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Mapping of Mammalian Purkinje Network on an Electrically Equivalent Circuit

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ABSTRACT: Purkinje network of a Magnetic Resonance Image cardiac dataset has been extracted using 3-D slicer. From that extracted model simplified circuit of Purkinje network has been generated with help of simplified version of cable theory. Also the length of each node of human heart has been identified using landmark tools of 3-D slicer. The action potential propagating through the network was simulated in MATLAB and the circuit was simulated in Multisim. This simulation was then represented with help of a 3-D printed heart visualization module. The main intention of designing a circuit equivalent to Purkinje network was achieved. However, the pulse of circuit was found to be lower than the actual pulse generated by the Purkinje network.

KEYWORDS: Purkinje network, 3-D slicer, Simplified cable theory, MATLAB, Action potential.

1 INTRODUCTION

Purkinje networks are specialized electrical conduction muscle. During the depolarization of atrium of the heart, a great impact has been imposed by the Purkinje network. This networks helped to generate full QRS complex of ECG. Purkinje network has the highest conduction velocity among all the nodes of the heart [1]. This network can be used to identify the block of the heart. An exact equivalent circuit of this network can be very useful for heart diseases patients

2 MATERIAL AND METHODS

This research is mainly based on four principle. Extraction 3- D heart model from the DICOM file was the first principle. Purkinje network extraction was the second principle. MATLAB simulation of this 3-D model was the third initiative. Simple cable theory was used to generate an equivalent circuit of Purkinje network was the fourth principle.

2.1 EXTRACTION OF 3-D HEART MODEL

The DICOM file of cardiac MRI was extracted with help of 3-D Slicer software. This DICOM file contained the MRI image of heart. Then, the MRI image has been resized and diminished the unnecessary muscle to gain our desired model. Then the model of 3-D heart generated with the help of slicer. Every node has been identified from that heart model by using landmarks. From that land mark the length of node and the length of Purkinje network have been measured.

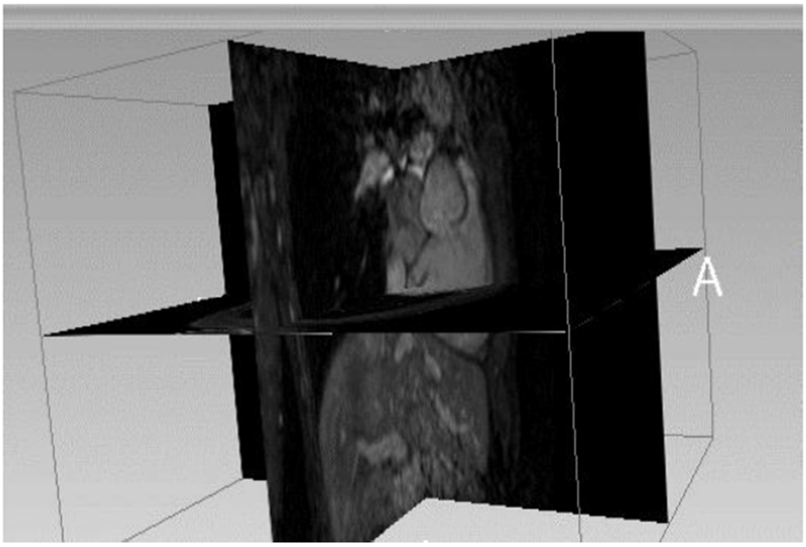

Fig. 1. Composite MRI view of heart [4].

2.2 Circuit Simulation

The circuit has been made, using the cable theory. The goal of this circuit was to find delay signal because the response of heart does not depend only electrical conduction. Single frequency signal has been given as input. 10 Hz frequency with 1 volt (peak to peak) amplitude has been given as input with the help of frequency generator. In normal case, the pulse of the heart propagate with 0.6 volt (peak to peak) and in real condition there is no ground connection but to do the circuit a common ground has been added. After that several blocks have been added instead of Purkinje cell. Then the output has been taken from every blocks to see the conduction delay. Here the simulation has been done within a segment. Electrical pulse is passed from one cell to another cell, to do that electrical block has been cascaded. To continue the propagation up to next segment a voltage control voltage gate has been used. The signal has been passed to each block of a segment and showed its corresponding conduction delay. Suitable resistor and capacitor values have been chosen to find the conduction delay. In the extracellular membrane 100 ohm resistors have been selected and 1 ohm resistors have been selected in intracellular space. Also 10 micro farad capacitors have been selected for membrane capacitance. Here the electrical conduction of muscle has not been considered.

