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PROLOGUE

It felt absolutely medieval. This wasn't a maneuver that would work with gradual pressure, like the tightening of a vise. It needed a quick, crushing force. So I used a head holder, with one-inch-long steel pins, to secure the skull to the operating table. That way, if my patient started to move, her head would remain still, and I wouldn't accidentally kill her.

The three metal pins would need to bite down into her skull after puncturing her scalp: one pin in her forehead, two in the back, all connected to a C-shaped clamp. While my assistant held up the patient's head from the neck, I explosively captured her cranium inside the steel device. The jarring noise from the metal gears made the students, nurses, and doctors standing behind me in the operating room fall silent. The first of several hundred steps that needed to go smoothly, quickly, and perfectly had just been completed.

So began my first time opening the skull of a living human being. I was a third-year resident at the University of California, San Diego, Department of Neurosurgery. My patient was in her midthirties and had come to the hospital's emergency room two days before, reporting a peculiar weakness and awkwardness in her left arm and hand. An MRI had revealed a bright white abnormality on her brain — a tumor the size of a peach.

Many times before, I had stood beside senior neurosurgeons, assisting, observing, and learning. But this was my first time going solo.

It's an odd thing—brain surgery. There's fear, of course, but also awe that you're literally inside somebody's head, which elicits intensity as well as excitement. I don't want to sound indelicate, but for me it's a thrill. Some people like skiing, or mountain climbing, or playing poker. I like operating on people's brains.

The risk is that I will nick a vein and a part of the brain will die. Or I will go in at the wrong spot and won't be able to reach most of the tumor. Or everything will seem to go perfectly during the surgery, but the patient will wake up unable to speak for the rest of their life.

The hope—and why I do it—is that this woman, who just got married three months ago and has much of her life ahead of her, will have her strength and fine control of her left hand restored as good as new.

Despite having abnormal tissue in her brain, this patient was pretty lucky because the mass wasn't malignant. Her life was not at risk from the tumor, just from me. But as long as the tumor remained and continued to grow, her muscle weakness could worsen and spread. It was nestled in the motor strip of the right parietal lobe—a half-inch-wide, seven-inch-long ribbon of brain tissue that sends movement signal to the left side of the body. This particular type of tumor is called a meningioma because it grows from the lining (*meninges*) of the brain. Since the skull can't stretch, the tumor knuckles into the brain, deforming it, without actually penetrating the tissue. The pressure, however, interferes with the electrical signals, leading to weakness.

After drilling off a circular piece of bone near the top of her skull—what brain surgeons call "turning the flap"—I gently sliced with a number-11 scalpel into the dura—the thin, cloth-like membrane that protects the brain. I scored and lifted the dura but went no farther.

And there it was. I could see the tumor on the very surface of the brain. In contrast to the glistening opalescence of healthy brain tissue, it was yellow, dull, and irregularly spherical.

I began by entering the center of the tumor, coring it like the yolk of a hard-boiled egg until it was hollow, leaving behind only its tougher rim. Then, I delicately worked its shell away from the surrounding brain, collapsing it into itself. This is the hard part, because the edges have bridging spider-silk-thin fibers, and the surrounding tissue is as soft as pudding. Slowly, methodically, I divided those wisps with a curved eight-inch scissor.

Two hours of doing this under magnification and illumination, and the tumor was out. I bathed the brain's surface with sterile water to check for any oozing or dripping blood vessels. Then it was time to close through reverse maneuvers. I reattached the bone flap to the rest of the skull with a thin titanium mesh and tiny plates and screws, stitched the scalp back in place, and finally removed the clamp holding her head still.

Three days later, when her brain was no longer stunned by my invasion, she had full strength back in her left hand and arm, and I knew what I wanted to be great at.

Fifteen years and thousands of operations later, brain surgery is still a thrill unlike any other. My three sons tease me about having gone to school until the thirty-second grade — literally twenty years beyond high school — but that's what it took to become a brain surgeon and also add a PhD in neurobiology. Even so, I feel like I've only just glimpsed at the mystery and potential of the human brain. It is my obsession.

