



Episode 26: A True Trailblazer
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Dr. Rubin: Hello and welcome to "Taking the Lead," a podcast from the Radiology Leadership Institute that profiles radiologists as leaders seeking insight and inspiration from a variety of perspectives and experiences. I'm Geoff Rubin. Today, I'm speaking with Katherine Andriole, Associate Professor of Radiology at the Harvard Medical School, Assistant Medical Director of Imaging Information Technologies at Brigham and Women's Hospital, and the Director of Research Strategy and Operations at the Massachusetts General Brigham Center for Clinical Data Science where she enables machine learning empowered research across the partners' healthcare system coordinating the execution of a portfolio of clinical and translational research projects in machine learning and artificial intelligence from inception to real-world implementation. From the design and deployment of picture archiving and communication systems prior to their commercial availability to image processing and analysis, business analytics, and machine learning, Dr. Andriole has been a leader in biomedical imaging informatics for over 30 years at both UCSF and Harvard. Recognized as the inaugural winner of the RADxx Trailblazer Award, Dr. Andriole has been a revered role model for women within the field of imaging informatics and data science.

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Kathy, welcome.

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Dr. Andriole: Thank you for that kind introduction, Geoff. I'm delighted to be here.

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Dr. Rubin: You were born and raised in my current hometown of Chapel Hill, North Carolina. What was your family life like growing up?

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Dr. Andriole: Well, so I was born at Memorial Hospital in Chapel Hill and as a Duke alum, it wasn't my decision to be born at the UMC Hospital. But then my family moved to DC for a few years and I've spent most of my life in Connecticut in sort of a rural, small town along the shoreline of Long Island Sound. It's a little bit east of New Haven where Yale University is. So people in the community were employed by Yale and some did farming and lobstering and oyster farms and so forth for a living in my home town.

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Dr. Rubin: It sounds like an idyllic place.

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Dr. Andriole: It was. It was a great place to grow up. I did a lot of outdoor kinds of activities and it was a very close community. It's grown since then but it was a wonderful place to grow up and being by the shore is something I've always enjoyed.

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Dr. Rubin: What led to that move from North Carolina up to Connecticut?

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Dr. Andriole: My father was in medicine and he was an intern and resident in internal medicine at UNC and then did a couple of years at NIH doing research training and then he returned to Yale where he had been a student and ultimately became a professor of internal medicine and specialized in infectious diseases. My mom was trained in surgical nursing and later on, was trained in psychiatric nursing and she was a huge influence on me. My parents divorced when I was a preteen and I think that's what made our family so close. I have two brothers and my mom and me but she took what was a volunteer organization in our rural town where people were starting to worry about teenagers and young adults abusing drugs and alcohol and she started a helpline, which ultimately became a mental health agency that treats chronic and acute mental illness for people in the home town and also provides basic needs for some of the working poor in our community to give them a hot meal, help with oil in the harsh winters of Connecticut, clothing, and diapers for children and things like that. She ultimately became the director of that counseling center and retired in her 80s.

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Dr. Rubin: Wow. That's quite an arc. You clearly grew up in a household where healthcare was a central consideration. Public service as well it would seem. You mentioned brothers and...was it just brothers or brothers and sisters?

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Dr. Andriole: Two brothers.

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Dr. Rubin: Two brothers?

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Dr. Andriole: Yeah. One older, one younger. Yes, definitely. I was influenced by my father's career, my mother's career, and being exposed to medicine and science. Education was very, very important in our family but so was balance of character and extracurricular activities. And I grew up a tomboy with my brothers who were both wonderful, wonderful athletes and continue to be and so I did sports at a time when there weren't a lot of opportunities for women to be participating in competitive athletics. So education was very, very important but so was sports and we're a sports-crazy family as you can imagine as a Duke alum. We're all Duke basketball fans.

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Dr. Rubin: That's marvelous. Even your dad with his history of being a Carolina student?

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Dr. Andriole: Yes. He was a great athlete as well but understood and was happy that I chose to go to Duke as an undergrad.

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Dr. Rubin: That's marvelous. Now you mentioned athletics as a central component of extracurricular activities. I wanna talk a little bit about your athletic career but before we do,

were there any other types of extracurricular activities that you engaged in growing up, hobbies, or organizations that you worked with?

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Dr. Andriole: Well, athletics took a significant amount of time to do at a certain level competitively but I did play the piano, love music, love the theater. My mom would take us frequently into New York City to see plays on Broadway and as well as the Yale Repertory Theater. So I got an appreciation for that. Yeah, I think those were important aspects. And I think volunteerism was another thing that we learned particularly through my mom with her activities in the town and that giving back and participating in some of these activities not only was a good thing to do but incredibly rewarding and something that I think she instilled in my brothers and me.

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Dr. Rubin: Superb. Getting then to your athletic career, what sports did you participate in? How did you get involved? How old were you and what was sort of the arc of your involvement in athletics?

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Dr. Andriole: Sure. Well, I was a competitive swimmer, to begin with. My older brother was an exceptional swimmer and then my younger brother as well. And so I participated in what was at the time AAU swimming, which was, you know, daily practices year-round and meets on the weekends and traveling to different places for swim meets. And then I suffered really all along a terrible ear infections and was told by my doctor that I needed to sit out of the pool for a year or so and that essentially ended my swimming career. And I took up track in high school and did that in the spring. And when I could no longer do high school swimming because of the chronic ear infections, the cross-country coach approached me and said, "Why don't you come out for the cross-country team?" And I naively said, "Isn't that for boys?" Because it was only a boys' team at the time. I'm a Title IX baby and he explained to me about Title IX and that that would enable me to participate on the team. And so I was the first female on the cross-country team in high school and it was a wonderful experience, and ran track, cross-country, indoor and outdoor track and cross-country in college as well. continued the running up for a good long time after that. I would have to say a different body ago I was an athlete so...but yes, it has always been a very important aspect of our family. We enjoy watching sports, participating in sports and so on.

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Dr. Rubin: That must've been a tough pivot to make from the pool to the track.

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Dr. Andriole: It was. It was very different but they were similar in that they are individual sports in many ways but a lot of team camaraderie because you work very hard. The training for swimming is very hard and maybe not as fun as...I know my brother's boys are all exceptional hockey players, ice hockey players. And that practice is hard but fun. And swimming was fun when I think about it and I wouldn't change a thing but it's very difficult training. And so was track. It's a little solitary. But being part of a team and part of the activity and the camaraderie, I made friends for life through those activities. But it was different.

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Dr. Rubin: Yeah, yeah. It's marvelous. Were your track events principally at distance running?

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Dr. Andriole: Yes. Well, middle distance, mile, 2 mile and then 5,000 and 10,000.

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Dr. Rubin: And it's interesting that you speak favorably about your experience as the only woman on the cross-country team. What experiences can you relay? Any stories that basically helped to underscore either your resilience amongst a bunch of boys or the welcoming nature that these guys had to bring you into the team?

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Dr. Andriole: Sure. Well, you know, they were very welcoming but I do remember the captain and some of the other really excellent runners had invited me to do preseason training with them and I think the first day that I went, we went for more miles than I had ever run in my life, And I think I came home and cried to my mom and said, "I don't know if I can do this." You know, I kept up but I thought it was really maybe something that I wasn't prepared for. And she said, "You can do it. You know, you can do it." And she supported me throughout and I was really very nicely received. But, you know, I can tell one story where we had a meet against our crosstown rival at their home course. And I remember we had just completed going through what the course route was and one of the boys on the other team shouted, you know, "What's a girl doing here? She can't be in the race." And to my surprise, my Branford teammates circled around me kinda like giraffes do when one of their own is injured. And they supported me and they said, "Leave her alone. She's in this race with us." And they said, "You better watch out because she's good." And I just felt the value of team and the camaraderie and the support and the fact that they appreciated that I had worked hard and was a part of the team.

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Dr. Rubin: Yeah. It's so impactful to have such a positive experience early on. That's terrific. Now in 2013, you were elected as a member of the Branford Sports Hall of Fame. What did you do to gain recognition so many years after your competitive athletic career?

