Automated generation of isochronal maps in the presence of activation block

M. Potse   A. C. Linnenbank   C. A. Grimbergen

Abstract

An algorithm for electrocardiographic isochrone drawing was developed that can deal adequately with lines of activation block. This algorithm recognizes block by comparing the apparent conduction velocity between each pair of adjacent grid points to an adjustable limit value. The algorithm is currently implemented in the MA${}^{P}_{L}$AB software package.

1   Introduction

In the field of cardiac electrophysiology, "isochrones" are lines that connect points of equal activation time. Isochronal maps are the common means of depicting an activation pattern. They are sometimes annotated with arrows to indicate the major propagation paths. An example is shown in figure 1. Creation of isochronal maps is a complicated process, which must be performed with care [1]. Spatial and temporal undersampling can easily lead to incorrect conclusions. Investigators therefore sometimes decided to draw isochrones by hand, based on computer-generated tables of activation times [2, 3]. An investigator who manually draws an isochronal map may use the drawn isochrones to change activation times that were used to create the map. This can be an advantage; for example, it may help in deciding which deflection corresponds to a local activation front. On the other hand, it allows for complicated methodology that is hard to reproduce, and allows preconceptions to have an influence on the results.

For efficiency and objectivity it may be desirable to have a computer program draw isochrones. Contour drawing routines are a standard part of most data analysis and visualization software, such as MATLAB. Some algorithms were previously described by Barr [4] and by Linnenbank [5]. However, isochrone drawing is more difficult than ordinary contour drawing of, e.g., potential maps because zones of conduction block have to be treated in a special way. Two situations that need special care are: (1) Activation times in adjacent electrodes differ to the extent that the apparent conduction velocity is lower than considered possible [6, 7], which implies that they cannot be part of the same activation front. This

can happen if conduction block is present and if a reentrant activation returns at the point where it started. In both cases, a standard contour algorithm would draw a set of crowding isochrones. This would inadvertently suggest the presence of very slow conduction. Instead, a line with a special style should be plotted; either a block line to indicate a total stop (the line with 'T' marks in figure 1), or a line that indicates the beginning and end of an interval of reentrant activation. This cannot be accomplished with standard contouring programs. (2) In some electrodes, no activation occurs within the given interval. If a standard contouring program is used, such situations can be handled by treating the region of this electrode as if it was not included in the grid, i.e. making a "hole" in the grid before feeding it to the contouring algorithm. No contours will then be drawn in this region. In case of an isochronal map, such regions would look similar to regions of very high conduction velocity, where isochrones are also at large distances from each other; the observer would have to discriminate these phenomena from the context of the entire map. Ideally, a block line or a patch with a different shade should be drawn for regions of conduction block.

A specialized program is thus necessary; however, to a large extent it can use existing algorithms.

2   Methods and results

An experimental program for electrocardiographic isochrone drawing, called "isomap," was developed. This
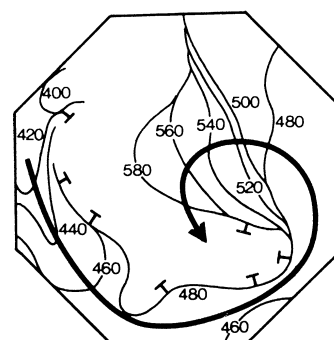
Figure 1: *Example of a hand-crafted isochronal map, reproduced from Van Capelle et al. [3]. The line with 'T' symbols attached to it indicates a line of conduction block.*

Matlab

isomap, limit = 2.5 cm/s
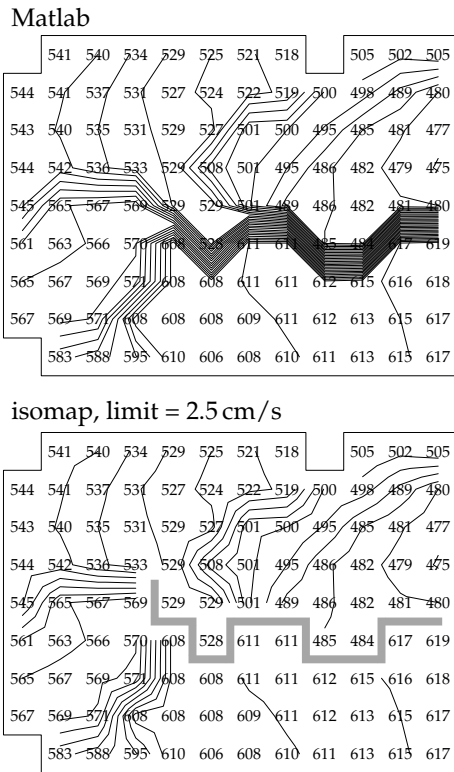
Figure 2: *Activation maps featuring a line of block [8] drawn with isochrones using the general contour function from Matlab (top), and using the specialized isomap program, with the conduction speed limit set to 2.5 cm/s. Block lines are rendered thick and grey. Activation times are indicated in milliseconds and isochrones are drawn at 5 ms intervals. Timings are relative to a pacing pulse that occurs earlier in the recording. Inter-electrode spacing was 0.1 cm [8].*

program can handle lines of conduction block (figure 2) and reentrant activation (figure 3) correctly. It can work on surfaces in 3-D as well as in 2-D, and with both triangulated and rectangular grids. In its current implementation it decomposes rectangles into triangles, so that only an algorithm for contour drawing on a triangulated grid is needed. This decomposition is performed in such a way that saddle points are treated correctly. Output of the isomap program is shown in figures 2 and 3.

