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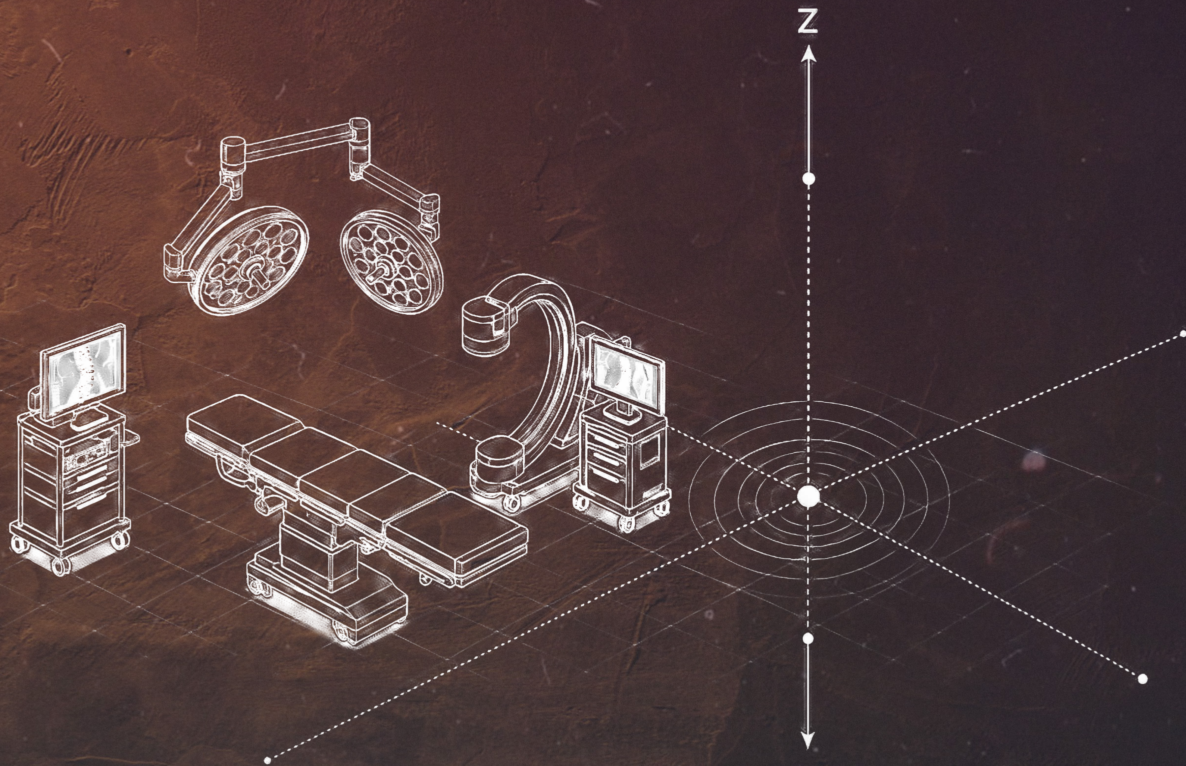

Taking Medicine in a New Direction

The Z-Axis

Matthew T. Kuhn | William A. Hendricks III, MD

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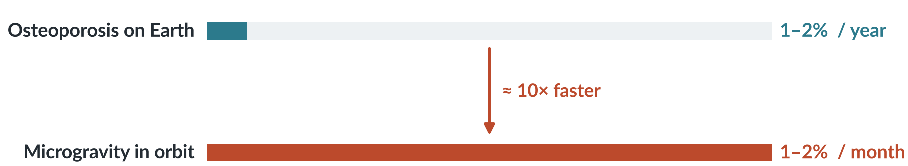
For sixty years, the job of space medicine has been simple: keep the crew alive long enough to bring them home. As spaceflight opens to ordinary people, that will no longer be enough. We will have to practice real medicine off-world. And when we do, we may find that the absence of gravity is not only a hazard to manage but a tool we have never had: a missing axis that could change how medicine itself is practiced.

