Detection of the origin of congenital heart disease-induced arrhythmias with electrophysiology mapping

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Introduction:

Congenital heart disease (CHD) affects approximately 0.8 to 1.2 percent of births worldwide, placing this disease among the most frequently diagnosed congenital disorders.[1] In 2017, a study analyzed 52,725,227 adult patient admissions from community hospitals in 44 states whose data was collected from the National Inpatient Sample database, and of those admissions, 109,168 patients had CHD.[2] Of those patients with CHD, 27,088 patients (24.8%) were diagnosed with arrhythmias.[2] Physicians can diagnose arrhythmias using stethoscopes, electrocardiograms (ECGs), and event recorders. However, with immense advances in modern day medicine, electrophysiology (EP) mapping has proven to become a powerful tool to map electrical impulse conduction in the heart both accurately and precisely. The high spatial resolution in addition to reasonable temporal resolution and noise floor allows physicians to attribute arrhythmias and causes of unexplained syncope to specific regions of the myocardium. This paper explains how EP mapping is conducted, discusses the spatial and temporal resolution of EP mapping, and provides information on the accuracy, precision, and reproducibility of EP maps.

Methods:

EP mapping requires an intravenous line in the arm to administer fluids in addition to telemetry monitoring and application of a blood pressure cuff for continuous assessment of vital signs. A combination of propofol and fentanyl administration is typically used for conscious sedation. Once a local anesthetic is applied to the groin, an introducer and catheter are passed through the femoral veins to the heart using fluoroscopic imaging. EP mapping consists of two parts once the catheter is present in the heart: mapping the location and direction of impulse propagation in sinus rhythm and inducing temporary arrhythmias via programmed electrical stimulation with the catheter or pharmacologic agents to identify the response in the heart. In most mapping systems, an expandable open irrigated 64-pole basket mapping catheter acquires action potential conduction data from the endocardial interface and in combination with the real time spatial coordinates, heart chamber geometry is constructed to display a high density electroanatomical 3D map.[3] The catheter's real time spatial coordinates in the heart are acquired by a method which involves the catheter recording the voltage and impedance drop from a low-level 5.6 kHz current externally applied with skin patches across the thoracic cavity from three orthogonal directions in addition to triangulation with a reference electrode.[4] The catheter records both unipolar and bipolar intracardiac electrograms at numerous points in the heart, and the conduction data is represented on a monitor as a 3D model of the heart with electric potential (between two electrodes in contact with myocardium) gradients over time. In the case that abnormal tissue causing the arrhythmia is identified, physicians may choose to eradicate the abnormal tissue by the means of radiofrequency ablation or cryoablation.

Current EP mapping systems offer interelectrode spacings of 2-3 mm, providing

spatial resolutions that extracardiac ECGs cannot. Localized cardiac electrical potentials at the electrode positions are included in the map after meeting four acceptance criteria, (1) respiratory gating, (2) relative timing of reference electrograms, (3) electrode location stability, and (4) cycle length stability.[5] The temporal resolution is greater than 1,000 points per minute while maintaining a low noise floor of approximately 0.01 mV. In total, EP mapping procedures can take 1 to 2 hours. Furthermore, EP mapping systems have a superior sweep speed of 100 to 200 mm/s in contrast to the traditional 25 mm/s to show electrogram waveforms more clearly. Filter settings for bipolar intracardiac recordings are established for proper signal acquisition: 30-50 Hz and 300-500 Hz for high and low pass settings, respectively.

Results:

Once the EP map is completed, an electrophysiologist assesses the data to pinpoint abnormal parameters denoting cardiogenic syncope and the structural origin of arrhythmias. Parameters suggesting a normal conduction pathway include a PA interval within 25-55 ms, an AH interval within 55-125 ms, a His Bundle EGM (HBE) duration less than 30 ms, and an HV interval within 35-55 ms.[6] These parameters can be used to identify any differences between diseased and healthy states of the heart. In procedures with experienced electrophysiologists and technicians, the life-threatening complications rate is below 0.5 percent, and interpretation of the data is accurate. However, heavily scarred cardiac tissue may result in data with low amplitude signals, making it extremely difficult to analyze the data for even the most experienced electrophysiologists.

EP mapping results have been shown to be accurate, precise, and reproducible. The intracardiac electrogram annotation using the RHYTHMIA HDx™ Mapping System was shown to have 99.98% accuracy. A study acquired 30 right atrial maps without any life-threatening complications; out of 70,862 points mapped, only 16 of them had to be corrected with manual annotation of the intracardiac electrograms (0.02%).[7] Out of 47 electroanatomic maps completed in another study, all the EP maps consistently showed potentials with high resolutions, indicating high precision. After analysis of the EP mapping data, ventricular tachycardia cardiac ablation procedures were conducted, and the arrhythmia stopped occurring in 75% of the patients.[8] Different technicians using the same mapping systems on the same patients have been shown to reproduce the same data; however, the colors on the representation of electrical potential gradients vary. The colors signify local activation time in comparison to the initial reference region. As a result, different technicians have varying EP maps in terms of color representation depending on the exact region of the heart the catheter was initially placed. If EP mapping does not provide insight into the arrhythmia, physicians may further conduct tilt table testing, CT scans, and cardiac MRI. Usually, blood tests and 12-lead ECGs are already completed before a patient undergoes EP mapping.

Discussion:

EP mapping serves as a very important tool for attributing arrhythmias to abnormal structures in the heart caused by congenital heart disease and providing physicians highly accurate and precise data to determine which region of the heart to ablate to obtain a normal sinus rhythm. With little complications during EP mapping procedures in combination with high spatial resolution, quicker recording speeds, reasonable temporal resolution, and low noise floor, EP mapping systems are superior tools for determining a CHD patient's

prognosis and treatment options compared to traditional ECGs.

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