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Not the Last Word

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# Not the Last Word: One of These Predictions, ± 1, Will Come True

**Joseph Bernstein MD**[1]

Every December, media pundits offer a list of predictions for the coming year. These forecasts are delivered with the confidence of someone who won't be punished for being wrong. I have always liked the format, probably for that reason. So, as I find myself in the late autumn of my surgical career—not quite December if my skills endure, but close enough—I thought I might try my own version. These are not predictions for the next year, but rather what I see coming in orthopaedic surgery over the next 25 years.

## Prediction #1: We will solve the problem of sluggish formation of bone but not of cartilage

I predict we will learn how to stimulate bone cells with purposeful vigor; to have them synthesize bone abundantly but not wildly. This will likely reduce the prevalence osteoporosis markedly, though fragility fractures, which are caused by more than just weak bone, will remain a clinical problem, albeit a smaller one. A more immediate win may be treating or preventing delayed unions of fracture.

The clue suggesting the feasibility of my surmise is that fracture callus never becomes a tumor. That suggests bone has a built-in molecular "governor" that prevents unregulated growth. The molecule might be a BMP antagonist, a Wnt inhibitor, or something in the sclerostin family (Google searching lets me name drop!). I predict that we will learn how to control this controller, and with that safeguard in place, we can be more daring in opening the spigot of bone formation, without unleashing a Sorcerer's Apprentice flood.

By the same token, I am not bullish on the prospect of solving the problem of sluggish cartilage formation. The fundamental reason is that bone remodeling is a natural process—we are programmed to grow new bone in adult life. By contrast, growing articular cartilage is not something postnatal humans have evolved to do. So, I predict cartilage regrowth technology that fully recapitulates developmental cartilage formation will not arrive within the next 25 years. But that's okay, given my next prediction.

## Prediction #2: Osteoarthritis will be reimagined as a bone disease

All medical students, or at least those hoping to match in orthopaedic surgery, know how to name the four cardinal signs of osteoarthritis on an x-ray. That means they can list at least three ways bone is affected by the disease. Nonetheless, many clinicians, and certainly many laypeople, still think of arthritis primarily as a problem of "bad cartilage." I predict that this mental image will shift. Arthritis will be considered, and more importantly, be treated, as a disease of bone.

Let's start from the beginning. Cartilage lacks pain-sensing nerves. Thus, when arthritis is symptomatic, the pain signals must come from either bone or synovium. The synovium can be irritated by many things, but bone registers pain most notably through stretching of the periosteum. In arthritis, this happens through intraosseous hypertension. I expect renewed attention to the fantastic work of C. C. Arnaldi [1] and others who followed similar lines of thought.

This change will not be merely semantic. Within 25 years, firstline

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osteoarthritis treatment will include bone-targeted pharmacotherapy to provide pain relief through pressure modulation. I predict we will have vasoactive medications that decrease intraosseous hypertension. (Full disclosure: I have been granted a patent on the use of Viagra to modulate intraosseous pressure [2], but, in the spirit of this column, I predict that I never will make a dime from it, as I have given the patent away.) We might also expect some surgical innovation here—something more elegant than drilling decompression channels. If nothing else, those tend to plug up quickly. I cannot think of what these procedures might be, but I am confident that some enterprising mind will.

## Prediction #3: Machine learning will teach us about surgical indications

What is a contemporary prediction list without mentioning artificial intelligence (AI)? Yet, because large language models (LLMs) evolve so rapidly, any forecast about LLMs is like a forecast of Boston weather in April—likely to be disproved, perhaps twice in one day. So, I will focus on a more established tool: machine learning.

I predict that machine learning will take over the setting of surgical indications. Consider one example: About 15% of patients who undergo TKA are not satisfied after surgery [3]. It would be nice to identify more of these patients preoperatively, and I predict that we will. Through electronic medical record (EMR) mining and machine learning, we will uncover the combinations of traits that correlate with poor outcomes and elude clinical intuition.