3   Discussion

An important feature of the isomap program is that it can automatically indicate lines of conduction block: if the activation-time difference between neigbouring electrodes is so large that the apparent conduction velocity is below a user-specified limit, the program assumes conduction block between these electrodes, and will indicate this with a special line style. Ordinary isochrones are not drawn in such regions. Since isomap can handle a typical activation map in a few milliseconds, the software operates fast enough to allow experimentation with limit values in an interactive way.

Provided with adequate software, computers are

Matlab   isomap
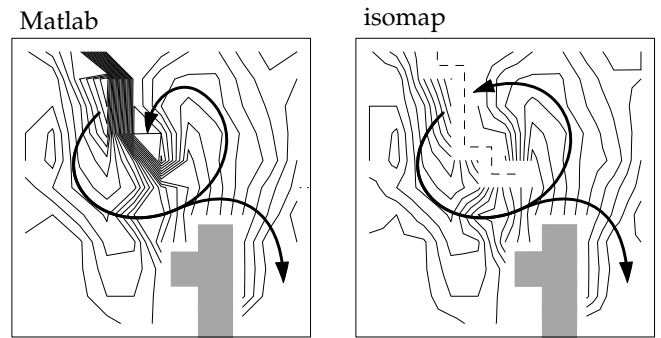
Figure 3: *Handling of reentry by the isomap program. These maps represent a circulating activation pattern [9]. The operator has chosen the time window where activations are detected such that all electrodes show one activation. If a standard contour algorithm (Matlab) is used, isochrone crowding occurs in the area where the activation front is at the begin and end of this window. This looks very similar to activation block, as in figure 2. Using the isomap program it is possible to draw a single contour in a special style instead, such as the dashed line used here. The grey area indicates a zone of activation block. Isochrones are drawn at 5 ms intervals.*

highly useful for the creation and inspection of large numbers of activation maps. It should be noted, however, that the clarity of hand-crafted maps (figure 1) is unsurpassed by computer programs—at least by the programs presented here. On the other hand, the process by which this clarity is obtained involves assumptions on the activation process that are not made explicit. It is therefore subjective, and the resulting maps are sometimes debatable.

A good compromise between efficiency and reliability is presented by computer programs that incorporate all possible clarifications that are not debatable. Isomap was created for this purpose. By letting the user specify isochrone levels, it allows the right number of isochrones for a given situation to be drawn. By letting the user state explicitly which delay signifies conduction block, it allows the creation of block lines in a documented and reproducible way.

References

[1] R. E. Ideker, W. M. Smith, S. M. Blanchard, et al. The assumptions of isochronal cardiac mapping. *PACE*, 12:456–478, March 1989.

[2] J. M. T. de Bakker, M. J. Janse, F. J. L. van Capelle, et al. An interactive computer system for guiding the surgical treatment of life-threatening ventricular tachycardias. *IEEE Trans. Biomed. Eng.*, 31(4):362–8, April 1984.

[3] F. J. L. van Capelle, H. Morsink, M. J. Janse, et al. Computerized DC epicardial mapping during experimental coronary occlusion. *Comp. in Cardiol.*, pages 99–102, September 1979.

[4] R. C. Barr, T. M. Gallie, and M. S. Spach. Automated production of contour maps for electrophysiology; III. con-

struction of contour maps. *Comp. & Biom. Res.*, 13:171–191, 1980.

[5] A. C. Linnenbank. *On-site recording, analysis, and presentation of multichannel ECG data*. PhD thesis, University of Amsterdam, The Netherlands, August 1996. e-mail: `a.c.linnenbank@amc.uva.nl`.

[6] A. Kléber, M. J. Janse, F. J. G. Wilms-Schopman, et al. Changes in conduction velocity during acute ischemia in ventricular myocardium of the isolated porcine heart. *Circulation*, 73:189–198, 1986.

[7] J. M. T. de Bakker, F. J. L. van Capelle, M. J. Janse, et al. Fractionated electrograms in dilated cardiomyopathy: Origin and relation to abnormal conduction. *J. Am. Coll. Cardiol.*, 27(5):1071–1078, 1996.

[8] J. R. de Groot. *Genesis of life-threatening ventricular arrhythmias during the delayed phase of acute myocardial ischemia. Role of cellular electrical coupling and myocardial heterogeneities*. PhD thesis, University of Amsterdam, June 2001.

[9] J. R. de Groot, F. J. G. Wilms-Schopman, T. Opthof, et al. Late ventricular arrhythmias during acute regional ischemia in the isolated blood perfused pig heart. Role of electrical cellular coupling. *Cardiovasc. Res.*, 50(2):362–372, 2001.