These days I not only perform brain surgeries, I also teach medical and graduate students to conduct neuroscience and oncology research in my laboratory at the City of Hope, a cancer treatment and research center in southern California. I travel to countries such as Peru and the Ukraine on surgical missions. I have written ten academic books and more than 100 papers about brain surgery and neuroscience used by medical students, PhD students, and neurosurgeons.

But there's something eating away at me that no amount of surgery or science is going to fix. It's a kind of infection of the mind spread by close contact with television, websites, sensationalist books, and certain companies eager to sell the public on simplistic pseudoscience and nonsense.

Perhaps you've heard claims like this:

- SOME PEOPLE ARE MORE LEFT- OR RIGHT-BRAINED. I explain how this myth was concocted.
- THE GUT IS A SECOND BRAIN. Not really. The brain does project nerves out of the skull to nearly every millimeter of your body, including an extensive network of nerves in your guts that monitor your gastrointestinal tract. But many patients have undergone multiple variations of near-total bowel removal without demonstrating any attributable mental dysfunction.
- BRAIN TRAINING IS BOGUS. In truth, leading researchers at top universities around the world continue to investigate the effects of computerized "brain games" and all sorts of other training methods to improve cognitive performance.
- MEDITATION IS NOT BACKED BY HARD SCIENCE. False. A recent groundbreaking study directly measured the mind-calming effects of meditative breathing, elegantly showing the practical physiology underlying this ancient ritual and now modern practice.

These days it's harder than ever to sort the facts from the phony claims.

And many of these ideas, peddled by self-declared experts, could be holding you back from reaching your real personal potential. I've treated patients who truly believed that herbs or meditation would cure them of their brain cancer, and thus they delayed life-saving surgery. I've met people whose strokes might have been prevented had they followed a few simple rules of staying neurologically fit. I've known students in my medical school classes who thought they would get better grades by taking "smart" pills, which, in truth, only allowed them to work longer and harder at being just as stellar or mediocre as they were to begin with.

This book is my attempt to separate the BS from the brain science, the hype from the hope. I want to help you achieve your goals and ensure that you and your loved ones never end up on my operating table.

To that end, I make no claims that are not backed by current hard science. I neither minimize the risks of alternative medicine nor exaggerate the benefits of traditional Western-style medicine. Knowledge is a moving target, and I share what we know now and what we hope to find out.

The wonders of the brain require no exaggeration. Between our ears live an estimated 85 billion neurons—as many brain cells as there are stars in the Milky Way galaxy. Each of those neurons has thousands of thread-like connections, called synapses, linked to other neurons in the brain—more than a hundred trillion connections. That's ten times more than the estimated number of galaxies in the entire universe. The brain's complexity is unparalleled and vast.

Even when brain surgeons know that a particular procedure works to relieve suffering, we often don't know why. I can implant an electrode deep into your brain that I know will relieve depression or OCD or improve Parkinson's disease. How? Brilliant question. When you find out, let's connect.

One thing we brain surgeons do know for certain is that every brain can make a comeback following a devastating illness or injury. We witness the living proof in our patients who have experienced strokes, trauma, or brain cancer and who manage to make incredible recoveries. They relearn to walk and talk, regain fine motor skills, and improve their cognitive functioning using techniques that can and must be practiced not only in a hospital but at home. If my patients can do it, why would anyone doubt that healthy people can push their cognitive power into a higher gear?

To help you get there, I have packed this book with practical, tested, real-world strategies and hacks to achieve peak performance from a brain-centric approach to diet, creativity, sleep, memory, and so much more — for young or old, healthy or ailing.

Don't worry, I am not going to tell you to put down your smartphone. Devices aren't going anywhere, and they are not inherently bad. It all depends on how they are used. In fact, my patients often use devices during their "brain rehab", and I'll show you how to use your digital tools to keep your brain sharp and agile.

In this book, I take you on a journey into the operating room, around the world on my surgical missions, and inside my research lab so you can see what it's like to be on the frontlines of brain science. I venture to the outer edges of frontier neuroscience to reveal the latest, most important brain breakthroughs that are turning science fiction into reality, and I share the stories of some of my patients who have made remarkable recoveries.