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Dr. Andriole: Well, the Sports Hall of Fame is an entity that was formed really to recognize people who contributed to sports in town, had success in sports, and people in all different sports are nominated. I think part of what people may have seen in my nomination was certainly participating in athletics at a high level even during a time that girls and women didn't really have many opportunities to participate competitively, certainly scholastically and certainly collegiately in high-level sports. You know, there were a few things you could do, swimming, running, maybe softball. There weren't opportunities to play soccer and lacrosse and hockey and all these different sports until after Title IX. And so after I became the first member of the team...

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Well, currently they have both a girls' and a boys' team and they've been very successful winning the state championships a number of years ago. I also think they saw that I had a

nice well-rounded background and that I was successful academically and a contributing member of Branford society and so I was honored with that induction into the Sports Hall of Fame.

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Dr. Rubin: That's fantastic. I'm sure that you're a terrific role model for folks in the town and particularly for some of the young athletes coming up. Do you still have a connection with Branford?

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Dr. Andriole: I do. The current coach of the cross-country team is someone that I ran with. He is a wonderful, wonderful runner and was a little bit older than I but was on the cross-country team and track and, you know, very supportive of what he's done and he's been very supportive of me. And it's great to see kids getting involved in a lot of these activities. And as you know, Title IX wasn't just about sports. At the time, the percentage of women who attended medical school was less than 10% and now we see, you know, a good 50% of women enrolling in medical school. So Title IX had a huge impact.

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I was very thankful for the men and women who put forward Title IX to enable women to get all the benefits of participating in sports. I mean, there's so many things you learn by participating in athletics. And it just gave women and girls an opportunity to participate in those kinds of things.

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Dr. Rubin: Yes. Well stated. What was your first job that you had outside the home growing up?

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Dr. Andriole: My first job actually was in my father's infectious disease lab over at Yale and I loved science and math. And I had the opportunity to do not only some research into some new technologies but also to do a service which I took very seriously and understood the impact on patient care and that was around the time when the aminoglycosides, antibiotics were relatively new. They were effective but also had a high toxicity, autotoxicity, and others if they were used in too high a dose. And so patients who were on these with very serious infections were typically monitored daily to see what the antibiotic level was and was the infection responding and I took that very seriously. I was just in high school but it was a role that I took and at a job that I took. I also had the opportunity to meet some other people in the hospital and in particular, people in radiology and CT was relatively new. And I was fascinated by imaging and the use of the computer to create these beautiful images that were something new at the time. And MR was very new as well. So I did definitely had exposure to science and math but in a translational sense being used to really impact care and patient management.

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Dr. Rubin: And so after high school, as you mentioned, you headed to Duke University and you earned a bachelor's degree in biomedical engineering. What attracted you to Duke and to BME?

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Dr. Andriole: Again, loving science and math. And that was a little bit uncommon for girls to enjoy math but, you know, my mom always said, "You can do whatever you enjoy. Just do it to the best of your ability." And she encouraged me to be involved in the sciences. And when I was looking at colleges, I was enamored with the thought of combining math and physics and a biomedical application. And Duke was one of the few that had an undergraduate program in biomedical engineering. So I went down to Duke and explored that. And, of course, I had the ability to run track. And the other thing I had the ability to do was to study at Oxford for a summer and that was a wonderful experience as well because I had really not traveled all that much. I certainly hadn't traveled internationally until I had gone to college. So I loved Duke. It was a fabulous choice for me and I am a huge Duke fan and a fan of the educational process that we had. The engineering school was a little bit smaller than it is now. And so it was very intimate. You would walk down the hallway and the professor would come out of their office and say, "Well, Kathy, what do you think about this course or how's it going?" And it was a very encouraging and supportive environment.

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Dr. Rubin: It sounds like fantastic education. You mentioned heading out to Oxford where I understand you studied English literature. That was quite a departure. What led you to study English from the English?

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Dr. Andriole: Well, you know, it was an opportunity to experience...then I became an anglophile from this experience but to go to a country where their history was so incredibly interesting. But I studied 20th century English literature and it was a great departure as you can imagine. We had to write a paper a week. We used the Oxford tutorial program where you weren't told how to prepare yourself for your individual meeting with your tutor. You could prepare as much or as little as you wanted. But you were told to assess a particular book or set of poetry and so forth. And I learned so much. I learned how to write. It's very different than writing an engineering lab report or a scientific paper. So I learned how to write and write quickly and I think I got a lot of critical feedback to learn how to express myself.

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Dr. Rubin: It sounds like a really fantastic experience, really enriching. Your household growing up, as you have described, was so steeped in healthcare and in the practice of medicine. I'm intrigued by your choice to go into the field of engineering and informatics. Did you ever consider a career in medicine and medical school?

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Dr. Andriole: Yes, I actually was in an MDPHD program at Yale. After Duke, I came back home and was in the MDPHD program. I didn't go further to complete my clinical training because, at the time, I studied engineering, which was again sort of an oddball thing for the MDPHD program. Not many people went into that. Most went into closer related to, you know, pharmacology or molecular biology and so forth. And so it was a long time but I had the opportunity to go from there out to California to participate in digital imaging really. So I was doing my research in radiology in classical machine learning, image processing but we didn't have images in a digital fashion at that time. We had film and yes, the CT scanners and the relatively new MR scanners and ultrasounds did produce digital images but they weren't

really built to get digital images off of the computer. They were built to print to film predominantly and that's how radiology and digital imaging was practiced. And I had the opportunity to go out to California always thinking that I would, you know, likely go into radiology but got involved in informatics, got involved in building PACS, picture archiving and communication systems before they were commercial entities. So I worked with Bernie Wang and Sam Dwyer and David Averon at the University of California, San Francisco, Ron Aronson as well. And we were actually building those systems, programming them ourselves and we implemented them at UC San Francisco and were using them clinically to show that it could be done.

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Ultimately, industry came forward with products that were viable and so forth but that's kind of how I got started in it and I just got more and more embedded in informatics and understanding now that we have images digital, what can we do with them? And I've really come full circle today with the machine learning and the Center for Clinical Data Science where we are actually reaping the rewards of having digital images and medical information that's in a digital format. And when I was in medical school, we had paper charts and you went to the folder and you went through the paper charts. So I'm that old. But we were really pushing the envelope and learning as we went. We didn't have a good, viable mechanism for doing projection radiography digitally so I was very involved in studying computed radiography, which used the photostimulable phosphor plate. Now, we have digital radiography where it has mostly taken over from computed radiography but those systems were really quite new. At the time, we didn't have informatics standards such as DICOM. We had to use hardware and software techniques to get data off of scanners to then use them in a digital fashion. So it was really an exciting time. We kinda did everything together. We laid networks in the hospital. We built display stations. We built archives, and so on, and so forth. And it was really a very, very exciting time.

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Dr. Rubin: That's fantastic. Clearly, your enthusiasm and passion come through. Just rolling back a minute to those days of your graduate training, so you actually completed medical school as well as completing a Ph.D. in electrical engineering. And it was only after you completed all that training and then followed where the road led you that you ultimately said to yourself, "You know, informatics, medical physics are really the areas that I enjoy and practicing medicine is something that I essentially can do through the informatics domain." Is that correct?

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Dr. Andriole: Yes, I think so. I met Bernie Wang who was at UCLA in a conference in Berlin, Germany and he said, "Oh, I need someone like you." You know, I speak a little bit of both domains, the clinical and medical vocabulary, and the engineering vocabulary. And I got involved with his group and he was, you know, very, very instrumental in developing PACS as was Sam Dwyer who was at UCLA at the time. And then we got recruited up to UCSF to really put this in a clinical implementation. And I enjoyed the clinical. I always thought I would and sometimes wonder had I completed that training as a radiologist, might that have been a better route? But, you know, there are multiple roads to an end and I just continued moving forward, doing what I was doing, doing what I felt was important to contribute, and here I am.

