**Computerized Left Ventricular Hypertrophy Detection**

Announcer: Welcome to Mayo Clinic's ECG Segment: Making Waves, Continuing Medical Education podcast. Join us every other week for a lively discussion on the latest and greatest in the field of electrocardiography. We'll discuss some of the exciting and innovative work happening at Mayo Clinic and beyond with the most brilliant minds in the space and provide valuable insights that can be directly applied to your practice.

Dr. Kashou: Welcome to Mayo Clinic's ECG Segment: Making Waves, continuing medical education podcast. Join us every other week for a lively discussion on the latest and greatest in the field of electrocardiography. We'll discuss some of the exciting and innovative work happening at Mayo Clinic and beyond with the most brilliant minds in the space and provide valuable insights that can be directly applied to your practice. Welcome to Mayo Clinic's ECG Segment: Making Waves. We're so glad you could join us. Today, we have an exciting episode planned for you as we discuss computerized ECG detection of left ventricular hypertrophy. We have an expert discussing joining us who will help us better understand this topic. Left ventricular hypertrophy represents pathological thickening of the left ventricle Recognition of left ventricular hypertrophy is important because of its adverse clinical outcomes if left untreated and the availability of therapies to reverse it if detected early enough. Numerous ECG criteria for left ventricular hypertrophy have been proposed over the years and computerized electrocardiography provides a means to alert clinicians to such findings. In this episode, we will focus on computerized ECG detection of left ventricular hypertrophy including updates made over the years, the process of identifying which criteria to use, and the clinical relevance as it relates to risk prediction. We're fortunate to have a recognized industry expert in the field of computerized ECG analysis, Dr. Bob Farrell, to discuss with this further. Dr. Farrell is a principal engineer in the diagnostic cardiology algorithms group at GE Healthcare based in Wisconsin. Dr. Farrell earned a bachelor of science degree in electrical and electronics engineering from North Dakota State University and a PhD in bioengineering from the University of Utah. He got his start in signal processing, pattern recognition methods, and algorithm development for physiological signals while completing his PhD dissertation on a neural network based alarm system for an anesthesiology machine in the early 1990s. Dr. Farrell started at what was then Marquette Electronics in 1996 and developed pulse oximetry and invasive blood pressure algorithms for patient monitors. In the meantime, GE bought Marquette in 1998, which is how he became and came to work at GE. In 2001, he was transferred to the diagnostic cardiology business in GE Healthcare and he has not looked back. Dr. Ferrell has spent most of his career advancing the GE 12SL* Resting ECG Analysis Program bringing several innovations and clinical enhancements to it along the way including improved PWA detection and rhythm analysis, the hookup advisory feature to provide real time signal quality feedback to technicians while acquiring the ECG, identification of right ventricular involvement in the presence of acute myocardial inferior infarct, a revamp of how paste ECGs were interpreted, detection of Brugada pattern, and a revamp of how left ventricular hypertrophy is interpreted. And that's gonna be our focus today. In addition to as many years of working on the 12SL* Resting ECG Analysis Program, Dr. Farrell has had a hand in several additional aspects of ECG analysis including stress testing and ambulatory recordings. He's currently a member of the board of directors of the International Society of Computerized Electro Cardiology. Dr. Farrell, what a true honor to have you with us today. Thank you for joining.

Dr. Farrell: Yeah, thank you, Dr. Kashou. It's very exciting to be here. Appreciate the opportunity.

Dr. Kashou: You know, we've been really looking forward to this and because the focus is gonna be around left ventricular hypertrophy, I thought maybe it's a good idea we start discussing the relevance as it relates to the ECG and LVH or left ventricular hypertrophy. There's so many modalities now available to us as clinicians, the echo, the cardiac MRI, and all that's evolving in how we use them. How do you see the ECG remaining relevant to our discussion of left ventricular hypertrophy?

Dr. Farrell: Yeah, well, I think the ECG is still very relevant for the analysis of LVH for multiple reasons. First, whether or not you believe that there is utility in diagnosing LVH from the ECG, you still need to take LVH into account when you're reading the ECG. And that goes for human over readers as well as computerized interpretation programs like our GE program. And you have to be able to acknowledge whether or not there's LVH when you're looking at old infarcts and especially when there's the so-called strain pattern and how that plays into ST-elevation or depression changes. So is that ST depression you see, is that related to a strain pattern or is it due to ischemia? So there's that. Also the accessibility of the ECG test. It's ubiquitous, it's all over. So when ECGs are ordered for all kinds of reasons and you essentially get a potential LVH interpretation for free out of that ECG test. And then also, there's a good amount of research that has shown that LVH by ECG is associated with poorer outcomes in its own right independent from other modalities, such as echo.