Space is an environment that is actively trying to kill you. Not in the dramatic, Hollywood sense of a meteorite shooting through the window and causing an explosive hull breach, or strange cosmic radiation storms blasting lethal gamma rays through the ship (though those risks are real enough). No, space tries to kill you quietly, methodically, and relentlessly through the simple removal of forces that biology has spent four billion years depending on.

Before Yuri Gagarin's 108-minute orbit in April 1961, experts argued that any sort of sustained microgravity exposure would be fatal. This hypothesis turned out to be false of course; however, the understanding that has emerged over the following decades has shown something more complex.[1] Within hours of arriving in microgravity, roughly two liters of blood and fluid abandon the lower body and migrate headward, flooding the sinuses, puffing the face, and elevating intracranial pressure that, when sustained for just a few months, presses against the optic nerve with enough force to flatten the back of the eye and cause permanent vision damage in what is called Spaceflight-Associated Neuro-Ocular Syndrome (SANS).[2] Without gravity loading the skeleton, bone rapidly demineralizes and literally dissolves into the bloodstream, resulting in a loss of the body's total bone mass at a rate of roughly one to two percent every month, which is approximately the same loss a postmenopausal woman with severe osteoporosis accumulates across an entire year.[3] The cardiovascular system, accustomed to pumping blood upward against gravity's constant resistance, finds itself suddenly overpowered in the wrong direction and begins down-regulating cardiac output.[4] The muscles built to hold a person upright against Earth's pull grow slack from disuse and atrophy. The immune system dysregulates in ways researchers are still cataloguing. Few environments are as comprehensively hostile to the human body as space..



01

THE ONLY FIELD OF MEDICINE DEFINED BY A PLACE

The field that formed in response to this assault is space medicine, a subspecialty that evolved from aerospace medicine and draws on emergency medicine, physiology, pharmacology, and wilderness medicine. Space medicine is about keeping humans functional in one of the least hospitable environments they have ever occupied, under constraints no other specialty has ever faced. It is the youngest field in all of medicine, and the only one defined not by an organ or a disease but by a place.

The International Space Station (ISS) was constructed by a consortium of fifteen nations at a total cost of approximately $150 billion and requires roughly $4 billion annually to operate. The ISS is the most advanced, capable spacecraft ever engineered and has kept people alive in orbit without a break for twenty-five years.[5] Yet, the onboard medical capability of the most expensive object humans have ever built is surprisingly austere. As of 2023, the ISS carries a small supply of 111 medications,[6] an automated external defibrillator (AED), an electrocardiograph (ECG), a portable ultrasound, intraosseous access devices, IV fluids, and an array of diagnostic tools adequate for basic biomonitoring. What it does not have is the imaging capability to diagnose a stroke, the surgical infrastructure to perform an appendectomy, or the intensive care capability to manage a critically ill patient beyond the brief window needed to reach the ground.

The natural assumption is that an environment as lethal as space must be met with an equivalent medical arsenal to match. So how does the most advanced spacecraft ever designed get away with a clinic you would be disappointed to find at a summer camp?

02

THE THREE PILLARS OF SPACE MEDICINE

The answer is that the station was designed to keep a healthy crew healthy, not to treat a sick one. Since the Apollo program, the space medicine playbook has been, at its core, a prevention strategy built on three pillars. Arguably, the overarching goal of this playbook is to mitigate the need to practice medicine in space at all.

First, the ultimate hedge against needing medical intervention in orbit is to meticulously filter the candidate pool for who gets flown by selecting only the healthiest, most physiologically and psychologically robust individuals. NASA can be this selective because there is no job opening more coveted on the planet. In the 2017 astronaut selection cycle, over 18,000 highly qualified candidates applied to the program. Only 12 were selected, yielding an acceptance rate of less than 0.1% beside which the Ivy League looks like open enrollment.[7]

> *For sixty years, our first line of defense against the unrelenting onslaught of the harsh environment of space has been elegantly simple: send people who can take the hit.*

In our personal experience, we have had the privilege of meeting a few astronauts, and universally, astronauts are some of the most approachable, friendly, down-to-Earth individuals (pun intended) you'll ever meet. And that makes sense; personability is literally part of NASA's screening criteria. But more often than not, they also tend to be literal superhuman athletes with resting heart rates lower than room temperature. If you somehow managed to annoy one of the most calm, collected humans on the planet enough to provoke a bar fight, you would lose that fight. Badly.