At one level, this prediction is not so bold. The technical machinery for data mining already exists. The essence of this prediction is that we will willingly cede clinical decision-making to anonymous algorithms. This shift is more sociological and ethical rather than technical or medical. Consider a model that predicts poor outcomes after knee replacement for people who are left-handed, have lived in Dallas, TX, and have exactly three dental implants. Today, most surgeons would dismiss that pattern as absurd and ignore it. Yet if the "Southpaw Texas Tooth Rule" were to be 96% sensitive and 94% specific for identifying appropriate surgical candidates, wouldn't it be foolish—and immoral—to privilege our intuition over a rule that works?

In the coming years, we will grow increasingly comfortable surrendering our intuitions and trusting processes we do not understand, or that even seem wrong. And for that, we may have LLMs to thank, as they have introduced a sense of magic into computing. Deciding who should undergo surgery may soon become just one more function of the Magic Box.

## Prediction #4: Orthopaedics ascendant—and not just in our own minds

Orthopaedics will become a more important specialty, not because of anything we did, but because of what everyone else has done. Specifically, when other specialties' work is improved, we will see fewer heart attacks, less cancer, and reduced rates of strokes. When this happens, people who were once burdened by arthritis but even more burdened by other diseases will become "liberated." The scare quotes around "liberated" are needed, because these people are not fully freed; rather, they will find their joints to be their new limiting factor. These people will now need urgent attention from us!

By a process of elimination, one might say, better healthcare from other specialties leaves orthopaedic surgery more important than ever.

Relatedly, if medicine defeats disease entirely, people will still not live forever; rather, injuries will become the critical limit on life expectancy. In fact, in a world where there are no diseases, the only doctors would be orthopaedic and esthetic surgeons. (Actually, that is insufficiently cynical: If the past or present is any guide, we will defeat diseases not with cures, but with daily maintenance therapies—think insulin more than antibiotics—with constant, Big Pharma cash flow. As such, the other specialties will be around, but only as treatment dispensers.)

By predicting this, I am not saying orthopaedic surgeons will be on magazine covers, but that's primarily because I predict magazines themselves will be obsolete within 25 years. In practical terms, when orthopaedic surgeons deliver more of the care that matters, more resources will flow their way. Indeed, in that regard, the first two predictions rely on this: The bone-growing and pressure-modulating medications that were forecasted above will be found because of the additional resources predicted here.

## Coda

The political scientist Philip Tetlock says that good forecasters are not only more right than wrong; they are well calibrated [9]. That is, truly good forecasters are accurate in their estimates of their accuracy. In hopes of living up to that standard, I will close with this: I'm 94% certain that at least 50% of these predictions will prove



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**Not the Last Word**

wrong. But the only way to find out is for you to save this column and read it in 2050. And for that shot at semi-immortality, I am 100% grateful.

**Michael Suk MD, JD, MPH, MBA**

**Orthopaedic Trauma Surgeon and Founder/CEO of The Suk Group**

Dr. Bernstein's predictions are engaging, but their greatest value lies in prompting us to examine how orthopaedics might synthesize advances in biology, technology, and decision-making into a systems-oriented future. Whether his forecasts prove accurate is less important than the deeper questions they raise about integrating these elements within our specialty.

Regarding Dr. Bernstein's distinction between bone and cartilage regeneration, this may be less clear than it seems. Bone healing is evolutionarily conserved, reflecting an intrinsic capacity for repair that persists throughout adult life, and continued advances in directing its biology are likely. However, while it is reasonable to predict slower cartilage regeneration in adult humans, this prediction may underestimate the trajectory of discoveries in bioengineering. If we shift from efforts to restore native tissue through endogenous processes to engineering functional replacements that may equal or even surpass natural performance over the next 25 years, the line between regeneration and replacement becomes less meaningful.