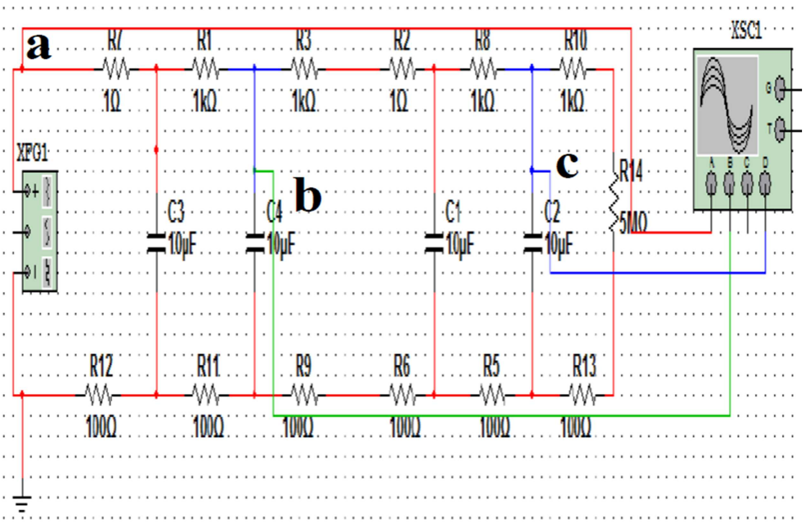

Fig. 2. Equivalent circuit of a segmented Purkinje network

2.3 MATLAB SIMULATION

Length of each node of the human heart has been measured using the landmark identification of slicer view. Hodgkin-Huxley model was used to find out the action potential. For potassium ion the effect of variable n was measured by conductance, G_k. The effect of sodium ion can be identified by the variable of m and h. The delay has been showed by the voltage. Simplified cable theory has been used by a number of series resistors with parallel capacitor. The change of the voltage has been represented by (x),

$$V_x = V_0 ee^{-\frac{x}{y}} \text{..} \text{ Eq 1}$$

Sodium, potassium and chloride ion has their own channel current. Sodium ion channel current is I_{Na} , potassium ion channel current is I_K and chloride ion channel has ionic current I_{Cl},

$$I_{Na} = G_{Na}(V_m - E_{Na}) \text{...} \text{Eq 2}$$

$$I_K = G_K(V_m - E_K) \text{..} \text{Eq 3}$$

$$I_{Cl} = G_{Cl}(V_m - E_{Cl}) \text{..} \text{Eq 4}$$

Using this equation, MATLAB function has been generated [1][2]. Analyzing all these equation we got the action potential curve for Purkinje network node. In the Table 1: delay has been shown for the Purkinje nodes. The number of nodes were increasing in left ventricle as the length of the Purkinje fibers were greater in there. The number of nodes were less in right ventricle as the length Purkinje fibers is less in there. Nodes number 9-18 was showed in Table 1 and also the value of each nodes length was given there.

Table 1. Conduction delay of Purkinje network

Purkinje fiber node	Length(μm)	Conduction delay(ms)
9-10	15.21 x10^{-6}	23.5
10-11	20.43 x 10^{-6}	7.5
11-12	35.97 x10^{-6}	8.6
12-13	14.81 x10^{-6}	9.84
14-15	15.13 x10^{-6}	10.5
15-16	21.60 x10^{-6}	11.2
16-17	13.96 x10^{-6}	12.3
17-18	13.41 x10^{-6}	12.8

3 RESULTS

3.1 PURKINJE NETWORK EXTRACTION

Electrical conduction of heart consisted of some specific node. SA node, AV node, Bundle of branch, Bundle of his and Purkinje fibers are the main electrical conduction path of heart[1]. Landmark has been given to each node using the Axial slice, Sagittal slice and Coronal slice view in Slicer. The landmarks were showed the minimum conduction path of human heart. Each node of human heart has been identified by a specific landmarks. Node number 1 and 2 contain the path of SA to AV node. Node number 2-3 contain the path of AV node to common bundle. From node 3 the path divided into two portion left ventricle and right ventricle. Node number 3-18 contain the electrical conduction path of left and right ventricle. Node number 14, 15, 16, 17 and 18 are the path of the Purkinje network from left ventricle wall. Node number 9, 10, 11, 12 and 13 contain the conduction path for Purkinje network from the right ventricle wall.