Dr. Kashou: And so you could see this and this is, I think, the repeated pattern of the ECG still remaining relevant, noninvasive, ubiquitous as you mentioned, a really relatively inexpensive test that's still available to us that could potentially be used as that screening marker for an important clinical finding. And I know over the years, GE has made some updates to the 12SL* program related to LVH. What drove those changes you made?

Dr. Farrell: Yeah, so we started looking into the LVH largely based on customer feedback. And we were getting, over the years, we had feedback from customers that they didn't understand our criteria, that it was opaque. Why did you call LVH on this? Why didn't you call LVH on this? And although we had disclosed what our criteria was in our positions guide, we know that that seldom ever gets read even though we put a lot of work into it. But anyways, so there was that feedback about kind of the opaqueness of it. And also sometimes we would confuse LVH strain with other T-wave abnormalities. And then separate from all of that were recommendations that were jointly published by ACC/AHA and Heart Rhythm Society recommendations to guideline to manufacturers. It was a series of six papers published simultaneously in both Circulation and Jack between 2007-2009. And two of those series of six papers were relevant to this discussion. One was a standardized statement list for any statement that you'd wanna make on an ECG. And then another part, specifically part five, was devoted to chamber hypertrophy. And so they had some recommendations that we took to heart. So we cracked open the box and everything was on the table. Do we wanna create new statements? Do we wanna have new criteria? Those are kind of the two parts of it. You know, how are we gonna detect it? What are we gonna say about it? And so we were an open book, I should say, an empty slate, blank slate. And so separate from

the customer feedback or maybe kind of tangential to it, we kind of had our own sentiment about that maybe we over call it on healthy people, especially young adults. And it was interesting talking to doctors about how important is that that we over call or even if we just call LVH, what's the significance of us calling LVH? And some doctors were very cognizant of the impact on a person's ability to get life insurance and would be reluctant to put LVH on an interpretation. But I would talk to other cardiologists that said, "No, that doesn't influence my decision at all. That's not clinically related. I'm gonna call it as I see it." So it was interesting to get to two different perspectives. But anyways, also a sentiment that we under call it in hypertensive populations. So we cracked, like I said, we cracked open the box, everything was on the table. We took the ACC/AHA recommendations to heart. But weren't all completely workable, we didn't think. There were some things that, with all the respect to the people that wrote them, and I know some of them, I know they're in the trenches reading ECGs, we're kind of in our trenches trying to make something that works for everybody. And so we needed to strike a balance there. And we had a series of medical advisory board meetings. And one of the authors, a coauthors of one of those papers, was in our medical advisory board meeting. And they acknowledged, okay, yeah, you don't have to take all this literally. Which was very liberating to us. So in the end, we made some very specific changes which were that rather than doing our criteria that we had had forever, since 12SL* was first written, which by the ways it was kind of like Sokolow-Lyon, but it wasn't quiet, it was kind of like Romhilt-Estes, but it wasn't quite. So we defined, excuse me, we implemented the criteria as published in the literature. So we settled on four, the first one being the R amplitude in lead AVL, pretty standard 1,100 microvolts. The next one, Sokolow-Lyon, greater than 3,500 microvolts. Again, pretty standard. And by the way, just as a side comment, some people may know, some people may not, but the R in AVL is technically part of Sokolow-Lyon, it was part of the original 1949 paper where they published both of those things. But typically when people think of Sokolow-Lyon, they think of SV1 plus the max of R and V5 or V6 greater than 3,500. But anyway, that's too, R in ADL and then the classic or typical Sokolow-Lyon, and then Cornell product, and then finally Romhilt-Estes. And I mentioned them in that order, or specifically that Romhilt-Estes is fourth, because we consider the other three to be what we call voltage only criteria and our statement hierarchy, which by the way, we kept our existing statements, and like I said, it's four statements, we were concerned that it's too much, but on the input of our medical advisory board, they said, "No, no, keep those, just change the criteria." So we've got a statement that says minimal voltage criteria for LVH, moderate voltage criteria for LVH, voltage criteria for LVH, and then finally the fourth one is just plain LVH, kind of what we call the full blown LVH. And by the way, the first two also had appended to it, comma, "consider left ventricular hypertrophy." So we had that kind of cascading or tiered set of statements. And so now with our four criteria, if any one of those is positive, we'll say the minimal voltage criteria statement. If any two are positive, we'll say moderate voltage criteria. If any three are positive, we'll say voltage criteria. If Romhilt-Estes is positive, or there's QRS widening, or repolarization abnormality, the so-called strain pattern, then we will say the full blown LVH statement. So I think it's pretty powerful the way we're doing it now. So we still have kind of the hierarchical statements that we had before, they're the same statements, just the criteria is different. And importantly, and also in the spirit and actually strictly following the recommendations to manufacturers, is that we list the criteria that are positive. So if you're positive for R in AVL, we say that right in there parenthetically. Same with Sokolow-Lyon, Cornell product, Romhilt-Estes. So we'll put all of those right in the interpretation now. One of the other things that we did was to really look into the strain pattern. We had some pretty naive