Dr. Bernstein's reframing of osteoarthritis as primarily a disease of bone is persuasive and compelling because it focuses on pain-generating structures amenable to intervention, but it is incomplete. Osteoarthritis is not limited to a single tissue; it is a systems-level disorder involving cartilage, bone, synovium, and neuromodulatory pathways that shape pain perception. Localizing it to a single structure may simplify treatment, but doing so risks obscuring the condition's complexity. Changing the dominant narrative may advance discussion but still risks reductionism. The future of osteoarthritis care may depend less on redefining the tissue of interest and more on integrating these components into a patient-specific model.

Dr. Bernstein's idea that machine learning will determine surgical indications raises an important issue. Improving outcomes is an ethical imperative, but medicine also relies on interpretability to sustain trust and accountability. The question is not whether these tools will be used, but how their outputs will be integrated into clinical reasoning in ways that do not displace physician judgment. Thus, the balance between predictive accuracy and human explainability will shape the role of AI in orthopaedics more than the capabilities of any single algorithm.

Finally, Dr. Bernstein's view that orthopaedics will become more central as other diseases are managed is plausible, but not certain. On one hand, increases in longevity and systemic health are expected to raise demand for musculoskeletal care while transforming how that care is delivered. On the other hand, nonoperative disciplines, biologic therapies, and distributed care models may expand alongside surgical intervention. Therefore, the result may not be the dominance of a single specialty, but rather the evolution of a broader healthcare ecosystem. Ultimately, the future will favor those who adopt a systems approach and integrate diverse elements rather than treating them in isolation. Progress will depend on synthesizing advances in biology, technology, and systems, and how orthopaedics will be integrated into these complex systems remains to be seen.

**Joshua Jacobs MD**

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**President, Orthopaedic Research and Education Foundation**

"*It's tough to make predictions, especially about the future*," the late Yogi Berra said.

The words of this inimitable philosopher-poet summarize my trepidation about prognostication. However, as I recently completed my seventh decade on this planet, I suppose I have a license to offer some guesses about what might lie ahead. I will frame these guesses as Yogi would, using a series of some of his other amphigoric quotes.

*"The future ain't what it used to be."*

Dr. Bernstein's commentary is written at a perilous time for the scientific community in the US, so this quote from Yogi Berra may seem particularly apropos. Having lived through multiple cycles of feast and famine in federal research funding, however, I do not share this pessimism.

For many years, including the last budget cycle, there has been broad bipartisan support in the US Congress for research funding. The advancements predicted by Dr. Bernstein, with which I largely concur, are predicated on continued research advancements in bone biology, the pathophysiology of osteoarthritis, and the application of information technology to the understanding, prevention, and treatment



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## Not the Last Word

of musculoskeletal disease. Research advancements require resources, and while the current federal government support is volatile, future policymakers on both sides of the aisle will continue to appreciate the value and return on investment for federal research funding.

That being said, musculoskeletal disease has been chronically underfunded in relation to its enormous burden of disease. This has been very difficult to change, despite decades of focused federal research advocacy. Over the next 25 years, philanthropy will be an increasingly important source of such funding [4], particularly considering the growing numbers of grateful patients with high net-worths who will seek meaningful ways to deploy their resources to affect change.

*"You can observe a lot by watching."*

One area that Dr. Bernstein did not discuss is total joint arthroplasty (TJA), which is an area I have been closely watching since my undergraduate biomaterials laboratory experience in the 1970s. TJA has advanced tremendously since those days and is here to stay.

In 2017, I had to argue in the Orthopaedic Research Society's "Great Debate" session against the proposition that "regenerative medicine will make orthopaedic implants obsolete in our time" [5]. Nine years after this debate, I still believe that TJA will be a commonly performed procedure 25 years from now. While I also believe that currently nascent disease-modifying osteoarthritis drugs and regenerative medicine approaches to end-stage joint disease will likely be effective in 25 years, these interventions will have a small but clinically significant failure rate, ultimately necessitating total joint replacement (TJR).