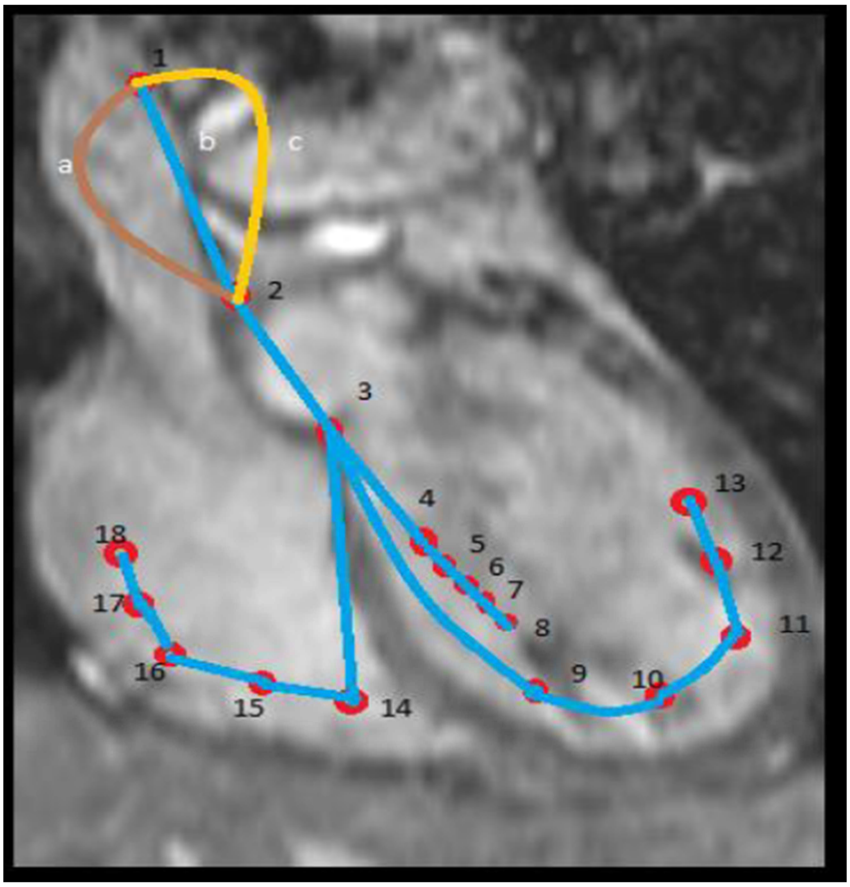

Fig. 3. Nodes Identification using landmark tools of 3-D slicer.

Though the conduction path from 9-13 in left ventricle is larger than the path from 14-18 in right ventricle. Node number 3-8 contain the electrical conduction path for Bundle of branch, Bundle his to Purkinje network.

3.2 CIRCUIT OUTPUT RESPONSE

Purkinje network has been generated using the simplified version of cable theory. The intracellular and extracellular space and gap junction has been considered. Intracellular space is measured with equivalent resistance, range of mega ohm. Extracellular space is measured with small resistance of ohomic range. Gap junction is with a parallel capacitor connected with resistor to invoke the conduction delay [3]. Conduction velocity of the Purkinje network has been showed using the simple cable theorized block circuit. In the output response, the delay has been showed sequentially. The red colored signal shows the input signal. After that the green and blue colored signal shows the sequential blocks response.