criteria, some very simplified criteria for whether or not we would call it repolarization abnormality or not. And by the way, I'm using those terms interchangeably, because strain pattern just rolls off the tongue quicker than repolarization abnormality. But anyways, we didn't do such a good job at that. And I'm pretty confident that we're much, much better now. So we did a lot of work in that area as well.

Dr. Kashou: You know, Bob, it's really interesting just to see, and you've already answered a lot of the things that I was thinking of asking, but thinking how it started with the customers giving you feedback and just now providing a level of transparency with the criteria you offer, and then some of the recommendations suggested by the ACC and AHA and some of those guideline advisory committees, it's amazing. I certainly don't envy the position that you guys were in because there's a lot, right? And when you look at the literature, especially on this topic, there are dozens of criteria proposed on this, especially in the ECG.

Dr. Farrell: Yeah.

Dr. Kashou: And you wonder, I was wondering, how do you select those? You know, mentioned so the Sokolow-Lyon, the two that come from that, the Cornell product, the Romhilt-Estes, is there a selection process? How do you select those four in I guess now you do also provide that statement that says that it's this one that is met. Is there anything there? And yeah, what are your thoughts or how do you make that selection process?

Dr. Farrell: Yeah, sure. So it wasn't probably as scientific as maybe you're asking for, but it was really knowing what... I talked to a lot of different cardiologists about what do you use? In your mind, when you're reading an ECG, what do you use? And Sokolow-Lyon was probably the most common response to that. Romhilt-Estes kind of, I don't think most people knew all the criteria of Romhilt-Estes, but when you read an ECG, it's all very, you know, if you know what you're looking for, they maybe didn't know that it's three points for this or two points for this point, but they take those factors into account, like left access deviation. You know, it's there, it's only one point. You know, the voltage criteria for that, I mean, that's three points. And then you look at things like the intrinsicoid deflection which is how where's the peak of the R wave and V5 and V6? Well, nobody measures that, but guess what, computerized programs can do it pretty well. And so when you have that delayed intrinsicoid deflection, that's actually part of Romhilt-Estes. So even though they didn't necessarily know that they were using it or doing it strictly by math, adding up the points, they were using parts of it. So to me, it made a lot of sense. Plus there was just so much written about Romhilt-Estes as well, that it's certainly proved its mettle. The other one was Cornell product. It didn't have quite the lifespan so far as Sokolow-Lyon or Romhilt-Estes, but there's been a lot of good work that came out of that group at New York Presbyterian. And also we've had a very long standing relationship with that hospital. So we knew Peter Okin and Paul Kligfield pretty well who authored a lot of that work. And so it was very easy to work with them to make sure we were doing it right. And hey, by the way, just wanna make sure this is the right cut point to use and you said this in this paper, but you said this and this paper, which way should we go? And so it was very helpful to work with them directly and implement it and make sure that we did it right.

