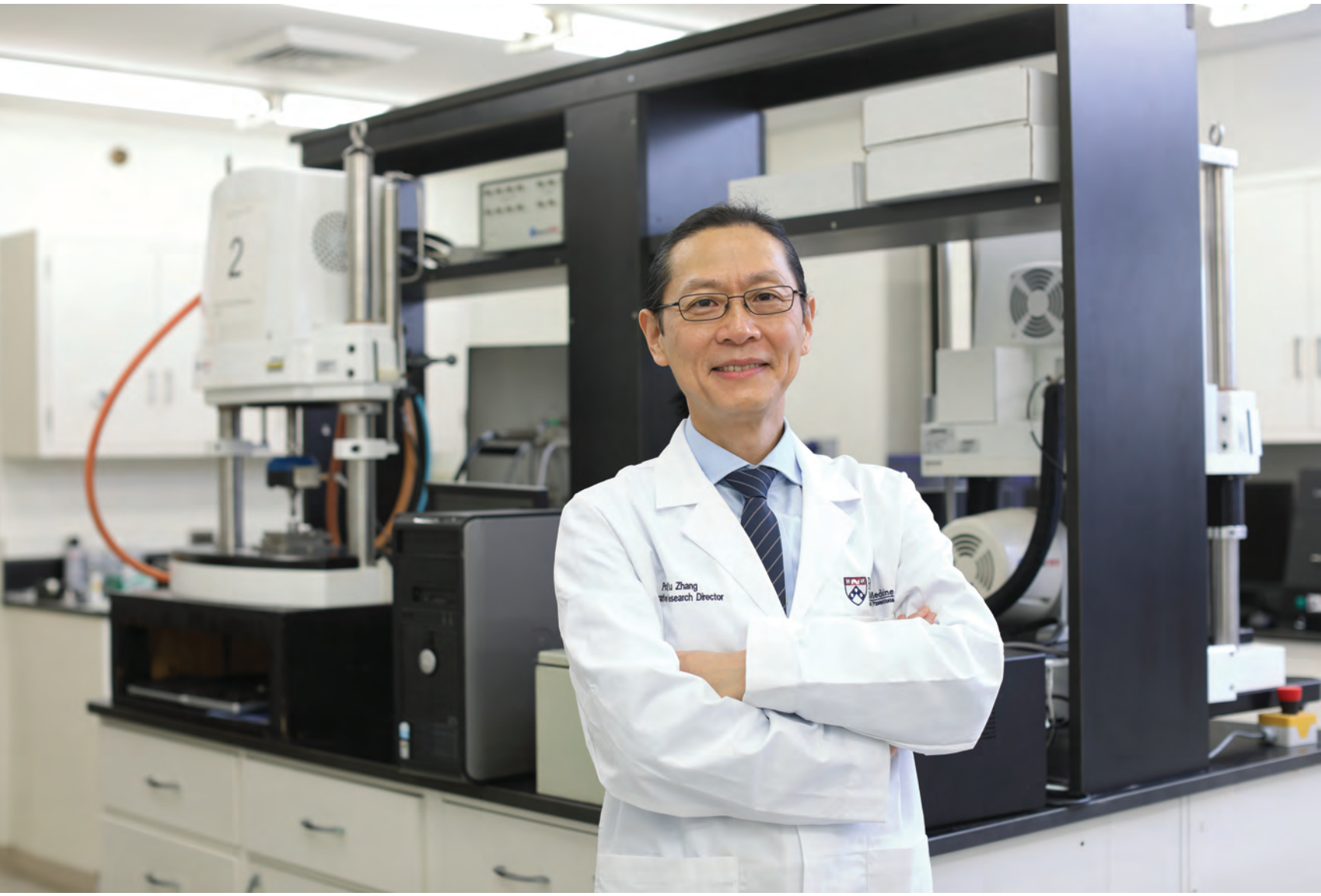


"Dr. Zhang is one of the most respected if not the most respected dental ceramic researchers in the world. His research, bridging the gap between dental material sciences and clinical practice, will take our scholarly activities to the next level."

— DR. MARKUS BLATZ

APPLYING PHYSICS EXPERTISE TO MAKING BRIGHTER SMILES

WITH A BACKGROUND IN PHYSICS AND MATERIAL SCIENCE, DR. YU ZHANG IS ADVANCING THE FIELD OF DENTAL CERAMICS

CERAMICS, SPECIFICALLY ZIRCONIUM DIOXIDE, OR ZIRCONIA FOR SHORT, has become increasingly relied upon in dentistry. From crowns and bridges to other applications, the resulting products can restore function and beauty to patients' smiles.