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Dr. Rubin: Yeah. You were having a very impactful career. Absolutely. Now, I see that 10 years passed essentially between your bachelor's degree at Duke and your completing your graduate degrees at Yale. Were you a medical student/graduate student during all 10 of those years?

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Dr. Andriole: Yes. Unfortunately, Ph.D. degrees in the States, as you know, require coursework and because much of the medical school coursework that I had to do for that did not really count for an engineering coursework, I spent a good two, three years doing just the coursework. And engineering degrees often take a significant amount of time. So yes, it took me a long time. I spent a long time in school and actually have never really left school, quite honestly.

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Dr. Rubin: I know the feeling. But if you love what you're doing, the time just passes. Continuing on that theme, after earning your Ph.D. from Yale, you essentially spent four years in postdoctoral positions before receiving your first faculty appointment at UCSF. Was there ever a pull toward industry for example? What kept you on task heading toward a formal academic faculty appointment?

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Dr. Andriole: You know, we were in a field and certainly I have been all my life where there's wonderful research going on in the industry, and collaborating with industry can really accelerate what work you are doing. Academia has its sort of personalities and pace and industry has a different and certainly, they have different ends but I think academic-industry partnerships is something that I feel can be very, very useful because I'm very interested in translational research and seeing the types of things that I and my colleagues work on being implemented and impacting clinical care quite honestly, patient care and how people operate in hospitals. And so, you know, I did have some pulls a little bit but, you know, ultimately, I enjoyed where I was and I enjoyed teaching. And that has been I think a big part of my career educating. I feel it's part of my job. It's the future of our profession and I find it incredibly rewarding to participate in mentoring and teaching. And so I got involved in really developing some courses that were de novo because people were kinda like, "What the heck is informatics and why should I care as a resident or a fellow or even a medical student?" And so I think that was part of the pull. And I was just having too much fun where I was.

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Dr. Rubin: It's a great message I think for folks. Sometimes there's a tendency to feel this sorta strong pull to sorta settle in and get on with it and to have the stability of a position that seems to have the implication at least of longevity. But following your passion, doing what makes you happy, and building on important work can be very, very rewarding. And clearly, whether it took 14 years from the time of your bachelor's degree until your first faculty appointment, you obviously accomplished and learned a lot during those years. It's fantastic.

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You spoke a little bit about those early years, UCLA and then up to UCSF developing PACS, laying networks, essentially building it as it goes. And I remember those heady days well,

perhaps from a slightly different perspective but still it is tremendously a lot of fun. What are some of the early lessons that you learned from your implementations of early PACS and CR systems that you find applicable to your work today?

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Dr. Andriole: Well, I think that you can think like an engineer or you can think like an academic where you are exploring something academically challenging and interesting but if you want to do translational research which, you know, used to be sort of looked down from the ivory tower academia initially, but if you want to do translational research, you need the domain expertise and you need to hear and listen to and understand the workflow of the environment in which the application is going to be implemented. And so technology is one thing but it very much is dependent upon the people involved and the processes, making something that is intuitive, something that doesn't interrupt the workflow, that kind of understanding of what's going on and just understanding that computers were new for a lot of people. I mean, I think I remember I carried a pager really 24/7 in those early days and we would go running to the clinical environment, to the ICU or the OR or the reading room when there was a problem and I can remember surgeons calling and saying, "This station isn't working." And we'd go up there and it had just been that the screen had gone to sleep and they needed to move the mouse.

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And, you know, seemingly obvious things for people who were in the engineering world but not so much for people who were expert clinicians and hadn't really used computers before. But there were some wonderful things that I learned. Keeping things simple and intuitive and having an elegant user interface would be a very simple intuitive one, not necessarily something that had all the bells and whistles. But it was a collaboration. We couldn't have achieved what we did without working with clinical folks. And I think today I would say the same about machine learning and artificial intelligence. We have wonderful data scientists who are pushing the envelope in the field and I think we're starting to see some of these technologies get into the clinical world. But the ones that are doing the best and that are the most useful and the most impactful are those that have clinician input.

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Dr. Rubin: Yeah, that's a lot of really important points that you just raised there. When considering radiology's value chain beginning with image capture, then image display and analysis to interpretation and communication, it's intriguing how your career has seen your focus shift across this broad value chain. Many engineers, scientists, investigators tend to focus in on one aspect of the value chain. It might be image capture or image reconstruction. But you've really spanned the whole breadth. I'm curious. What are your thoughts on the domains of image capture or display versus information extraction and clinical inference?

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Dr. Andriole: Well, you know, I think we were thinking big picture. I think it's important to become an expert in something and go as deeply as possible into a particular area. But I don't know that you can understand the display aspect if you don't understand how the signal was acquired for example. And so I felt that understanding the whole image cycle, the whole image cycle as you articulated, it was very, very important and I think we had to work with the acquisition modalities to get them digital. So that was step one and once we did that, well, how are we going to view these? How are we going to store these and communicate?

So it all linked together. And I think thinking back then, I kind of did what was needed and got involved in what was the next step and how would we make this thing work with kind of the future in mind. What will happen if we can have all of this data digitally and then we can analyze it and perhaps do knowledge discovery and so on? But it took a lot of work and it took different steps and focusing on those different areas to get each one of them to work together.

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Dr. Rubin: Yeah. Maybe just drilling into this topic a little bit further, just sort of reorient me if I am a little bit off base but you articulated the evolution of the nature of our images from analog toward digital and all the steps in getting to DICOM standards and really to the point now where the analysis of images is just a very digitally-driven focus. And then when we get to the domain of the application of machine learning in clinical informatics and applying it for clinical inference, it seems that we're thrust back into a relatively analog world where decisions are not necessarily quantitative. They're not necessarily cut and dry. There's a lot of overlying utility functions and probabilities that are very difficult to define. And I'm just sorta interested in your perspective as an engineer, mathematician, scientist in moving into a domain where the digital and the quantitative is less a fundamental underpinning of what you are working with in trying to impact your ultimate outcomes.

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Dr. Andriole: Well, I think we struggled with similar concerns when we were moving to PACS and doing things digitally back to the acquisition modalities. People would say if your family member was having a chest X-ray, is this good enough? And we had to do a lot of studies to show that yes, the spatial resolution is by definition less than an analog imagine but the contrast resolution is higher and we can see what we need to see because we can process the data and so on. We had to at each step of the way convince those people, radiologists who were making these interpretations and impacting management decisions, to trust the technology. And that was not easy in the beginning. And I think we're in that phase now with machine learning. Part of the issue with machine learning is that...the interpretability of it and people are looking into that. The other piece is that it's also very data-driven and oftentimes the model is the data that you use to train it. And so how does this generalize perhaps from the patient population in which it was derived to the more general population and is there bias in that information and how are we going to implement this because it requires now integration standards that are really just being formed and adopted so that we can, instead of have it on a workstation down the hall, have it embedded in the workflow so it actually is a useful clinical decision support for the clinicians using it. The problem that we have now is we don't have that coordinated aspect. I think this is a team sport to make this happen. Again, like PACS was where you need clinicians involved in the activity and defining the use cases, defining the problems and being involved in understanding what the model is doing and when you get certain answers from the model, there is often a clinical explanation of, you know, a clinical mimic or something like that that perhaps the data scientist without a clinical background might not recognize but by involving clinicians, we can do a better job and make it more useful.

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Dr. Rubin: It's interesting. I mean, it seems to all hang together, the fact that you essentially have followed the innovation wave, sort of the advanced wave of new development and such and PACS is mature and digital radiography is largely mature. And rather than just sorta

hanging with that, moving along to the areas that are new and exciting, it makes a lot of sense. After 10 productive years at UCSF, you made the move back east to Harvard and Brigham Women's Hospital. What led to that midcareer transition?

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Dr. Andriole: Well, to be honest, I wanted to be closer to family. So I'm very close to my family and my mom and my brother was back here. He had just had twin boys and I thought if I was gonna be involved in their lives that it was time to come back closer to home. So that was a big piece of it. I loved my time at UCSF but it was very far away for me. And so that was one of the reasons that I decided to come back to the East Coast.