Second, for the rare medical events that screening cannot prevent, the next line of defense is vigilance and improvisation: NASA employs a dedicated team of flight surgeons to rigorously monitor the health of every single astronaut onboard the ISS. The entire population of humans who have ever been in space at one time, at any moment in the sixty-year history of spaceflight, reached a record of just nineteen in September 2024.[8] For context, nineteen is a full roster for a recreational softball team. Monitoring nineteen people is still a substantial logistical undertaking; it has also been a manageable one.

In 2020, an anonymous NASA astronaut developed a deep vein thrombosis (DVT) in the left internal jugular vein approximately two months into a six-month ISS mission. The blood clot was completely asymptomatic and was discovered only serendipitously during a routine ultrasound being conducted for a vascular research study monitoring fluid redistribution in zero gravity. With no established protocol or historical precedent for treating an obstructive DVT in microgravity, NASA consulted Dr. Stephan Moll, a clinical hematologist and DVT expert at the University of North Carolina, to direct the case from Earth. This telemedical intervention was ultimately successful, but it relied entirely on the luxury of time, the lack of acute symptoms, and the improvisation of an intervention using only the supplies currently manifested on the ISS.[9]

Third, if a significant medical event exceeds the capabilities of the ISS, low Earth orbit allows for a rapid emergency evacuation to a hospital within a few hours. Historically viewed as a theoretical fail-safe, this absolute threshold was crossed in January 2026.

On the evening of January 7, 2026, veteran NASA astronaut Mike Fincke, serving as the pilot aboard the SpaceX Crew-11 mission alongside Commander Zena Cardman, Kimiya Yui, and Oleg Platonov, abruptly lost the ability to speak for approximately 20 minutes. Although the aphasia passed relatively quickly and Fincke reported no pain, the event obviously triggered immediate alarm. NASA's team of talented flight surgeons had no means of imaging his brain nor a way of establishing a definitive neurological cause with the basic ultrasound and diagnostic tools onboard the ISS. Unwilling to risk a secondary, potentially catastrophic cerebrovascular event without access to advanced imaging such as a magnetic resonance imaging (MRI) or computed tomography (CT), NASA ordered the first medical evacuation in the twenty-five-year history of the ISS, and eight days later, on January 15, 2026, the entire Crew-11 mission splashed down off the coast of San Diego. Months of testing afterward have failed to identify a cause, though the medical team is, in Fincke's own words, "almost 100 percent sure that this is a space-related thing."[10]

Notice what the pillars of space medicine rest on: a small crew of individuals with near-perfect health profiles that is never more than a few hours from a hospital bed, being monitored 24/7 by a dedicated team of some of the best doctors on the planet. It is an elegant arrangement and an alarmingly fragile one. The moment you saw through any single leg of this three-legged stool, the whole thing, and in this case the patient included, comes crashing to the ground.

All three legs are about to be sawn through at once.

The three-legged stool

01	02	03
SELECTION	**MONITORING**	**EVACUATION**
Fly only the perfectly healthy	A crew small enough to watch one by one	A hospital always a few hours away