As well as telling you some of the most remarkable cases I have worked on, each chapter includes one or more of these special sections:

- NEURO BUSTED, where I address popular myths and misunderstandings;
- NEURO GEEK, where I dive a little deeper into cool (if wonky) scientific theories, discoveries, and history; and
- NEURO GYM, where I boil down the science to actions you can apply to your own life.

You'll find solid, state-of-the-art information, and you won't have to follow an exhausting and time-consuming regimen to see results.

As a surgeon who works with patients on a daily basis, and as a dad with three boys and a wife who is a cancer scientist with her own rigorous schedule, I know that life can get in the way of your best intentions.

If I give a patient a list of ten postsurgery recommendations, I know that 95 percent of them won't follow through on all ten, so I point to the two or three items on that list that are the highest yield. I will do the same for you here, focusing on the brain-building strategies that won't waste your time. The three strands that make up this book – Neuro Busted, Neuro Geek, Neuro Gym – represent the wisdom I have gleaned from working with my patients. They encompass the concept of "neurofitness," which I set as the ultimate goal for patients who pass through my practice, but which applies to all of us.

I've been waiting to write this book to share these life lessons for a decade, until a stage in my life when I am no longer a rookie but far from a retiree.

I hope you find it worthwhile.

Rahul

1

AN ANATOMY LESSON LIKE NO OTHER

I hated Anatomy 101. The basic class for all incoming medical students, mine took place in a giant room reeking of formaldehyde and crammed with naked corpses on steel tables, each one surrounded by a coven of students eager to begin digging into it.

I found the whole thing gruesome and repellent yet somehow simultaneously dull. Where was the risk in dissecting a cadaver? The whole thing was unsettling, so much so that I never once held a scalpel during that entire first year, insisting instead on merely observing as other students cut and explored. Surgery, apparently, was not in my future.

Even the brain, upon first meeting, proved to be as much a disappointment as the rest of the body. For all the lectures and textbooks extolling its wonders, the thing I saw that first year of med school — dead and bloodless — looked like a beige, corrugated cauliflower. I could see why the ancients ignored it for millennia. The one thing that caught my attention about it was how hard the thing was to get to. To penetrate the skull, we were issued an ordinary electric saw from a hardware store and told to make a circular cut around its circumference.

My disinterest, even disdain, for human anatomy disappeared in my third year of medical school, the first time we were permitted to observe heart surgery on a living patient. The intensity, the stakes, the adrenaline were what I had been waiting for. Until then, I had been seriously questioning whether medicine was for me. It had all been books and boredom and dead bodies. Now blood was flowing. I knew I wouldn't be able to spend my career only writing prescriptions. Horrible as it sounds, I needed to get my hands bloody.

After completing four years of medical school at the University of Southern California, I was accepted into a general surgical internship at UC San Diego, intending to become a cardiac surgeon. The heart seemed like the gnarliest of surgical specialties. Neurosurgery never entered my mind; I hadn't observed a single brain surgery in four years of medical school.

That first year of internship, we would-be surgeons rotated, month by month, through each specialty, from trauma and orthopedics to plastic surgery, abdominal, heart, ear-nose-throat, and, supposedly, the brain. But we were considered such rubes that the neurosurgeons never even allowed us into the operating room, keeping us outside to serve as glorified scribes in the pre- and postoperative areas.

At the end of that year, however, a rumor started floating through the hospital's hallways that the neurosurgeons were about to fire their own chosen intern; for some reason, he wasn't working out. That subspecialty was so elite that they took only a single trainee per year, compared to the three or more in every other specialty.

One evening, a neurosurgery resident sat down next to me in the hospital cafeteria and mentioned that his department couldn't run without that one resident per year.

"They're looking to grab someone from the other surgical services," the guy told me.

"Who are they thinking of hitting up?" I asked.

"They're thinking about you," he said.

I thought: *Really?*

I knew the least about the brain. That is one of the areas that surgical interns ignore if they're not planning to specialize in it. You just don't waste your time on it because, down the line, if you ever have a case that involves the brain, you punt to a specialist, no questions asked.

"You have a reputation," the resident told me. "You know the least but get the most done. They like how you work and how you don't flinch. The professors' main concern is whether you'll have enough time to catch up on the knowledge base and pass the exams. They know you have the hands — the cardiac surgeons told them — but they wonder about your smarts."

