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Endo-Epicardial Breakthrough: A Tale of Two Sides

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Cardiac mapping has profoundly impacted diagnosis and treatments of focal and macro-re-entrant tachyarrhythmias. When the resolution of atrial mapping was increased, it revealed more specific patterns of activation during atrial fibrillation (AF) such as breakthrough waves. These breakthrough waves arose from circumscriptive areas from where they expand to a variable degree into the surrounding tissue. These breakthrough waves during AF were described as nonrepetitive events occurring scattered throughout both atria without any fixed pattern of activation.[1-3] Coupling intervals of breakthrough fibrillation waves were often longer than the dominant AF cycle lengths, so they were not a "driving source". Unlike the unipolar QS morphology at the origin of focal atrial tachycardia, most unipolar electrograms recorded from the initiation sites had a rS morphology. All these features suggested the presence of transmural propagating waves approaching the surface area from below.

As transmural conduction of fibrillation waves can only occur in the presence of endo-epicardial asynchrony, the hypothesis of asynchronous activation during AF was conceived. We subsequently provided the first direct proof of endo-epicardial asynchrony of the atrial wall during AF in humans by performing intraoperative simultaneous mapping of the endocardial and epicardial layer of the right atrial free wall. This study revealed not only the presence of endo-epicardial asynchrony, but also that breakthrough waves occur at both the endocardial and epicardial side.[3, 4]

The existence of asynchrony in activation between the epicardial and endocardial layer has been known for many years[5]; however, its importance in atrial arrhythmia pathophysiology has just recently started to be recognized. Simultaneous endo-epicardial mapping demonstrated that endo-epicardial asynchrony can be present up to 50% of the time during atrial fibrillation. For the majority of observed breakthrough waves, waves had passed by on the opposite side only a few moments before indicating that asynchronous fibrillation waves conducted through the atrial wall resulting in breakthrough waves.[2] The structural architecture of the atria is likely a key player in these phenomena. The first study of asynchrony performed by Schuessler et al. already associated endo-epicardial asynchrony with regions composed of pectinate muscles and cardiac fibers with different alignments.[5] Sites of breakthrough will presumably correspond to sites where intramural fibers connect the two layers. Although observations of asynchrony are limited to the right atrial wall for now, the variability in fiber orientation at the left atrial wall provides a suitable substrate for left atrial endo-epicardial asynchrony as well.[6]

Evidence that the concept of waves conducting from one side to the other is not only limited to atrial fibrillation has now been provided by Pathik et al.[7] Their elegant study demonstrated in a sample of 26 patients by using high-resolution endovascular mapping

that breakthrough waves occur at the right atrium during macro-re-entrant tachyarrhythmias as well. Breakthrough waves were present in about half of the cases, mostly at the posterior right atrium, situated near sites of slow or blocked conduction. Breakthrough sites were in a couple of cases verifiably embedded in the arrhythmia circuit and could even be critical in maintaining the circuit. In the latter case, the breakthrough site signified a shift of the circuit pathway after ablation to an alternative route consisting of a preserved pathway on the opposite side of the atrial wall and transmural conduction after the ablation line. The breakthrough sites near areas of conduction block demonstrate that barriers for conduction are not always transmural. Conduction can be preserved at the other side of the wall causing conduction to continue on only one side which results in asynchrony and consequently endo-epicardial breakthrough waves. These interesting findings underline the fact that the electrophysiology of the atria is not 2-dimensional and we should start seeing the atrial wall as a 3-dimensional structure where new waves can originate from cardiac fibers coursing on the other side of the wall. Although they are, unfortunately, not able to directly confirm an epicardial source for the breakthrough waves in this study due to technical limitations, supporting evidence was well provided by demonstrating unipolar rS electrogram morphology at breakthrough sites and stability of breakthrough sites during pacing.

The fact that asynchronous patterns of activation within the atrial wall can have such a key role in multiple arrhythmia pathophysiologies emphasizes the relevance of evaluating cardiac electrophysiology from more than one perspective. The two sides of the cardiac wall can clearly exhibit discrepancies in barriers for conduction, creating differences in timing and possibly patterns of activation between both sides. Disturbances in conduction on one side can greatly effect patterns of conduction on the other side and each can represent a continuous source for new breakthrough waves on the opposite side. Therefore, new techniques in order to accomplish mapping in all 3 dimensions of the atrial wall in clinical practice should be further explored. The interplay between the endo- and epicardial side can be critical in arrhythmia pathophysiology and to fully understand their hold on each other during arrhythmia requires representation of both sides during mapping in future investigations.

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