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Dr. Rubin: Got it. And how has your academic focus evolved since arriving at the Brigham 16 years ago?

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Dr. Andriole: I think at the Brigham, I was very involved in clinical decision support. Some of those value-added systems that have now become adopted to a certain extent, Harvard, both across Brigham and Women's and MGH had internally-developed electronic health records. And so they were fairly advanced in the electronic health record activities as well as doing digital imaging. And so I had the opportunity to get involved in that. I also, during that time period, instituted a series of classes for the residents to introduce them to informatics because I think people were starting to recognize that this was something that every radiologist and others should have some foundational knowledge of. But that was a really interesting time at the Brigham. And we were very involved in those kinds of activities. One of the things that we did was implement speech recognition for report generation. Rather than using the traditional mechanism of the radiologist dictating and then a transcriptionist listening and typing what they heard, it went immediately to speech recognition. So that was a relatively new technology and we implemented that and found some interesting aspects of that implementation and the impact of that as well. And then came the opportunity and the formation of really a cross-partnership between Mass General Hospital and Brigham and Women's Hospital that was instituted by both the chairs of radiology, Jim Brink at MGH and Giles Bolan, and then Keith Dryer who was seeing the impact of data science and artificial intelligence and so on in other areas, in other industries and how might this impact medicine. And so we started the Center for Clinical Data Science and I transitioned to that full-time and have been involved in that since.

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Dr. Rubin: Superb. And within that center, you became the director of research strategy and operations, which sounds like a big job. What does that role entail?

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Dr. Andriole: Well, it really means enabling people to do research using these technologies. At the time we started, there was maybe a handful of people and the group has grown to over 40 now. But part of my job was to enable people throughout the enterprise across both MGH and Brigham and not just radiology although we started heavily in radiology because it is very amenable to convolutional neuro networks and machine learning in particular. But to hear what their research activities were and to see how we could facilitate that either through infrastructure... We had a wonderful collaboration with NVidia as well as other industry

partners, GE, Fuji, Phillips, and so forth and Nuance as well. And using the wonderful compute infrastructure that we had, could we facilitate research in this area. One of the things that we were very, very focused on, while basic research in machine learning is very, very important, again, we were more interested in the translational aspect and taking these projects and use cases really from the beginning all the way to translation into the clinical environment and even commercializing some of those, although I was more on the research side. But again, it brought back some of the old days of implementing PACS and the fun that we had and really the important work that we were doing.

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Dr. Rubin: Yes, and as you, I think, articulated, the Center for Clinical Data Science at this point operates well beyond medical imaging exclusively. And about what percentage of the work that you connect with is imaging, radiology related, and what percentage is outside of radiology?

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Dr. Andriole: I think in the beginning it was almost all. I would say maybe 90% imaging. I would say now it's probably closer to 65%. Still quite a lot of imaging but including pathology images, derm images as well. And I think, you know, that was warranted because we need to understand working with images how important that was. It was formed out of radiology and so that's where we started. But it has really exploded and now we have more requests for collaborations than we can meet, which is I suppose a good problem to have. But we're seeing work with electronic medical record data. Certainly, there was a lot of activity during the COVID pandemic, much of it around workflow and resource availability and so forth as well as looking at imaging. Although imaging isn't hugely prominent in the diagnosis of COVID though, it maybe useful for the management of patients and understanding do they need to be stepped up to ICU and so forth. But we have spread out. We've looked at all different fields, worked with an anesthesiologist at the Brigham who does high-risk OB and she was explaining that her nightmare is her first sort of 20 minutes of delivery when she's administering anesthetic and monitoring mom and baby. A long story short, we looked at developing a model that could help sort of predict when to give presser if the blood pressure went too low and so forth. So that was a totally new activity. We have another activity with GE as a collaborator on this but a different department than imaging GE where we're collecting data from the ICU beds. And that is more of a predictive kind of activity. Can we predict adverse events before they happen by looking at all those signals? Even had a psychiatrist who worked in addiction medicine to see if they could build a model to detect marijuana toxicity in patients because you don't see it in the blood and they used a near-infrared imager and a machine learning model to predict which patients were inebriated I guess is the word from THC.

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So a huge variety of things that people have been looking at. And, you know, the sexy part of the machine learning is the diagnosis and that kind of thing but there is a lot of back-office things that have already been implemented that I think are incredibly useful, things like predicting no-shows. As you know, having an empty MR scanner is a very expensive piece of equipment to be sitting. And can we predict which patients might be no-shows? Things around billing and workflow and coding and so forth. The less sexy things but very impactful things that machine learning can be used for. Detecting artifact in imaging, movement artifact while the patient's still in the scanner knowing whether we need to repeat or not. So

these are the kinds of things that people are thinking about, not just the imaging detection, detecting a finding of some kind but yeah, it's exploding.

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Dr. Rubin: It sounds like it and it's a great breadth of dimensions that you're involved with. And the business analytics can be very, very important and empowering to enable the resources to flow to the clinical analytics and such. So I think it all sounds fantastic. Talk to us a little bit on your view of the continuum of translational clinical research to clinical innovation. And with so many diverse ideas coming up in the center and new projects that are being worked on and developed and then you've got these models that you're testing and reporting on, what does the process of actually seeing those solutions migrate into the day-to-day clinical or business analytic chain look like and how do you participate in helping that take hold?

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Dr. Andriole: Well, I think it's interesting. It's a very difficult part as you know. People think, "Oh, I'm gonna do machine learning. I'm gonna build a model." And in fact, there's a pipeline that starts with defining the cohort of data and finding the patient data and so forth, doing data wrangling and understanding that, labeling the data. All of that is very much a bottleneck and a bulk of the time that people spend when they really realize, "Hey, I'm gonna do this for clinical data." The other piece that's very difficult is sort of the last mile and implementing it into the clinical arena. And that's also a very exciting part but difficult because it does require collaboration with industry perhaps if you want to embed it into the workflow. It requires collaboration with leadership, clinical leadership. And at our institutions, they are the ones who make the decisions around which applications they will accept or allow or test in their environment. Some of the things that we do initially are test these tools clinically in shadow so that we're not impacting the clinical workflow at that stage to see that it does work reliably and so forth, getting moderate feedback. And then putting it into the true clinical world and assessing the so what, you know. This is a cool technology but what was the impact and does it help with accuracy? Does it decrease interreader variability? Does it decrease costs and so on and so forth? Does it maybe alert you to something you weren't thinking about when you were going over the thousands and thousands of images that a radiologist is viewing in their very busy day?

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So this phase is a very difficult phase and we are creating a clinical research organization type of structure around this. Part of that reason is to evaluate these tools and evaluation is a tricky thing because it requires some way to standardize across the different models. And right now without having the same data sets that the models were built on, you know, understanding the generalizability, a lot of the tools have not been very generalizable and have not worked well when they've been tested in the clinical environment. So we're trying to put some framework around this, and also working with the FDA who is also learning with all the folks who are doing work in this area because it is so new and what the regulatory requirements around this are going to be. We're fortunate to have leadership all the way to the CEO of what was called Partners Healthcare and is now Mass General Brigham. Dr. Anne Klibanski who is the new president and CEO of Mass General Brigham is our biggest supporter and leadership through the chairs in the department and so on, and in an environment where people are enthusiastic about trying new things, very passionate about

applications that they're interested in. And I think you really need the leadership from the top down to be able to take this from the lab into the clinical environment.

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And as well as having commercial entities involved with us. It's not my area of expertise on the business side but working with them you learn quite a lot about how they are constructing their business, what their goals are, why they're interested in a particular aspect of a project, and so forth. So it's a very interesting process. It's a team sport. It's very much a team sport. But leadership from the top down I think is very, very important. And an outlay of funds is important because some of the compute infrastructure when we started, was very, very expensive. I think moving computing to the cloud in the future is gonna become more affordable and people are starting to do that now. But I think in the beginning, we were able to go there because leadership had the foresight to invest some money in infrastructure and in the entity that became the center.