While beautiful and hard, ceramics are also brittle and susceptible to fracture. For Dr. Yu Zhang, Professor in the Department of Preventive and Restorative Sciences, unraveling the challenges and developing solutions within the field of dental ceramics has become his professional pursuit.

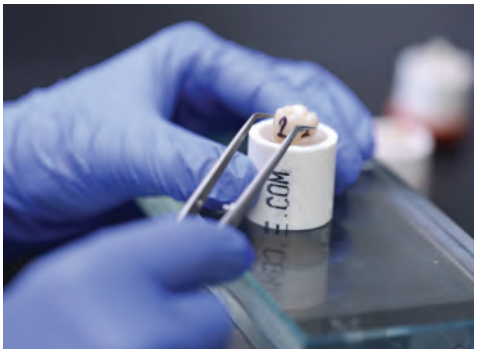
Having joined the Penn Dental Medicine faculty in July, he brings a unique background in both physics and materials science. With 130 scientific publications and counting, Dr. Zhang has for the last two decades applied this expertise to the problem of how to improve dental materials, making them both a good aesthetic match for natural teeth, while also enhancing their strength and durability.

"I came into the dental field with experience in material properties and material characterization techniques," says Dr. Zhang. "By bringing all that into dentistry, where researchers had not been exposed to the types of research my colleagues and I had been doing in physics and engineering, it has allowed us to make some interesting insights and advancements and continue improving the materials dentists use to treat patients."

For Dr. Zhang's new colleagues at Penn Dental Medicine, including Dr. Markus Blatz, Professor and Chair of the Department of Preventive and Restorative Sciences, his presence in the School opens a host of possibilities for collaboration and innovation.

"Dr. Zhang is one of the most respected if not the most respected dental ceramic researchers in the world," says Dr. Blatz. "His research, bridging the gap between dental material sciences and clinical practice, will take our scholarly activities and global reputation to the next level. And his expertise in CAD/CAM ceramics is an especially nice fit, given our enhanced focus on digital innovation."

OPPOSITE: Dr. Yu Zhang, Professor in the Department of Preventive and Restorative Sciences, joined Penn Dental Medicine in July 2020.



AN UNEXPECTED ROUTE

As an undergraduate and master's student in Shanghai, China, and Victoria, Australia, respectively, Dr. Zhang enjoyed the intellectual pull of physics. He also spent several years working in industry as an engineer. But as he was concluding his master's degree, it became clear that stopping his education there would limit his career options. But he was married with a child at that point, and securing an income was important.

"I was fortunate to get an Australian postgraduate award from the government, which was very generous, and would allow me to pursue a Ph.D. in physics at the University of Melbourne," says Dr. Zhang.

He accepted the award and began his studies, but after "a lot of soul searching" and consideration of his family's future, he saw

more possibilities in engineering. He went on to transfer to Monash University, where he earned a Ph.D. in 2002 in materials science and engineering.

His background in physics came in handy while pursuing materials research. "There was a lot of talk about crystal structure," he says, "so that was a nice transition."

In that time period, Dr. Zhang recalls absorbing the insights of seminal papers from Penn faculty members, including a 1997 *Nature* paper by I-Wei Chen of the School of Engineering and Applied Science, focused on a lightweight yet hard and tough ceramic material.

Reading such works about how to develop stronger, more durable materials inspired him, and he was able to put that motivation to use in a postdoctoral position, working with Brian Lawn, an Australian who worked at the U.S. government's National Institute of Standards and Technology, based in the Maryland suburbs of Washington, D.C.

His move to the United States also marked Dr. Zhang's transition into the dental field. Lawn placed him on a project aimed at reducing the brittleness of ceramic materials. Zirconia was introduced as a material used in restorative dentistry around this time, beginning to replace the traditional gold crowns and porcelain-fused-to-metal restorations.

"In dentistry people look to ceramics from an aesthetic point of view — how beautiful it can be in restorations — but frequently overlook how susceptible to fracture it is," notes Dr. Zhang.

Combining his training in materials with Lawn's expertise in mechanics, the two began investigating how manipulating materials could achieve more desirable properties. Their work attracted attention from the dental community.

"When you put two different materials together, there are thermomechanical stresses that arise. I thought up a way to circumvent this problem."

— DR. YU ZHANG

BEAUTY AND MIGHT

These successes also helped land Dr. Zhang his first position as an independent investigator, at New York University's College of Dentistry, where he would remain for 15 years. A focus over that time was on zirconia, an attractive restorative material for its strength, if not its durability. But as a white, opaque material, it was far from lifelike.

"It's pure white," says Dr. Zhang. "Maybe that's good if you're in Hollywood, but for ordinary people it's not a good match for the various shades of natural-looking teeth."