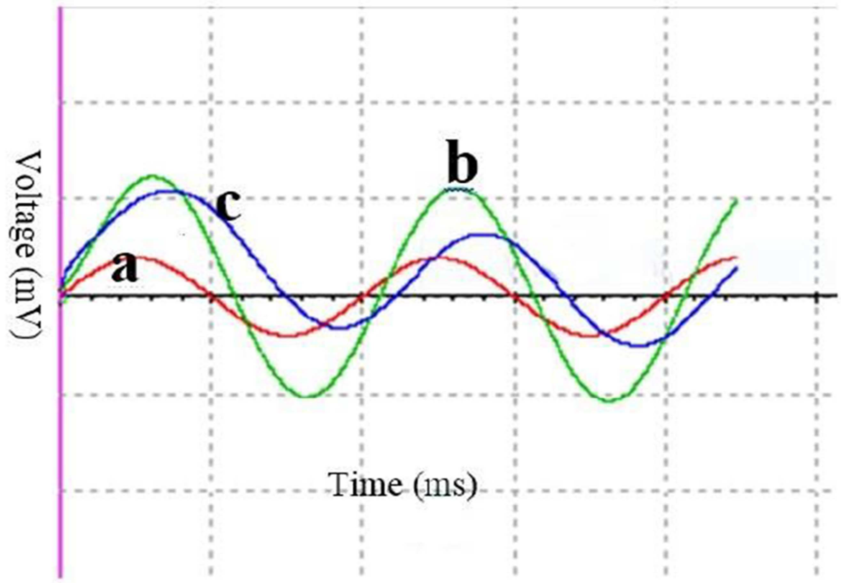

Fig. 4. Delay propagation of multiple segment.

3.3 MATLAB OUTPUT RESPONSE

Several nodes were taken from the 3D slicer model. Then the length of node to node was measured. Using the length of SA node, AV node, Bundle of branches node, Bundle of his node and Purkinje fiber node, the simulation of whole heart has been generated. First the delay was added

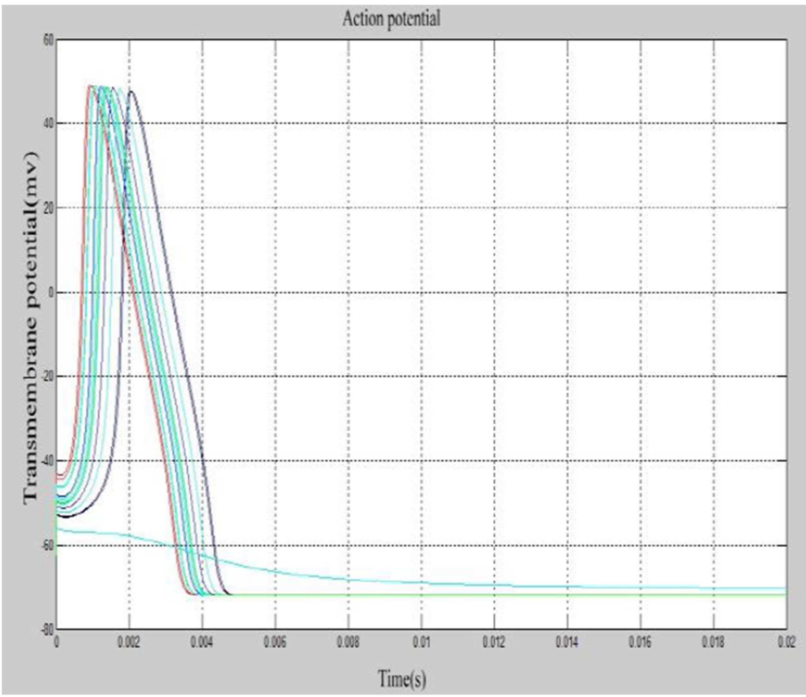

Fig. 5. Conduction delay of Purkinje network.

Then using this, the delay of each node was generated. The combine wave shape is dependent only on the Purkinje network action potential propagation. Action potential propagation in rest of muscle was not considered. This is the reason of getting a distorted form of ECG like wave shape.