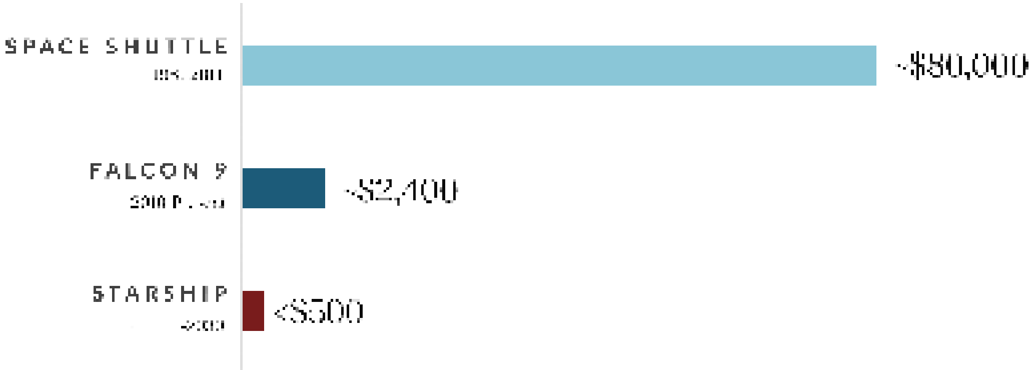
03

THE COST OF LAUNCH

Through the Space Shuttle era, lifting a kilogram of payload into space cost approximately $80,000. That price was not incidental to the character of the space program; it was the character of the space program. At those numbers, spaceflight was solely a government activity conducted for government purposes, with government employees selected by government physicians to government standards. The expense enforced discipline at every level, including medical discipline. You could not afford to fly someone who has even the slightest chance of having a medical emergency in space at $80,000 per kilogram. You could barely afford to fly anyone at all.

FIGURE 04

The collapsing cost of reaching orbit



SpaceX's Falcon 9 brought that number to roughly $2,400 per kilogram, a fourty-fold reduction achieved through the relentless engineering pursuit of a singular idea: launch a payload into orbit with a giant rocket, design an autopilot smart enough to gently land that rocket back on Earth, and fly it again. Starship is designed to push costs lower still towards a few hundred dollars per kilogram.[11] Rocket reusability is doing to spaceflight what the jet engine did to air travel, turning a rare and ruinous expense into something approaching a commodity.

Governments used to send astronauts to accomplish specific scientific and technical missions that justified the extraordinary expense. But when the cost of lifting a kilogram to orbit falls twentyfold, the population of people with a legitimate reason to go to space changes drastically. Lower launch costs have elevated the domain of space from a capital sinkhole to an economy of commercial viability. The World Economic Forum projects the space economy to grow to $1.8 trillion by 2035.[12] The in-space manufacturing market alone is forecast to grow at over eleven percent annually through 2035.[13]

The International Space Station is scheduled to be retired in 2030. Instead of a government owned successor to the ISS, NASA is funding the private sector through the Commercial LEO Destinations program with the explicit plan to become a customer of space rather than a landlord. Four companies are actively developing those stations, each with their own spin.

2030

THE YEAR THE ISS RETIRES AND THE PRIVATE ERA BEGINS

Vast is designing Haven-1 and Haven-2 as the first outposts built around paying customers rather than government payloads. Their free-flying stations include self contained habitats with their own power and life support systems, and are essentially mixed-use buildings launched in orbit: labs for microgravity research, floor space for in-space manufacturing, and cabins for tourists who want a window seat on Earth. The $500 million financing round Vast closed in March 2026 would have been unimaginable for a space station developer a decade ago.[14]

VAST	AXIOM SPACE	Starlab	ORBITAL REEF
$500M	$525M	$217M	$130M

With the ISS retiring in 2030, NASA is becoming a customer of space rather than a landlord. Four privately built stations are in active development.

Axiom Space is designing modules to berth directly with the ISS, draw on its power and life support systems, and perform commercial operations. When the ISS is ultimately deorbited, that same module and its successors are designed to undock and continue as an independent Axiom Station. In June 2026, Axiom closed an oversubscribed financing round of more than $525 million, bringing total lifetime funding past $1 billion.[15]

Starlab, a joint venture of Voyager Space and Airbus, is taking a different approach. Instead of assembling a complex over years from a series of modules, Starlab is being designed as a single, large habitat that goes up in one launch, and is meant to be continuously crewed from the moment it stabilizes. NASA has put more than two hundred million dollars behind that architecture.[16]

Orbital Reef, a consortium that includes Blue Origin, Sierra Space, Boeing, and Redwire Space, rounds out the group of stations that NASA has chosen to back directly. Under a funded Space Act Agreement, NASA has committed $130 million to Orbital Reef's design work, specifically to help bring into being a commercially developed, owned, and operated station that can host NASA science alongside private industry.[17]

The capital is no longer chasing flags and footprints. The Second Space Race is chasing factories, laboratories, server farms, military outposts, and even hotels, and every one of them needs people to build, run, and repair it, which lends the phrase "orbital mechanics" an unexpectedly literal second meaning.