The conventional solution is to place a layer of porcelain over the zirconia. But when these two materials are fused one on top of the other, the porcelain becomes more susceptible to fracture. Zhang recognized this as a problem that could be addressed with physics. "When you put two different materials together, there are thermomechanical stresses that arise," he says. "I thought up a way to circumvent this problem."

The solution was to avoid the "sharp" interface altogether by instead creating a product in which one side of the material was all zirconia, and the other was all porcelain, but the fractions of each gradually change across the interface. Working with Lawn, he got a grant to develop and study such gradient materials in 2007, work that continued being funded for 10 years.

Additional composition manipulations could even give ceramic materials bioactive properties, perhaps repelling microbes. "This could be of great use in dental restorations as well as craniofacial implants," he says.

To address the somewhat unnatural opaque appearance of zirconia, Dr. Zhang had another innovative approach. "The goal is to make the material translucent with respect to visible light," he says. "If it's translucent in the infrared or ultraviolet wavelengths of light, it won't matter because we don't see those."

ABOVE: Dr. Zhang and Sonaj Vardhaman setting up a fatigue test on a mouth motion simulator.

OPPOSITE: Niyati Reddy analyzing wear facets on an anatomically correct monolithic zirconia crown using a stereo microscope.

Instead, he picked the light to which the human eye is most sensitive: green light at a wavelength of 555 nanometers. "If we shine this green light through zirconia, we'll perceive it as translucent," he says. Based on work in classical physics light-scattering theory, which he had studied during his undergraduate and master's years, he proposed adjusting the microstructure to make zirconia translucent while maintaining its durability, publishing a paper on the breakthrough in 2014.

"We use light-scattering theory to calculate what microstructures we desire," says Dr. Zhang. "Then when we go to the lab to make the materials, we use an idea that I-Wei Chen published in *Nature* in 2000 that shows you can densify ceramic if you bring it to a very high temperature for a moment, then drop the temperature." That two-step sintering process allows for the precise manipulation of material microstructure.

NEXT-GENERATION MATERIALS

Other applications of this type of manipulation abound. Dr. Zhang notes that in conversation with Dr. Mark S. Wolff, Penn Dental Medicine's Morton Amsterdam Dean, who overlapped with him during his tenure at NYU, they have discussed how X-rays do not penetrate zirconia, making it difficult to see if there is decay underneath a crown or other restoration in the mouth. If Dr. Zhang applied a similar principal to zirconia as he did when making it translucent under green light, he could create an imaging method that would allow dentists to "see" under restorations to maintain patients' oral health. Working with Jian Xu of Electrical & Computer Engineering, Louisiana State University, the team is currently fine-tuning wavelengths to image through zirconia and other dental ceramic materials.

Dr. Niyati Reddy, a research assistant in the Zhang lab, is part of the team helping develop more advanced materials for dental health applications.

Another novel approach to dental-materials creation that Dr. Zhang is looking forward to exploring at Penn has to do with the processes by which dental products are crafted into the size and shape required for use in patients. Typically, dental technicians grind ceramic restorative materials using diamond burs to give them the correct final form. This grinding requires frequent replacement of the expensive burs, plus it exerts a lot of stresses on the zirconia to achieve surface removal by chipping away small amounts of material. By potentially introducing tiny cracks into the finished product, this approach can compromise the long-term stability of products, as the cracks serve as weak points that can lead to product failure when subject to the normal stresses of chewing and grinding.

By using a different approach, known as "ductile machining," it avoids introducing these defects, achieving an accuracy of form, and maintaining the integrity of the material while preserving diamond burs. Dr. Zhang has submitted a grant to pursue this study. "It's the best of both worlds," he says. "You preserve the tool, and at the same time, you get a better product."

SYNERGISTIC STRENGTHS

Dr. Zhang was eager to come to Penn to collaborate with Drs. Wolff, Blatz, Chen, and others, including Michael Bergler of Penn Dental Medicine's Center for Virtual Treatment Planning, "a craftsman," as Dr. Zhang describes him.

"Michael has a lot of experience in machining and grinding materials, because he's a superb technician," says Dr. Zhang. "I benefit a lot by talking with him, by working with him, and I'm hoping he can be part of the grant I'm working on to develop new protocols for machining ceramics."

Already in close collaboration with Dean Wolff and Dr. Blatz on improving materials for prosthodontic procedures, Dr. Zhang also hopes to expand collaborations across the University, reaching the medical and engineering schools as well.

"We have so many strong clinicians and researchers here," he says. "I want to strengthen my own research by learning from all of them."

> "You can densify ceramic if you bring it to a very high temperature for a moment, then drop the temperature."
>
> — DR. YU ZHANG