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Dr. Rubin: It's so valuable to emphasize the importance of commitment amongst the spectrum of stakeholders and particularly all the way up to the sponsors of the effort from the C suite, department chairs, system leaders. It really speaks to the culture of the organization to support this kind of work. I'm interested in your perspective on the domain of implementation science and the extent to which you see that domain as a particular scientific discipline to leverage in the course of facilitating clinical implementation and translation.

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Dr. Andriole: Well, there are people who really are experts in this and I would not say that I am although I have done implementation and learned a lot of it. But I think there's the technology and then there's the workflow and the people. And those three pieces work together and even work against each other and you need to understand that aspect. And it is very difficult because you are implementing in the clinical environment or simulating a clinical environment as closely as you can without interrupting the clinical work. And that's what we've had to do and it makes it very, very difficult. But I think we need to learn more about this and I think we've learned a tremendous amount since I've been at the center. It just solidifies in my mind that the clinicians have to be involved as we have learned the nuances. You can start with the base model and then you go to implement it and something that you might not have thought about as a data scientist is brought forward instantly by a clinician. And so I think a lot of preparation has to happen before you go to the implementation phase and you need to have a robust...from a scientific standpoint and even a product development mind frame before you put it in front of a clinician to actually test in the clinical environment. You can show the different versions to clinical champions as we call them or people who are more involved in the project but you really need to cover all the bases. And we've had an interesting structure at the center where we, again, are multidisciplinary data scientists, clinicians from across the Mass General Brigham who are absolute experts in their fields but maybe not a data scientist. We have folks who understand the business world. And then we have a project management types of folks who are very involved in being a bridge between the clinician and the data science side that help with that implementation and managing that whole project. And I think those are different types of expertise. It would be difficult to have all in one person. I think in the old days we kind did that at PACS but now it is very much an expertise in each of those areas. And so we have people who are interested in doing those particular roles.

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Dr. Rubin: It's very empowering to be able to work with such cross-disciplinary teams and to leverage that diverse expertise and just to underscore the point that you make that even in a domain of such advanced technology and computing capability, data-driven, it often falls down to individual relationships and connections that can be made in order to get things done. And I think you made that point very clearly. You're working with clinicians. You're working with administrators. I imagine some applications are more clinically focused. Others, the business analytics, more administratively focused. Are there any principle differences or generalizations that you can describe in terms of the approaches when working with clinicians versus administrators and developing analytical tools and any sort of best practices that you wish one group might adopt from the other?

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Dr. Andriole: Well, it's an interesting question. I haven't really thought about it. You know, the way I think about it is that we're working with the domain experts. And so whether that domain expert is clinical in the sense or someone in the administrative realm, that is their domain expertise. You know, building some of the business analytics tools in the beginning, do you have to be a computer programmer to use these tools? Well, oftentimes the computer programmer doesn't know the particular use case for that particular application and it's the domain expert who knows that. And so you need to make it intuitive and usable for them. It's kinda like driving a car. You know, I can drive a car. I can put gas in. I don't really know how a car works and I don't have to read a manual to use the car, to drive the car. And we've strived to make these tools in that fashion but you really need to be embedded in that domain and you need to have some kind of a champion. And so I just view them as, you know, this is a clinical expert. This is a workflow expert. This is a medical physics expert and so forth. And we're fortunate that the environment that we have is full of people who are energetic and enthusiastic about what they do and willing to share and be part of these different projects. But I think it's imperative to have that clinical expertise or that administrative expertise or nursing expertise, whatever it may be, to be intimately involved, at least one person that can help drive that. There are just things that you just don't think about unless you have that involvement from the expert, whomever that may be.

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Dr. Rubin: Yeah, that's very well stated. How would you advise a health system CEO who called you up and asked you how they should go about assessing the value that they might realize from a machine learning implementation? And what infrastructure would they need in order to realize that value?

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Dr. Andriole: Well, I think when we started, that would be a difficult question. I think it's advanced so rapidly that now I see people being able to, for example, go to the cloud and pull down an application. I would advise them to investigate this in their own environment. And by that, I mean, see if it generalizes to their data. And think about what is the problem you are trying to solve with this particular tool, not just because it's a cool technology and everyone's doing it but is there a reason. So, you know, do you have a high rate of no-shows? Do you have a high rate of poor image quality that you want to perhaps catch at the scanner? Do you have a huge volume of cases coming into your emergency department that puts maybe let's say the stroke patient at risk of being read in a timely fashion because it's buried

with hundreds of cases and might an alert saying, "I suspect stroke in this," setting off the stroke team and so forth be something that would be a benefit? So it's certainly can be impact on patient care. That's often... Outcomes are a very difficult thing to prove but ultimately, I hope we get there. I think it can be improvements in efficiency and cost. And as a reminder, because people are very, very busy to certain things they might not have thought about or missed because they're a human being and get interrupted in their workday and so on, certainly contraindications and things like that can be alerted to. But I think interreader variability and even teaching. The educational aspects of this I think is something that people haven't talked a lot about but I think there is a tremendous educational aspect to it.

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And maybe even using these as screening tools and helping to maybe reorder the worklist. You know as you sit down in front of a workstation you have a huge list to get through in a day and how do you do that or balancing the workflow. So I think you really should look at an application that's going to solve a specific problem that you have. Can having this particular application bring you new business perhaps, you know, thinking as a CEO? Can it improve certain things? Can it improve efficiency and so forth? So I would start with the why, the use case of why you would be interested in a particular application and then I would test it before buying it to see how well it generalizes because we are in the problem now of, quite honestly, the models are very dependent on the data on which they were trained. And for a lot of good reasons as well as bad reasons, we are not very good at sharing data across institutions. And we may have homogenous patient populations in so many areas. So how do we make these algorithms generalize to the world population and to different severities of disease and how it may look and so forth? And that's data-driven. And so you need to test it in your own institution.

[00:57:10]

Dr. Rubin: Yeah. Great points. It's evident why it's important to validate a model that's developed on a specific patient cohort to assure that the performance of that model will be adequate in a different cohort such as the one at one's own hospital. But the capabilities, particularly outside of academia, for a healthcare organization to perform that kind of testing and to know from a reliability perspective that they have the data to convince themselves that if they rely upon this model that they are doing a service to their patients and to their practice is a bit of a bridge to reach. What are your thoughts about the core capabilities that nonacademic hospital systems need to develop in order to essentially participate in this world of leveraging model development and are there third parties that can help with that?

[00:58:18]

Dr. Andriole: Well, yes. I think so. Two points. I think the American College of Radiology has been very active in, through the Data Science Center. A number of us are involved in that to try and, how should we say? Make AI more generalizable to the world, not just through the data but that everyone can use it. And I think validating models and performance much like a Good Housekeeping seal of approval. I think you'll see those organizations like the ACR or perhaps the RSNA and others as well as individual institutions, ours, for example, coming forward and helping to give a standardizer, a normalized assessment of how a model is doing. We're doing this with models that are internally developed at our institution as well as we'll be assessing models developed outside even by vendors who wish to have their models assessed. So I think maybe in that realm sort of an overall...and a society,

professional society is a good place to look for that kind of approval of, you know, do no harm and so forth. The FDA as well but that doesn't really tell you how well it's going to do perhaps at your institution. I also think the second point is education and I keep harping on education because I think it's very, very important. Let's just even start with radiology as a smaller bucket of all of medicine and say I think there needs to be some understanding of this particular technology and field, not necessarily to build their own models and so forth but an understanding of how to evaluate applications, read the literature critically and so on and so forth.