Yet, 25 years from now, those TJR procedures—along with the pre-, peri-, and postoperative management approaches to managing them—will be very different. We will be using advancements in nanotechnology, quantum medicine, biotechnology, and information technology (including quantum computing and AI) to produce smart, durable materials that will provide real-time feedback on device performance and host response. Biomarkers that can demonstrate the presence of subclinical osteolysis and implant failure [7], the propensity for chronic pain [8], and the susceptibility of an individual to an immune response from degradation products of implanted engineering materials [6] will facilitate a precision medicine approach to TJR that will guide personalized implant material selection as well as pharmacological and behavioral interventions. This approach will mitigate adverse outcomes and reduce the number of revisions, making TJR even more successful than it is today.

*"You've got to be careful if you don't know where you're going, because you might not get there."*

Dr. Bernstein and I share a vision of the ascendancy of our specialty. We will get there only if we—as individuals and the professional organizations that serve us—are intentional about supporting research. This can take many forms, including serving as a principal investigator, collaborating with basic scientists, assisting in patient recruitment for clinical trials, mentoring and nurturing budding surgeon-scientists, serving on grant review panels, collaborating with philanthropy professionals to raise research dollars from grateful patients, and regularly donating to organizations that fund musculoskeletal research and early stage researchers such as the Orthopaedic Research and Education Foundation. The future awaits us; let's embrace the possibilities.

**Joseph Schwab MD, MS**

**Director of Spine Oncology for Orthopaedic Surgery, Cedars-Sinai Medical Center**

(Note: Dr. Schwab is a cofounder of GS-HealthMatrix, LLC, which holds patents on several wearable devices that his research group has conceptualized, designed, manufactured, and tested.)

Dr. Bernstein's predictions are quite reasonable, and I share his confidence that at least one of them will come true. However, I would like to use this space to offer my own prediction on what will truly transform orthopaedic surgery over the next 25 years.

Our understanding of human physiology and of its pathological deviations will be profoundly expanded by wearable devices in the near future, with major consequences for medical care and clinical practice. This is not a bold prediction in itself, as wearable technologies have been part of medicine for decades. What will be transformative, however, is the integration of multimodal wearable devices with our recent ability to acquire large volumes of data rapidly, store them efficiently, transmit them wirelessly, and analyze them with increasingly powerful computational tools.

The potential of this transformation can be appreciated by considering one of the most successful wearable technologies in medicine: the electrocardiogram (EKG). Imagine practicing in an era when palpation of the pulse and auscultation through the chest wall were the only ways to study the heart. The advent of the EKG transformed our understanding of cardiac



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electrophysiology and clarified the physiological basis of sounds physicians had heard for centuries. Only after normal patterns were defined could abnormal states be recognized, quantified, and ultimately treated. Therapies that have since saved countless lives are a direct result of that advance.

The EKG also required physicians to determine where to place leads and how to interpret the waveforms they generated. At first, this work belonged to specialists who both performed and interpreted the studies. Today, EKGs are routine, often technician-administered, and increasingly automated. Multimodal wearables may follow a similar trajectory, but they will involve multiple organ systems, including the musculoskeletal system.

Most readers are already familiar with wearable devices on the wrist or finger. These devices resemble the EKG in one important aspect: they passively collect signals generated by the body. Such passive monitoring may prove clinically valuable, but a newer class of multimodal devices will likely be even more consequential.

Multimodal wearables do not merely receive signals passively; they deliver energy into the body in the form of sound, low-voltage electrical current, or light. By introducing energy at selected frequencies, these devices can probe specific physiological properties rather than simply record the body's baseline outputs. These frequency-tuned interrogations will allow for targeted studies of underlying mechanisms that passive monitoring devices cannot capture. For example, tissue impedance can be measured by applying low-voltage current and analyzing the signal throughput. At defined frequencies, these measurements may provide insight into fluid shifts, solute composition, perfusion, or ischemia in a noninvasive manner.

Making sense of this new information will be challenging, yet the rewards may be substantial: a deeper understanding of disease, earlier diagnosis, more precise monitoring, and the development of therapies built on physiologic measurement rather than inference. In this way, multimodal wearable devices may help usher in a new era of medicine.

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