"Thanks, I guess," I said, unsure how to respond.

Within a week, the professors and I sat in a meeting to discuss their formal offer to switch to neurosurgery.

"Why don't you give it a try," one of them said. "If you don't master the content, we'll fire you."

He laughed. The others laughed, too. They weren't kidding.

"I've never even seen a brain surgery," I told them. "Before jumping ship, I'd like to see one."

They offered for me to observe a bifrontal craniotomy scheduled for the next morning. The operation, they said, begins with removing most of the skull over the forehead.

"And you can do that without killing the patient?" I asked.

They laughed again at my naiveté.

But there was no more laughter the next morning, at 7:30 a.m., when I stood across from the surgeon on the other side of an operating table. His patient, lying before us, was covered by a sheet except for the top of his head, which had already been shaved. The surgeon cut the scalp, drilled and cracked open the bone, incised open the dura, and revealed undulating white flesh speckled with tiny blood vessels. For a moment, it felt like a violation. Heart surgery is impressive, but in some ways it's like working on a car engine: it's all valves and pistons and fuel lines. But the brain is different.

Here at the mysterious core of human being, I thought maybe a living person's skull should be sacred space, taboo to enter.

That feeling lasted about five seconds. Then came the thrill. If the cranial vault is a sacred sanctuary, so be it: I could become one of those few trusted to enter it. Later that day I let the professors know: I would accept their offer to enter neurosurgical training.

So began my anatomy lesson like no other. Now please allow me to show you inside my workshop.

BEYOND THE SKULL

To begin: the brain doesn't actually sit inside the skull; it floats, protected by a natural shock absorber called cerebrospinal fluid, or CSF for short. CSF is produced at a rate of about two cups per day from inside the brain's deep, hidden chambers: the ventricles.

Although it looks like water, CSF is filled with bioactive ingredients that serve as the brain's "nourishing liquor." It carries bioactive factors that keep the brain fit and also drain away the brain's waste products.

A weird thing about the brain is its peculiar texture when you touch it. You might assume it's like a muscle, or body fat—that you could push your finger into it as you would into someone's belly, and it would smoosh in a little and then rebound. But that's not how it works. In reality, the texture of the brain is like no other flesh. It's more like flan or bread pudding. Push your finger against it, and your finger will sink straight in. Take a thimble and you can scoop up an easy million or so brain cells.

Those cells on the outer lining of the brain, by the way, are the most precious ones. You have probably heard of the cerebral cortex. That's not just a synonym for the whole brain. The word *cortex* comes from the same Latin word that gives us *cork*, which grows on the bark of a type of oak tree. The cerebral cortex is the bark on the brain — incredibly, less than one-fifth of an inch thick — where most of the magic happens in human beings: consciousness, language, perception, thought.

Visually, the most notable feature of the brain's surface is how it looks like tightly tucked hills and valleys. Each of the little hills is called a gyrus, with a soft "g." (So it's "*jie*-russ," not "guy-russ.")

The valley or sunken section is called a sulcus, which is pronounced with a hard "c." (So it's "sulk us.")

The reason for all this folding is that it permits a greater surface area. Unfolded, the cerebral cortex would be the size of an extra-large pizza. The brain wants the most acreage it can get of that thin but powerful cortex, so it figured out a way to fit more of it into the skull, by folding it like an accordion or a pleated curtain.

What you have to understand about the cortex is that it's all "gray matter," the central bodies of brain cells. Under a powerful microscope, these neurons appear to line up vertically like pine trees in a forest. And like the roots of a tree, each neuron has a branched network of thread-like connectors that link to other neurons. These connectors — the biological equivalent of cables — are the "white matter." Sixty percent of the brain is white matter.

The incoming fibers that carry messages *from* other cells are called dendrites. The outgoing fibers that send messages *to* other cells are called axons. So if one neuron wants to talk with another neuron, it sends an electrical signal down its axon to meet one of the other neuron's dendrites. But they never physically touch. Think of Michelangelo's painting in the Sistine Chapel of God and Adam's fingers reaching toward each other.