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And so I've instituted at Brigham a data science pathway for our fourth-year residents to spend time doing work in this area and fellowships and so on and I know other institutions are doing similarly. I just think this is absolutely critical to start educating people much like we had to do with PACS back in the day because, rightfully so, healthcare providers want the evidence and want to understand what they're using. And right now, understanding the machine learning aspects and the internal workings...a lot of people call it a black box although we can understand what it's doing, image-wise, it's looking at features that we as humans in the human eye assess but I think a base foundational level understanding of the field because people are gonna be using these technologies going forward. And I think every site needs that. And unfortunately, I don't think everyone is in a position to provide that education just yet but hopefully through our societies and other educational activities we'll be able to do that.

[01:01:05]

Dr. Rubin: Yeah. It's marvelous. So you have that passion for education and I wanna touch upon that in a moment. But I'm still intrigued about the topic of translating particularly out into community organization. And if you consider a rural hospital in New Mexico versus an urban hospital in the Midwest or even centers in other countries and such, if local data are needed in order to really understand the performance characteristics of a model at that site, what is the overhead required to get to clinical implementation? Does there need to be somebody who is going to essentially format and label local data in order to effectively test it on the model? I mean, there seems to be, if that's the case, quite a bit of overhead in doing that, or is there a pathway where you can just take raw data from a center and have relatively automated processes to filter, format, data wrangle as you say, and ultimately though label those data in order to validate the model?

[01:02:17]

Dr. Andriole: Well, there are a couple of technologies. And I'll say we're getting there. I wouldn't say we're quite there yet. And there are a number of tools that are available, even open source in the academic community as well as industry products that are quite good to help with all of those steps. I would say still the bottleneck is the labeling because that requires expertise. But you can do automated labeling so to speak using machine learning. So it learns on a small set that has been labeled and then automatically labels going forward. And it does require a check and so forth. The other thing that people are doing now is building collaborations and doing what's known as federated learning. And this gets around the issue of patient privacy and data security and transferring data to different sites. Instead of that, you move the model to the data and then you try it on your own data and so forth. And we're seeing a lot of effort happening with multi-institutional collaborations where they

work the model, build with their data, add work on your data, so on and so forth. And now you're combining all of this together to build a more generalizable model.

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Right now, it is a bit of a lift to actually develop some of these and I think that hopefully that will change but people are even talking about using visual search and reporting to "label" what's going on in an image as an example in radiology. And there are new algorithmic investigations happening looking at what is known as unsupervised learning where you are learning from a data set that does not have labels and you're just looking for the patterns in the data. And there are some techniques where even I would say semi-supervised learning where there are a number of mathematical techniques that people are exploring that's sort of on the basic science side if you will of data science that people are looking into because this is a huge bottleneck. But one of my hopes is that these technologies will be put into underserved areas and remote places and places where they don't have the luxury that you and I have at an academic medical center with expertise. So there are a couple of applications that I'm aware of that we're working with that are beings built exactly for that. And so that's exciting to see. But we're not quite there yet, unfortunately, Geoff.

[01:04:44]

Dr. Rubin: Well, you have certainly articulated your commitment not only to the development and implementation of machine learning models and the application of data science but to dedicate substantial time to teaching as well. You've co-developed and directed a web-based national imaging informatics course. You lead hands-on learning modules for the RSNA, locally developing programs at Massachusetts General Brigham. What is your approach to carving out the time to teach and develop educational programs? And what drives you to continue to do it amongst all these other responsibilities?

[01:05:27]

Dr. Andriole: Well, it's difficult to take time out for teaching but I feel like it is an unwritten part of my job. Certainly, mentoring is something that I think is very valuable. You know, I've been fortunate to have some wonderful mentors but I think with this new technology there does need to be some formal education. Adult learning today is more hands-on in many ways than when I was learning. I learned math by reading a textbook from beginning to end. Well, students don't do that these days and so there are different mechanisms for teaching. I find it rewarding. I find that when you have to teach, you know, intelligent trainees something, you need to understand it quite well. And so it enables me to learn more about what I think I know and to teach that in an enjoyable way. My style has always been to use clinically-relevant examples. Teaching medical physics often you think you need to bring ice-cream and pizza in to get the residents to listen to it but if you make it relevant to them not so they can build a CT scanner but how would they understand artifacts when they're interpreting and so forth. So I've always tried to make it clinically relevant. But, you know, it's the future of our profession and I think it's a responsibility of people to teach. Not everybody likes it but I do think it's important to share the information that you have and to learn along with the trainees and that's just something that I have had a passion for and I don't know how I find the time, Geoff. Bandwidth for everyone is smaller and smaller and with us being remote, I heard the statement that we are not working remote. We're living where we work. So yeah.

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Dr. Rubin: So true.

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Dr. Andriole: We're doing it.

[01:07:13]

Dr. Rubin: Yeah. You recently published a paper on the need for machine learning curriculum for radiologists in the JACR. How would you propose to implement such a curriculum? I mean, obviously you've described the implementation locally where you've done it. But it sounds like you would foresee machine learning curriculum being a part of all radiology resident training. Have you sort of gotten a line of sight on how to make that a reality?

[01:07:44]

Dr. Andriole: Well, I think it should be. Much like informatics really wasn't taught and now there are a few questions popping up on the boards for informatics and people are interested in it. I think, yes. I'm starting locally, building content. As you mentioned, you know, a number of us are very involved in our professional societies including the ACR and the RSNA and SIIM, the Society for Imaging Informatics and Medicine where education is very much a goal of those societies and developed some content as well as courses that people can participate in. Again, it's gonna take leadership. I teach the medical students once a month on informatics and on machine learning and, you know, I think that should be embedded even in the medical school curriculum and it is starting to be. It's a slow process. You have to start somewhere and you sort of generate a community. We did this very much again around PACS and around imaging informatics becoming really thought of as a subspecialty of radiology in a way. And we all work together. Those of us who were doing the work in the area across the country and the world who were implementing these things and shared mistakes that we made and so forth and really became collegial competitors in some senses but friends and colleagues. And a lot of those folks are very enthused about teaching what they're doing. There's a tremendous stress, I think. I don't have clinical responsibilities as many do and there's a tremendous stress economically to do a huge load of clinical work and that makes it very, very difficult.

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But I think if you are in academic medicine and one of the reasons why I've stayed in academia is because I think education is extremely important, which isn't to say that you can't do it in other mechanisms but it's just part of me and it's sort of the three-legged stool that I think about in terms of the research, the teaching, and the clinical service duties that you do in academic medicine. And I just happen to have maybe a little more emphasis on the education than some but it is something I enjoy and find very rewarding. And my favorite thing is seeing a mentee now sit on a board or be up on the stage giving their research presentation or being part of a committee that's impacting what we do and seeing them shine when I remember spending time with them late in the nights helping them prepare their first paper presentation and so on. So it's a bidirectional activity in my opinion.

[01:10:15]

Dr. Rubin: Yeah. That is a very rewarding feeling to see mentees becoming mentors themselves and even potentially serving on committees that your one-time mentees are now chairing. In mentioning mentors and mentees, you said that mentors have played an

important role in your career. Can you share a little bit about that? How have mentors contributed to your career development and what have you learned from your mentors that you try to bring to your mentees?

[01:10:50]

Dr. Andriole: Sure. I've had some wonderful mentors. They've all been men except for my mom who's been my most wonderful mentor of all. Just a passion for learning and education and learning the persistence and perseverance of working on something to get to a certain end. That really started my undergraduate days with an advisor I had, the late Theo Hilkinson. He was the Duke Biomedical Engineering chairman at the time. Then in my graduate days, the late Stelios Orfanodokus was my adviser there. And then when I went out to UCSF, David Averon was a tremendous mentor and colleague. And we worked together and planned out activities on a restaurant napkin as we...over a dinner plan what we were gonna do for the next few months or a year. And others. Bernie Wang who was very, very instrumental in developing PACS in the early days. Sam Dwyer, the late Sam Dwyer. Rick Moran who was a medical physicist who is one of those medical physicists who really gets it and understands the clinical relevance and so forth and he's been a wonderful mentor to me. Paul Chang, Eliot Siegel. You know, just to name a few. And they all encouraged me. They treated me as a colleague, got me involved in things like the SIIM organization, and have become, you know, lifelong friends as well. And my mom basically led by example as a leader, as a community volunteer, as a wonderful mother. She's been my greatest mentor.