04

ORBITAL MECHANICS

Screening a workforce for perfect health fundamentally cannot be applied at commercial scale; nobody staffs a factory or a research lab by solely recruiting Olympian athletes. The workforce of the future space economy will be ordinary people with ordinary health profiles: people with aging joints, high blood pressure, asthma, and love handles. They are not only capable of getting sick; with a broader range of bodies going into space, they are far more likely to.

Put it plainly: someone is going to have a heart attack in orbit. Someone will suffer a ruptured appendix. Someone will break a femur. The question is not whether these things will happen. The question is whether medicine will be ready when they do.

That leaves the third pillar, the assumption that a hospital is always a few hours away. If needed, a crew in low Earth orbit can be evacuated to a hospital within a few hours. A crew on the Moon is three days from the nearest hospital. A crew bound for Mars is, for most of the voyage, simply beyond rescue: no vehicle can turn around, and a one-way radio signal can take as long as twenty-two minutes to reach Earth, so a single question to a flight surgeon and its answer can consume the better part of an hour.[18] In space, no one can hear you scream. But even if they could, it would still take 20 minutes before they heard you.

FIGURE 06

As far as help gets

NASA takes the problem seriously enough that it is developing, with Google, an artificial-intelligence crew medical officer to ride along, on the blunt assumption that a Mars crew facing a medical emergency simply cannot reach Earth in time for a consult.[19] On Mars, responding to a medical emergency will have to happen where the patient is, performed by whoever is there, with whatever they have on hand.

Here's what all this means. We are about to put more people into space than ever before, for longer than ever before, in worse health than ever before, and farther from medical care than ever before. Adapting our medical protocols to sustain human life off-planet for years at a time will be a massive undertaking, requiring brave new ways of thinking, bold ideas, and a willingness to challenge the standard of care. But inside that undertaking is a more intriguing question about what lies beyond the horizon. What if we look beyond just adapting medicine to the harshness of space, and ask a much bolder question:

> **What if the environment of space isn't just a hazard to overcome, but a revolutionary new therapeutic tool?**

05

EVOLUTIONARY LEAPS IN MEDICINE

The idea sounds backwards, especially since we just spent the past few pages talking about exactly how the environment of space is so detrimental to our health. How could the very thing doing all that harm also be a therapeutic tool? But the history of medicine is built upon a foundation of transmuting the things that can hurt us into things that help us. Look no further than the scalpel; in the hands of a clumsy engineer with thumbs that barely qualify as opposable (aka Matthew Kuhn), the scalpel is an agent of lethal chaos. But in the hands of a surgeon honed through countless hours of practice, the scalpel is an agent of miracles (aka William Hendricks, MD).

Some of the most transformative advances in medicine came from challenging conventional assumptions that were held as absolute truths.

Before 1846, pain was not a complication of surgery. It was surgery. Up until then, a surgical operation essentially involved a conscious patient being held down by a couple of strong men, and the primary measure of a great surgeon was speed. Robert Liston was famously regarded as "the fastest knife in London", and in surgical lore he could "take a leg off at the hip in under thirty seconds".

If an operation couldn't be finished in thirty seconds of screaming, it basically was not attempted, which put the entire inside of the human body permanently off-limits. Pain was assumed to be intrinsic to surgery, and by some, was even thought to be an essential stimulus required for the body to survive the operation in the first place. Then on the morning of October 16, 1846, in the surgical amphitheater at Massachusetts General Hospital, a dentist by the name William Morton held a glass inhaler of ether over Edward Gilbert Abbott while the surgeon John Collins Warren cut a tumor from his jaw. Abbott laid peacefully still through the whole operation. Warren turned to the doubting gallery of the greatest minds in surgical medicine and defiantly proclaimed, "Gentlemen, this is no humbug." William Morton was the founding father of anesthesia, granting surgical medicine a new tool they never had before; time. Almost overnight, anesthesia unlocked a whole universe of surgical procedures that theretofore were universally accepted as impossible.