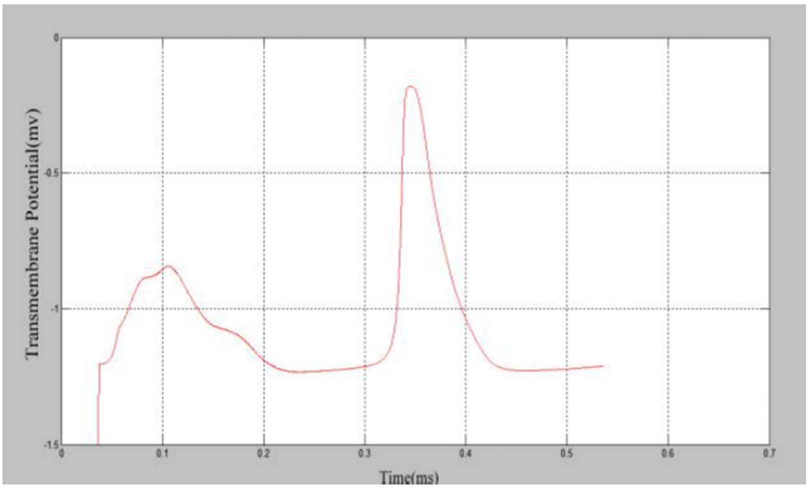

Fig. 6. Combine wave shape of one complete cycle conduction delay cycle of Purkinje network

3.4 VISUALIZATION MODULE

Electrical pulse has been given to atrium using Arduino Mega interfacing with MATLAB. The propagation start from SA node. Then the pulse has been given to AV node using the same procedure. Next the pulse has been sent to common bundle. After that the pulse has been given to Bundle of His. Next the pulse given to the Bundle of branches. Lastly the pulse has been given to Purkinje fiber. When the atrium muscle depolarized, light has blinked and showed the propagation. During the depolarization of ventricle, specifically in Purkinje fibers, the led blinked and showed the propagation. The propagation time has taken from Table 1. Depolarization of one complete heart cycle has been generated with help of MATLAB simulation.

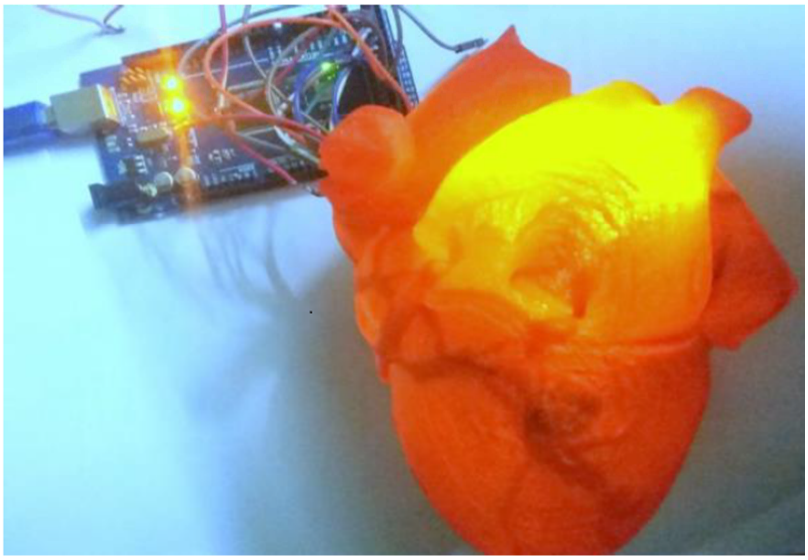

Fig. 7. Depolarization of Atrium.