Dr. Kashou: Yeah, it really does make sense. Maybe that's the best logical way given not only are many, but you're also being transparent with the approach. And I think that's as a clinician, what you want, is how did you give this diagnosis of voltage criteria or LVH based on this in the Cornell product? I mean, there's some of these I don't even remember because there's so many cutoffs. I think the Cornell is even sex specific based on male and female, I think 20 and 28 is that cutoff. AV, I think it's V3, the S wave, and then the R wave and AVL, I'd have to even look it up. But as you can see, I don't remember all these. And having that, which the computer's good at. And I think we have to give credit where credit's due is the computer's very good at measurements whether it's rate control. You know, if we learn how to use the computer, just like now how we use other computerized software, it can play to our advantage clinically. Now the one thing I did want to talk about is the ECG LVH, the left ventricular hypertrophy, and how that you mentioned related to outcomes. Can you talk a little bit about ECG, LVH, and the risk prediction, and how the changes you've made over the years, the GE 12SL* program, have aided in risk prediction?

Dr. Farrell: There's been some really good studies that have been published in the last few years that, well, there's a lot of studies that have talked about individual LVH criteria, whether it's Romhilt-Estes, whether it was Cornell voltage. And by the way, I forgot to mention earlier, so there's two criteria that came out of the Cornell group, Cornell voltage and Cornell product. Cornell voltage came out first, I think that was in the '80s, and then Cornell product came out in the '90s. Cornell product takes the Cornell voltage and then multiplies the times a QRS duration. And that's where you get the area from. And yeah, and I say Cornell product for short, but the long verbose name of it is Cornell Voltage QRS Restoration Product. So you're multiplying the Cornell voltage times the QRS duration and you get units of microvolt milliseconds. But anyways, so there's been papers published on outcomes with Cornell voltage and then Cornell product. And you named the criteria and somebody studied outcomes. But not so common are showing the power of combining criteria. And so there were some studies that combined Cornell product with Sokolow-Lyon. And for heart failure in patients with aortic stenosis and for MI, stroke, or cardiovascular death, and hypertensive patients, those are two different papers that I just mentioned, in almost all of those cases, the hazard ratio for the combined, if you're positive for both of those, is double to triple what the hazard ratio is for those adverse outcomes of either one alone. So that's pretty powerful. And it speaks to our approach about how when you see on the ECG, on the interpretation, that there's more than one criteria positive, it's more serious. And then we've got this science backing it up, specifically for the criteria that we've selected in our program. And then strain especially is a pretty big deal. And anytime you've got that statement, LVH with repolarization abnormality, it's not good for you. And they have the worst outcomes. There was a paper published by Victor Froelicher at, I believe it was the VA hospital, I think out of Palo Alto, California. And he looked at outcomes because they were, and this was I probably 20 years ago, but he looked at just what our program said, what the 12SL* program said, and by statement, so whatever that statement was, the statement that had the poorest outcome, the greatest prediction of death, was LVH with repolarization abnormality. So yeah, that's just a known predictor of all cause mortality. And then other publications showing it in, again, congestive heart failure in hypertensive patients and for MI in patients with aortic stenosis. So those are papers that I've read. And I'm sure that there's others out there.

Dr. Kashou: Yeah, Bob, I like that idea that the combination, because a lot of people talk about the nonsensitive nature of some of these ECG criteria, but there is something to it. If you have almost additional data points that are adding up to that, and you mentioned additional criteria met, right, the Sokolow-Lyon, the Cornell product, maybe the patient has hypertensive heart disease, right, or is an elderly, these things are tipping you further. Maybe left bundle branch block is present, which a lot of people with LVH may also have that. And that also probably complicates the criteria use or prior anterior MI. And so it's like these things adding up. And you mention the strain pattern. I like the idea as clinicians, it's more of just using the computer for what it's meant to, right? And I think using the good parts of it, where the measurements giving you some extra data points to support your clinical decision making. So let's close here because I think there's a lot. And like I mentioned, that left bundle branch block and some of these other patterns that can complicate matters and I don't wanna overextend my time, 'cause I'm truly grateful for it. Now the detection of left ventricular hypertrophy is important given its clinical consequences and therapies available today. Computerized ECG detection of LVH or left ventricular hypertrophy has evolved over the years to even aid in risk prediction. And we saw it today. It is exciting to see the advances made in the future that lies ahead in the field of electrocardiology. Dr. Farrell, thank you for sharing your insights into computerized ECG analysis detection of LVH. This is such an important topic. You're clearly an expert, you're a leader in the industry. And on behalf of our team, thank you for taking time out of your day to join us. It's been a true pleasure.

Dr. Farrell: Thank you very much, Dr. Kashou. It's been an honor to have a chance to be here and speak to this audience.

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