[01:12:25]

Dr. Rubin: Another recent endeavor of yours was the sprint challenge. Can you tell us a little bit about that initiative?

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Dr. Andriole: The spring challenge that was through the "New England Journal of Medicine"?

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Dr. Rubin: Yes.

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Dr. Andriole: Yeah, so I actually had a colleague who had a family member who suffered from hypertension and so this particular challenge was really trying to get people involved. I think Zack Cohane from Harvard Medical School and Boston Children's Hospital was very involved in initiating this challenge where they provided a data set, well-curated and so forth to encourage people in medicine to recognize, "Hey, there's this thing called data science that will give you some tools and ability to do knowledge discovery and so forth." And so we joined with a couple of students at MIT and some colleagues at the Brigham at the time to participate in that challenge. And it was a huge response. I can't recall the number of teams that participated but it got a tremendous response and I think it was something that really initiated interest in this in a lot of different specialties for sure from just sort of an academic kind of activity to, "Hey, this could include knowledge discovery and maybe even a screening tool or something going forward." But the big impact of that was that they provided this data set. And others have done that. Ron Summers from the NIH has set out a number of wonderful data sets that people have used, the chest X-ray data set that the RSNA used in its first challenge several years ago, and so forth. So there are people who are

pushing the envelope and trying to sort of democratize AI if you will and make data available so that the feeling that I have and I think the people who initiated these challenges have is that the more people who are involved in this, the faster we get to solutions. And so being all-inclusive and encouraging people to participate.

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And challenges are one thing that people use in machine learning because it's difficult to normalize the models and their performance unless you have a base data set on which you are training and testing. So these have been a way in the computing community that people kind of can get a normalization or standardization of how algorithms are performing. And so we've adopted this in the clinical world and I think the first time we did this with the RSNA, Luciano Provaldo, a former fellow of mine, led this along with Saffron Halaby who is out at Stanford. We found that it was very difficult and the annotation of these data sets we got the Society of Thoracic Radiology involved. And there's a lot of detail that's involved in preparing the data sets and understanding the data sets such that you can interpret the results on the back end. So I think we learned a lot of the detail of how this really works and how it happened as well as providing the community and maybe even inviting people outside of medicine such as the data scientists or the pure engineer computer scientist to say, "Hey, you know, we need help and this is a very interesting, exciting field to be doing data science." And so I think it served a number of purposes.

[01:15:51]

Dr. Rubin: Yeah. One of the things that I thought was very interesting about this particular challenge was that recognition came to those who could develop novel inferences about the underlying data which, if I'm remembering correctly, related to severe hypertension. It wasn't necessarily an imaging data set. And what was fascinating is the sort of clinical associations that were derived in the actual new medical knowledge that was achieved through the analysis of this data set.

[01:16:25]

Dr. Andriole: Oh, absolutely. You know, I've been focusing a lot on the translational aspects but there is a tremendous amount that can be done on the basic science side. Maybe that's not even the right word to call it but the knowledge discovery side and biomarker development and correlation of findings. You know, I think in the old days, even older than I, the way medical knowledge was acquired is you saw a soquila of symptoms and lab tests and so on in a patient and then a couple of weeks later you saw another patient with something similar and lo and behold, you collected half a dozen patients that had a similar soquilla and then you wrote a paper on it. Well, today, we can multiple that by orders of magnitude and say, "Here's the data. What might we find that couldn't possibly have been found in the way that we were doing medical knowledge gathering and knowledge discovery?" And I think that's the really exciting part about it as well as the utility of what's being done. I mean, right now we're doing a lot of sort of the low-hanging fruit, detecting a fracture, detecting a lesion in the breast, looking for stroke, so on and so forth and those are very important things. No question about it. But what about a biomarker for detecting pancreatic cancer earlier? Is there such a thing? And we've looked at, for example, body composition, the amount of muscle and subcutaneous and visceral fat in patients as a biomarker for pancreatic cancer. These are things that by getting the domain expert involved, we're going to explode with knowledge going forward. And I think it's really exciting. All aspects of it are very, very exciting.

[01:17:59]

Dr. Rubin: It seems that this is really the sort of shiny object awaiting us to reach out to and that is to be able to harness clinical outcomes as a basis for understanding the value of the imaging that we produce and the information in particular that we derive from that imaging. I think that radiologists have been put into the position of needing to articulate the value that they bring in clinical care. And the arguments that are constructed seem logical and there are certainly data to suggest that the things that we discover, the information that we derive does have an impact. But there are so many ways in which imaging can provide a downstream impact that we don't have the ability to communicate because we don't have the ability to see it, to know it. And I'm kinda curious. What do you see as the critical developments needed for us to really probe that most distant part of our value chain? In other words, really building a pipeline to understand how the images that we produce today and the information we derive ultimately impacts the healthcare of the patient down the line?

[01:19:20]

Dr. Andriole: Well, you know, I think that is a very important question and obviously, I believe that it does and it will. And many of us involved in this have that feeling. I think, again, the detection piece...the human being...the human eye is really very good at detecting certain things. Not so good at quantifying things. And quantification is a very tedious activity given the tools we currently have in digital, medical imaging. And might we be able to automate some of that? So for example, we'll do change detection. Look at the changes in a tumor. Is it getting better or worse to really give a more quantitative answer to the oncologist who's looking to make management decisions based upon this serial imaging. Are there findings that perhaps the human eye isn't very good at seeing such as changes in texture that may indicate that there's a change going on in the development of the lesion either for better or for worse that we can quantify that would give more information? And are there things...you know, you and I live in a world in academic medicine where we have expert, expert, expert but that's not true in every part of the world and even in every part of the United States where we have people who are experts in very specific diseases and so forth. And can we raise the quality of care elsewhere and really impact patient management? I think change detection is gonna be one of those things and people are starting to look at time series of things. Again, we've started with detection or screening kind of tests.

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But what about predictive? We have a patient who's had abdominal surgery and they're in ICU. Are we worried they're gonna get C. diff infection and can we preempt that by looking at temperature and different signs and symptoms that are charted? Might we be able to preempt them from getting so sick with that infection? I think these are the types of things where we're gonna see more go to prediction. I also think population health kinds of activities are going to be very, very important. I think here's where some knowledge discovery will come out that will change how some things are being treated because quite honestly in medicine, two plus two isn't four. It's not as cut and dry as that. And I think more medical knowledge is exploding as we speak and maybe corraling that knowledge and consuming it, making it in a consumable fashion as a decision support, is really where the impact of these technologies are gonna be. And I think it's gonna be, at some point, I hope it will be even not noticeable to the user that that's what they're using, that it's just part of their daily work. But we are not there yet. And there's a lot of work that needs to be done to get there but I do think we're gonna move from these simple detection kinds of things to more predictive change detection, risk prediction, so on and so forth.

[01:22:18]

Dr. Rubin: Excellent articulation of the scope of opportunity and it really peaks the mind to think about how radiologists will practice in the future and the scope of practice. There's many, many opportunities to make an impact that we don't have today through these evolving technologies and capabilities.

[01:22:39]

Dr. Andriole: I would like to say that I don't see these technologies replacing the radiologists. These technologies are very difficult to implement. They're also difficult to interpret and you can get a very good performance but the wrong answer without understanding what's going on. and so that's why I think it's important for us to understand these. I also say the clinical gut check is the ultimate. And if it's not making clinical sense to you, then that's where you need to take over what's going on because these are mathematical operations that can go wrong. There's a great example of a study that was done. I'm forgetting the specifics but I think it was looking for perhaps pneumothorax in patients. And there were two different data collections. One was done from an outpatient facility and the other was done from an ICU service area. And long story short, the algorithm had a high accuracy of predicting which patients had pneumothorax but the reason that it was doing that is it learned that on all of the ICU patient imaging there was a radiology technologist marker that was very prominent for that particular facility. And they learned to recognize that marker as that patient population was more likely to have pneumothorax than in the general outpatient population. So it was getting a decent answer for the wrong reasons. So these are things that have to be understood and the clinical gut check is always extremely important.