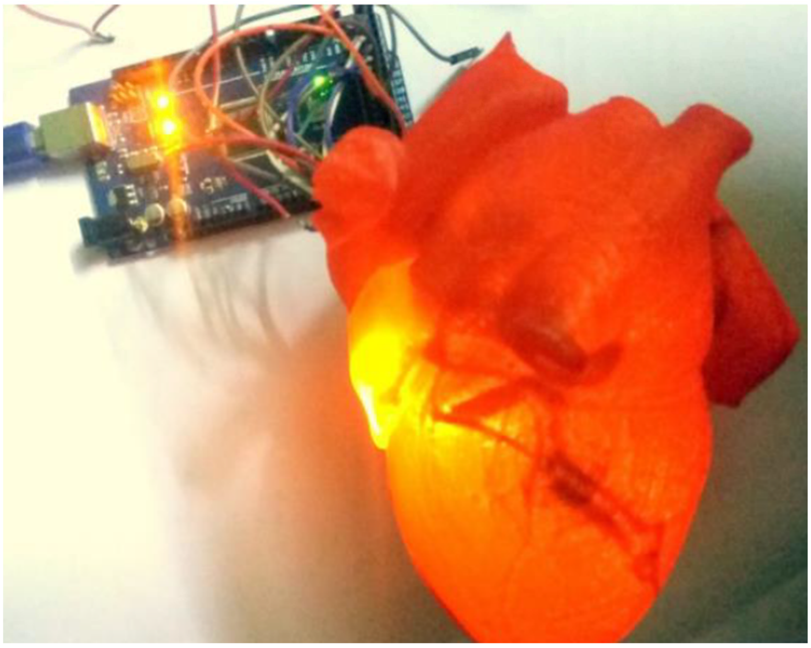

Fig. 8. Depolarization of AV node.

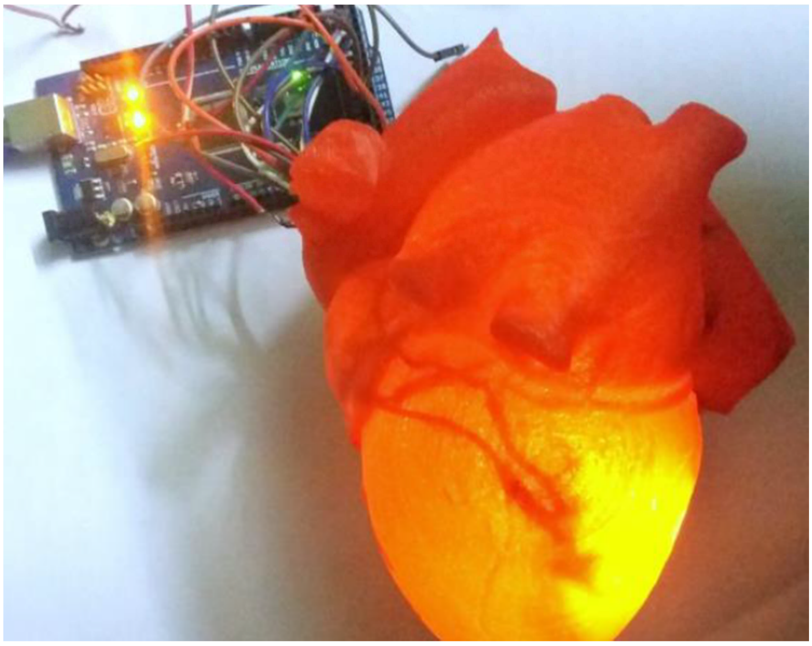

Fig. 9. Depolarization of Ventricle.

4 CONCLUSIONS

Purkinje fibres are generated a large network inside ventricle wall. Using this network, heart block could be identified. Nodes of the human heart and its length has been measured from the 3-D heart model. Using this measurement in the MATLAB the conduction velocity of the heart has been measured. From simplified version of cable theory circuit we got another conduction velocity. However, we used an equivalent circuit of Purkinje fibre and the length is measured from the 3-D model. So the output may not be as exact as the real one. Future work could be done by using the data of real MIR or CT scan.

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REFERENCES

[1] R. P. Malmivuo Jaakko, Bioelectromagnetism, “relative merits of electric and magnetic measurements in cardiac studies”, vol. 7. 2004.

[2] N. Angel, “Equivalent circuit implementation of demyelinated human neuron in spice,” *Mastar’s Thesis and Project Reports,* California Polytechnic State University, San Luis Obispo, 2011.

[3] S. Dhein, T. Seidel, A. Salameh, J. Jozwiak, A. Hagen, M. Kostelka, G. Hindricks, and F.-W. Mohr, “Remodeling of cardiac passive electrical properties and susceptibility to ventricular and atrial arrhythmias,” *Front. Physiol.*, vol. 5, p. 424, Jan. 2014.

[4] “Cardiovascular Physiology | EM Cephalgia.” [Online]. Available: http://emcephalgia.com/acem-primary-exam-notes/physiology/cardiology-physiology/cardiovascular-physiology/. [Accessed: 19-Nov-2015].