NYU-HHC Clinical and Translational Science Institute

David Levy, PhD
Associate Dean for Collaborative Science

Keith Micoli, PhD
Director, Postdoctoral Affairs

Jeremy Paul, PhD
Assistant Dean for Basic Science Research Operations

Robert Schneider, PhD
Associate Dean for Therapeutics Alliances

Naoko Tanese, PhD
Associate Dean for Biomedical Sciences
Director, Sackler Institute of Graduate Biomedical Sciences

NYU School of Medicine
NYU LANGONE MEDICAL CENTER

MED.NYU.EDU