The heart vector origin point definition

See Figures 2-3 in Perez-Alday et al, Computers in Biology and Medicine, Volume 104, January 2019, Pages 127-138:

We define VCG origin point based on its electrophysiological and biophysical meaning: the electrically quiet, or isoelectric state of the heart when the heart vector does not move in 3D space. The electrically silent period is defined as the segment between the end of repolarization and the onset of P-wave (if present), or the beginning of QRS complex. The definition of the VCG origin point determines the definition of the VM ECG baseline.

Algorithm to detect the VCG electrically quiet origin point

Two time interval windows are identified to select an isoelectric segment in the TP segment. The first window (w_1) is dynamically calculated from the RR' interval using the following equation (eq. 1):

$$W_1 = floor(RR'_{interval} \times 0.8 - 372.69 * 0.5). \qquad \text{(eq. 1)}$$

The center of the window, T_C, also depended on the RR interval and the type of beat under investigation. Two cases are identified: (1) T_C = 260ms, if RR interval (RR_{int}) < 600 ms and median beat ≠ Supraventricular (S). T_C = 320ms, for any other case: RR_{int} ≥ 600 ms for any type of beat or RR_{int} < 600 but median beat =S.

$$T_C = \begin{cases} 260\; ms\ to\ the\ left\ of\ R_{peak},\ \ if\ RR_{int} < 600\; ms\ and\ beat\ \neq S \\ 320\; ms\ to\ the\ left\ of\ R_{peak},\ \ Any\ other\ case \end{cases} \qquad \text{(eq. 2)}$$

The second window (w_2) is a fixed window of 320ms with same T_c center. If the edges of w_1 were larger than the edges of w_2, the edges of w_1 were set to be the same as w_2.

Following selection of the isoelectric baseline, the algorithm uses two approaches to select the flattest line on VM and XYZ leads signal within w_1: (1) clustering of the signal with the least variance in a given window and (2) minimum absolute change of magnitude closest to the end of the window.

Searching for a candidate segment with the least variance

We calculate the variance on the X, Y, and Z lead signals with a moving window of 20ms ($movvar_{XYZ}$). Using the MATLAB function *movvar*, we identify the segment with the least amount of variance i.e. the flattest portion of the signal. Candidate points are identified by looking for the segments containing the largest number of counts from the histogram of $movvar_{XYZ}$ with a fixed bin width of 10 μV^2. Once candidate points are identified, they are separated into clusters. The clusters are then defined such that the minimum distance between the edges of neighboring clusters was larger or equal to 8ms in order to reduce the impact of noise within the signal. The algorithm selected two candidate clusters comprised of the largest number of elements with which to perform origin point calculation.

The absolute voltage gradient across X, Y, and Z is calculated with a time step of 10ms. Then, the average of the sum of the absolute voltage gradient across the X, Y, and Z leads of a given cluster is obtained. The cluster with the smallest average gradient is chosen to best approximate the isoelectric segment, and the origin point is chosen at the median time point of that candidate cluster. If the last criteria was not met and the algorithm could not identify an origin point candidate within w_1, the search for an origin point is carried on to w_2 with the algorithm described above.

Searching for a candidate segment with the least change

As an alternative approach, we attempt to identify the isoelectric segment by computing the sum of the absolute voltage gradient on the X, Y, and Z leads:

$$\sum_{x,y,z} |\nabla VM| = \left|\frac{dV_x}{dt_n}\right| + \left|\frac{dV_y}{dt_n}\right| + \left|\frac{dV_z}{dt_n}\right| \quad \text{(eq. 3)}$$

Then, we compare the gradient at any time step $\Delta t_n$and their neighboring time points (Δt_{n-1} and Δt_{n+1}) against the minimum of the sum of the voltage absolute gradient (eq. 4) in the window w_1

$$min \sum_{x,y,z} |\nabla VM| = \underset{t_n : t_n \in w_1}{\operatorname{argmin}} \left(\left|\frac{dV_x}{dt_n}\right| + \left|\frac{dV_y}{dt_n}\right| + \left|\frac{dV_z}{dt_n}\right| \right) \qquad \text{(eq. 4)}$$

The candidate origin point is the middle point of the segment where the comparison is below a threshold of 0.1 mV, to look for a stable isoelectric line. The comparison is performed starting at the right edge of the window w_1 (closest to the R peak), then working backward toward the preceding T wave with a time step of $\Delta t_n = 4ms$.

Final selection of the origin point

At the final step of the algorithm, the two previously identified candidate origin points are compared using the following criteria: area under the curve of reconstructed VM and sum of average absolute gradient in 10ms time steps. Individual VMs are reconstructed for each candidate by defining the candidate as the zero-value baseline. The area under the curve for each VM is computed only in window w_1. The sum of the average absolute gradient of each VM, with a time step of 10ms, is calculated around each candidate. The final heart vector origin point with the smallest area under the windowed VM curve and the minimum average voltage gradient is selected.