[01:24:11]

Dr. Rubin: I'm glad that you made that point. In fact, I personally have no concerns that radiologists face replacement. In fact, to the contrary. I think that our scope and role is to expand and, in many respects, evolving to become informatologists where we need to learn to use inputs of more diverse informational elements, data elements in assessing images and in providing the impact of images. And these tools are just going to empower us to have a bigger impact and hopefully allow us to interpret ever-increasing complexity and size of data sets more efficiently and effectively by the proverbial partnership with the computer.

[01:24:58]

Dr. Andriole: Oh, absolutely. I mean, you think about many, many very talented and brilliant people go into radiology from medical school because, you know, you're the detective. And you have to understand the anatomy and the pathology and all of the different things that are going on and you're really kind of the knowledge broker if you will. And this is just another input that I think we hope will be beneficial and., yeah, very, very, very exciting times. And I think radiology has been a field that has adopted technology really quite readily in terms of adopting them into clinical practice pretty quickly.

[01:25:36]

Dr. Rubin: Yes, yeah. The future's very bright. You mentioned SIIM and you've had a very long association with SIIM, the Society of Imaging Informatics in Medicine. In fact, you were the first woman to serve as president of the Society for Computer Applications in Radiology before that organization was rebranded as SIIM. What aspects of SIIM continue to

hold your focus and attention and why do you believe that physicians, scientists, and engineers should get involved with SIIM?

[01:26:03]

Dr. Andriole: Well, I think it was a wonderful opportunity for me. That's right. It started as SCAR and got rebranded as SIIM because they felt that informatics was really all of medical imaging, not just radiology. But I had the opportunity to be involved on a little committee very early in my career and it's a very collegial society. It's a small sort of...smaller niche society than certainly the RSNA but it was very collegial. And I was sitting alongside some of the giants in the field and being able to sit on the committee with them and I just continued working and learning and was ultimately asked to be the first woman chair of the society and it was a fantastic experience. SIIM is a multidisciplinary society as well. So while it was initially formed by radiologists, there are industry members, there are nonclinical research scientists, there are the IT personnel, there are administrators and so on. And so it's a very multidisciplinary society and I think one of the things I learned by having the privilege of chairing that society was how to speak to people with different backgrounds and to understand the different needs and desires of those different constituents. You know, ultimately, we were all reaching for the same goal but coming from different angles. And I really learned a lot. You know, I think it remains today a very collegial society. I'm pleased to see that we have more and more clinicians becoming involved in the society and at an early time in their training as residents and fellows. So it's a wonderful community of people collaborated on many, many activities with people all over who are part of that community.

[01:27:56]

Dr. Rubin: Not long ago you were recognized as the inaugural winner of the RADxx Trailblazer Award for your pioneering work in imaging informatics. Congratulations for that well-deserved honor. We've had several past guests discuss RADxx but I wonder if you would provide us with your perspective on RADxx and why it is important.

[01:28:19]

Dr. Andriole: Thank you, Geoff. That was a wonderful honor to receive and the society...or I don't know exactly what to call it. It's an entity, a group. Geraldine McGinty, who's been a wonderful role model for women in academic medicine as a leader and as well as in the business world as well as others who have been involved...because as you know, there haven't been a lot of women involved. I can think of maybe one other female in my electrical engineering Ph.D. classes or a very few women faculty members that I had the opportunity to work with because they just weren't involved in the field. But Geraldine McGinty felt that it's important to have a community, I guess is the best for RADxx, is a community of people who are interested in women in imaging informatics, supporting them, giving them community to go to, supporting their activities, giving them confidence, giving them colleagues to communicate with and mentors, and so on.

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And I think it's a great activity. It's supported by Ambra Health and it started really...I think the first was having a little reception at one of the SIIM meetings and then there's a reception every year at RSNA. And it's just a wonderful activity where all kinds of people, men, and women have received these awards but men and women are encouraged to participate. So it's not exclusively X sex but it's people who are clinicians, physicians, radiologists. It's people who are technologists, people who are on the business side, people who are in the industry,

and so on. You know, I grew up with two brothers who were my biggest supporters and role models as well but, you know, it's nice to have women be able to look at other women who are in a particular area that you might be interested in to show that this is something that you can do if you're interested in it. And I think having this entity, this community of people in informatics who are interested in bringing more and more women and underrepresented minorities into the field, I think is a good activity.

[01:30:32]

Dr. Rubin: No doubt. It's marvelous. And hopefully, a very effective catalyst into bringing more women and underrepresented minorities to the field of informatics, as you say. It's fantastic. Let me ask you how do you unwind. Do you have any hobbies or activities that you pursue outside of work that reenergize you?

[01:30:53]

Dr. Andriole: Well, running has always been my mental health. So sports for sure. I love music as well. But sports is something that, you know, I grew up training daily for most of my life until I got pertussis. And that did knock me back quite a bit in terms of lung capacity and so forth. But running is my mental health now as well as physical health and when I don't do it, I recognize that I really wish I could get out for a run or some kind of physical activity or tennis or go swinging the golf club. And tennis and golf by the way and running has been another way for me to make friends and colleagues and build community in the informatics world. You know, as I went to a lot of these meetings with predominantly men there, I was able to get out on the golf course or the tennis court and play or go for a run with them. And, you know, it's interesting what you learn about people when you get involved with them in an activity like that. And it's always been a wonderful, wonderful experience for me. Right now, three of my nephews are elite ice hockey players and, you know, a great joy that I get is watching them compete. And so that's one of the main things that I really, really enjoy. And I missed of course the spring, the NCAA basketball tournament unfortunately due to the pandemic but hopefully, that'll be back in some fashion.

[01:32:23]

Dr. Rubin: Hopefully so. It's great that your knees are holding up for the running. Oftentimes that's a weak spot for somebody who's been so active for so many years. It's great that you're able to continue to pursue all those activities. What would you say have been your most rewarding moments as a leader?

[01:32:44]

Dr. Andriole: Well, I think leading at SIIM...you know, I was the captain of my track team in high school. That was interesting to get largely an independent group of people working together for one cause. But leading the SIIM organization I think was a learning experience as well as, you know, a humbling and rewarding experience. But I think it gave me an appreciation of different points of view. I think I learned to listen and understand other points of view through that experience. And now I would say my leading is through mentorship. Seeing the success of SIIM as it has grown and a number of the programs that were put in place during my leadership time such as the emphasis on research and funding some of the research as well as the educational activities. And then from a mentor standpoint which I really think is an essential activity for all of us to do regardless of whether you're in an academic field or something else that passing on information to the next generation and sometimes it's just enabling them and giving them an opportunity to succeed. I've found great

joy in that and seeing many of my mentees who have remained close and continued contact and so on. So I think there are activities that we all do that, you know, certainly, we enjoy. They take time but I think are very rewarding. And those are some of the things I take away from and see them succeed and see the society succeed is something that I think I had some kind of contribution to. So I take pride in that.

[01:34:24]

Dr. Rubin: What advice would you give to a young scientist or a physician who's inspired by your journey and would like to pursue a similar path?

[01:34:32]

Dr. Andriole: Do what you love. Be excited. Enjoy what you're doing. You know, my mom always said, you know, "You can do math. I don't care. Girls can do math. Do what you like. Do what you enjoy but do it to the best of your ability." And that's my best advice. Do what you enjoy.

[01:34:51]

Dr. Rubin: Well, Kathy Andriole, I can't thank you enough for joining us today and sharing your journey, your expertise, and perspective as a top data scientist and someone who has, as the award identified, truly blazed a trail as one of the leaders in the field and particularly, taking on those leadership roles to bring women into the field and to others who are underrepresented. It's been a real pleasure to have you on the podcast.

[01:35:23]

Dr. Andriole: Oh, thank you, Geoff. I'm honored to have participated. Thank you so much.

[01:35:36]

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