Infection was the next domino to fall. Up until the late 1860s, surgeons wiping their knives on their boots between cuts were simply following guidelines for state-of-the-art surgical technique. Suppuration in a wound was referred to as "laudable pus," a positive sign that healing was underway. An operation that resulted in the patient's death was commonly attributed to "foul air." That is until Joseph Lister argued in 1867 that the true killer was not the air but living things too small to see, and began soaking wounds, instruments, and his own hands in carbolic acid. His post-surgical mortality rates were so low that his contemporaries accused him of falsifying his outcomes, and surgical societies fought his recommendations for years. When antiseptic technique was finally accepted as best practice, it made the very concept of elective surgery possible, because a patient could at last be opened without accepting a near-certain fatal outcome.

By the late nineteenth century, pain and infection had both been reduced from "unavoidable complications of surgery" to "problems that could be controlled," but the living body itself remained opaque. Anatomy was learned from the dead. In the living, an examination relied exclusively on what could be inferred from touch and the faint sound of a stethoscope. A bullet lodged deep in the chest, a fracture hidden inside a joint, or anything inside the body that could not be palpated was effectively invisible until someone cut down to it. Operations were planned on educated guesswork, and surgeons would open the chest or make an incision in the abdomen with the hope that they were close enough to the problem to make the risk worthwhile.

Then, on the evening of November 8, 1895, in a darkened physics laboratory in Würzburg, Wilhelm Röntgen was studying cathode rays in a vacuum tube when he noticed that a barium-platinocyanide screen across the room glowed faintly whenever the tube was energized. The unexplainable phenomenon caught his attention and curiosity. Röntgen began placing opaque objects between the tube and the plates; first he tried books and blocks of wood. He then tried his own hand and watched as images slowly emerged that revealed the bones inside his living flesh, shadows of structures no eye had ever seen in an intact body. One of first X-ray images ever recorded was that of his wife's hand, her wedding ring starkly visible around the bones of her finger.

Within a year, X-ray imaging had been installed in hospitals across Europe and America. Surgeons could locate bullets they could not feel, confirm fractures hidden by soft tissue, and plan operations on the strength of images rather than pure inference. Broken bones, foreign bodies, and some tumors stopped being conceptual guesses and became things that could be seen and measured before a single incision was made. Diagnosis had acquired line of sight through the skin, something we take for granted today, but at the time was the closest thing to real magic the field of medicine had ever witnessed.

Consider these three evolutions to the standard of care together. Anesthesia removed the challenge of pain. Antisepsis removed septic shock as a natural endpoint of surgery. Radiography removed the assumption that the inside of a living body had to remain unseen. Each of these advances took an unassailable assumption about what medicine could do and showed it to be contingent.

FIGURE 07

Three times, a limit taken for the very nature of medicine turned out to be a wall with a new medicine waiting behind it. Gravity is the fourth.

06

UNLOCKING THE Z-AXIS

The next universal law of surgery to fall will be gravity. Gravity is so universal that we do not write it down when we list constraints of surgery. It is simply presumed. It decides the layout of the operating room, the serialized progression of surgical procedure, the posture of surgical technique, and the positioning of the patient on the operating table. It does so so consistently that it has never appeared on anyone's list of things holding medicine back. It is the floor we all stand on.

But what if it wasn't? Let's imagine what it looks like to take surgery in a new direction - literally.

If you were to look at a photograph of a rudimentary, blood-stained surgical amphitheater from the 1890s side-by-side with a sleek, multi-million-dollar robotic suite from 2026, it would be immediately obvious that surgical technology has evolved in quantum leaps. That said, the general layout of surgery hasn't changed much. Stripped to its core essence, surgery still involves a team standing around the perimeter of a patient on a table.

For centuries, medicine has been physically and conceptually trapped on a two-dimensional plane.