The space between, called a synapse, is where a variety of chemical messages swirl. Those chemical embers, called neurotransmitters, float across the synaptic cleft. There are dozens of these neurotransmitters — some that you might have heard of include dopamine, serotonin, epinephrine, and histamine — and they all have different effects on neuronal communication and function. Put it all together, and you can begin to understand the design that can generate the infinite variety of feeling, thought, and imagination that humans experience.

NEURO BUSTED: BRAIN CHEMICALS PLAY MANY ROLES

Some people think of dopamine as the "feel good" neurotransmitter, the one that showers your brain when you are overcome with feelings of love or happiness, or activates with the help of drugs like cocaine. But like all neurotransmitters, it has multiple functions. Yes, dopamine is closely involved in generating subjective feelings of pleasure. But a lack of dopamine in the brain causes Parkinson's patients to struggle with movement. And when medicines like L-dopa are given to replace deficient dopamine in order to address movement issues, the range of possible side effects are quite revealing. Some patients develop a gambling addiction, and some can become hypersexual. The bottom line is that assigning one feeling or cognitive function to each neurotransmitter is a gross oversimplification. All neurotransmitters — including not only dopamine but also epinephrine, norepinephrine, glutamate, histamine, and many others — play different roles in different parts of the brain.

But let's get back to the large map of the brain. Functionally, the cortex is divided into four sections, or lobes, each devoted to a particular set of tasks. Structurally, though — seen from the top — the brain is also divided into a left half and a right half. Connecting the two halves, deep inside the brain, well below the cortex, is the corpus callosum (Latin for “tough body”), a bundle of hundreds of millions of axons. Each of the four lobes, and all the other brain structures located deeper in the brain, exist in pairs, just like your eyes, your ears, and your limbs.

Let’s start with the lobe most unique to humans: the huge frontal lobe that bulges beneath our foreheads.

FRONTAL LOBE

The frontal lobe plays a primary role in motivation and reward-seeking behaviors.

When you’re carefully paying attention to what your teacher or boss is saying, that’s your frontal lobe at work. Doing math? Frontal lobe. Crossword puzzle? Frontal lobe. Trying to figure out how to handle a former friend who has lately been talking behind your back? The integration of all those feelings, memories, and possible responses requires the quarterbacking of the frontal lobe.

And when you feel like jumping out of your car and screaming at somebody in a traffic jam, it’s the frontal lobe that’s supposed to step in and say, “Hold up, not worth it.”

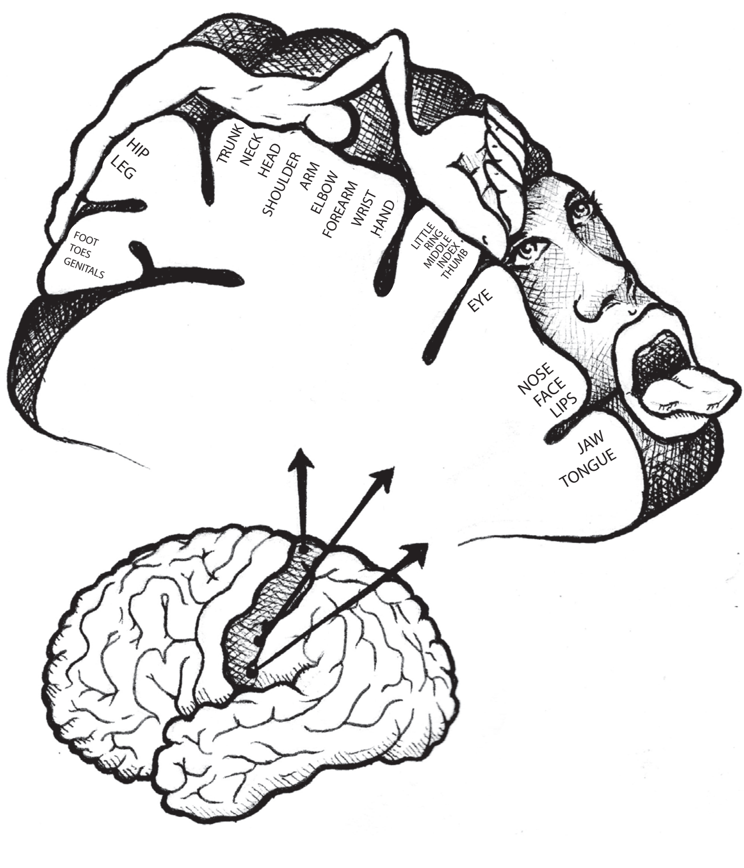
Actually, that kind of complex decision-making and juggling of conflicting possibilities is managed by a section of the frontal lobe called the prefrontal cortex, or PFC. Just like it sounds, the PFC is the most forward-facing part of the frontal lobe. This is where some of our most human faculties lie: planning, personality, rule learning, and other “executive” functions that permit us to live in a complex, nuanced world pummeling us with stimuli.