Modern surgery is a beautiful, high-stakes orchestration of human precision, split-second decision making, and spatial logistics. However, as surgical medicine has continued to mature and complexify, it has also presented with complications that are harder and harder to ignore: the more life-saving technology we pack into the confined space of the operating room, the less room there is to actually practice medicine.

Mastering surgical technique requires mastering the economy of motion. Surgery takes a devastating physical toll on its practitioners, which is why after decades of warring with ergonomics, surgeons often suffer from chronic neck pain, herniated discs, and permanent nerve damage. Ironically, the expiration date of the spine is routinely exceeded by that of the medical license. Billions of dollars have been spent developing immensely complex robotic surgical systems simply to negotiate a tenuous, expensive truce with this tension. We have since grown comfortable with how we have improved the economy of motion with technology, in ways inconceivable during the advent of anesthesia. And we are so profoundly accustomed to this reality that we don't even recognize it as a constraint. We have accepted that this is how surgery is done.

This framework naturally becomes less grounded when you step into a weightless environment. You unlock the Z-axis. Without gravity anchoring everything to the floor, the operating room ceases to be a flat blueprint and expands into a true volumetric workspace. This completely rewrites the rules of how a surgeon moves, the workflow of the staff, and the physical nature of an operation.

Imagine an operating theater where the ideas of up and down no longer exist.

Instead of lying flat on a hard table, a patient could be perfectly stabilized in the dead center of the room. The medical team would no longer crowd shoulder-to-shoulder on the tile, fighting for sterile real estate. They could position themselves dynamically at any angle, whether directly above, squarely below, or floating completely upside-down relative to the patient. To pose a deliberately exaggerated thought exercise, suppose a patient experienced a horrific accident and now requires both chest and spine surgery at the same time. Without gravity getting in the way, two surgical teams can float on opposite sides of the patient, working simultaneously without ever bumping elbows.

Space even transforms the inside of the body, giving a whole new meaning to internal medicine. Surgeons long-ago developed surgical techniques leaning on the constraints of gravity, but gone will be the days of table-up and reverse Trendelenburg. Without gravity dragging the organs downward, the contents of the abdomen naturally loosen and drift apart. The organs essentially float within the cavity, requiring the design of new retractors and techniques specific to each organ's new axis. The operating room itself would be able to dynamically adapt to the moment. Lights certainly won't have to be bolted to the ceiling casting shadows; they can float autonomously, shining directly where they are needed. Monitors and surgical trays won't take up floor space or trip up staff; they can be suspended in mid-air right next to the surgeon's hand. A new axis means a new economy of motion, with techniques no one has had a reason to invent yet.

Of course, surgery in zero-gravity involves its own complications and introduces spectacular new ways to be wrong. Without gravity to discreetly sweep mistakes toward the floor, a hemorrhage loses all respect for boundaries. Blood doesn't neatly drain into pools; it clings to instruments or floats through the air as hazardous droplets, threatening to turn a localized bleed into an atmospheric condition. But these are fundamentally engineering problems. And engineering problems can be solved. The concept of a floating operating room is merely a conceptual biopsy of a much broader untold story about the future of medicine. If simply removing gravity can completely reinvent surgery, imagine what it can do for the rest of human health. Imagine what it can do to an intensive care unit, a resuscitation bay, or a birthing suite.

07

BEYOND THE ATMOSPHERE

As space travel becomes cheaper and more routine, we are rapidly moving toward a future where certain therapies may work fundamentally better in space than they ever could on Earth.

The technical hurdles are massive, and building these capabilities will undoubtedly be dangerous and wildly expensive. But if we stop looking at space medicine as just a compromised, constrained version of terrestrial medicine, perhaps the frontier of human health does not stop at the edge of the atmosphere. The greatest medical advances of the coming century may come less from another molecule than from changing the physical conditions medicine is practiced under. For the whole of human history, that condition has been a single flat plane. The Z-axis is the first genuinely new direction medicine has ever been offered, and we are finally in a position to leverage it.

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ABOUT US

Human physiology remains the most significant limiting factor for space exploration. Humanity is bound by the sky, rather than bound for it. Our mission is to lift that constraint.

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