Another subsection of the frontal lobe, near the outside edge of your eyebrows, can be found only on one side of your head: the “dominant” hemisphere, usually meaning the left side (if you’re right-handed) but very rarely on the right side (even if you’re left-handed).

This section, called Broca's area, is where your ability to speak resides. In chapter 3, "The Seat of Language," there is a full description of Broca's and other nearby areas that control not only the ability to speak but to understand.

PARIETAL LOBE

Running just a few inches from the crown of your head back toward the nape of your neck, the parietal lobe controls sensation. In the first half of the twentieth century, a Canadian-American neurosurgeon,



Wilder Penfield, mapped exactly which parts of the parietal lobe correspond to which parts of the body. Using a tiny probe with a forked tip and a minuscule current running between its tines, he tickled the parietal lobes of living, conscious patients who were undergoing brain surgery.

(It may sound arcane, but we still use awake brain surgery to help patients. It turns out the surface of the brain doesn't feel. The scalp feels pain, but the surface of the brain has no pain receptors. It relies on its emissaries, the nerves it sends out into the face and the body via the spinal cord. So, if I numb your scalp and open your skull while you're under, and then taper off the anesthesia, you will wake up groggy, pain-free, and able to let me know if I'm touching something that interferes with your ability to move, talk, see — or anything else.)

Step by step, Penfield systematically marched up and around the parietal lobe to identify the corresponding feeling of touch, throughout the body. This area felt like someone touched my foot; that area felt like the stroking of a cheek. Penfield surveyed the cartography of the parietal lobe to generate what is today known as the cortical homunculus, or "little human."

Notice that just your tongue, lips, and fingers get about as much area in the brain devoted to them as the entire portion of your body below your thighs. No wonder a kiss or caress stirs us.

Amazingly, more than forty years since Penfield's death, his maps remain so accurate that we still use them today as a general guide to where the motor and sensation functions are located.

OCCIPITAL LOBE

The portion of your brain at the very back of your head is called the occipital lobe, from the Latin roots *ob* ("behind") and *caput* ("head"). It's the brain's visual processing center. An injury or stroke to *both* the left and right occipital lobes causes blindness, even though the eyes work fine.

Where things get weird is if you injure only the left occipital, or just the right. Depending on where the damage occurs, sometimes the effect on vision is barely noticeable. Occasionally, however, the person develops a manageable condition called homonymous hemianopsia: partial blindness in *both* eyes but on just the left side of their visual field, or just the right side. They can see fine looking straight ahead, but their peripheral vision is shot.

TEMPORAL LOBE

Place a finger one inch above each of your ears. Just below that spot are the two halves of the fourth lobe: the temporal (as in the *temples* of your head). Not surprisingly, they handle the processing of sounds in general and the understanding of speech in particular.

Dr. Penfield also used his electric probe to tickle the temporal lobe. When some spots were stimulated, he found, a person would suddenly be unable to understand speech. In other spots, they would have an astonishing variety of sensations: of dreamlike states, of suffocation, burning, falling, déjà vu, even profound spirituality.

I once used an electrical stimulator on the temporal lobe of a patient who had a tumor deep within it. Seeking to find a spot where I could safely dissect deeper, I stimulated here and there, each time asking what, if anything, he was experiencing.

"Listening to Kendrick Lamar!" he said at one point. "Kendrick's rapping!"

It was so vivid, the man told me, it sounded like I'd turned on a speaker next to his ear.

DOWN UNDER

The four lobes we discussed are just the lobes of the cortex, the outermost layer of the brain. Underneath, the axons and dendrites connect and channel the billions of neurons above to each other and to