LIVING HEART HUMAN MODEL: PACEMAKER LEAD INSERTION AND CARDIAC CYCLE SIMULATION

Cardiovascular disease is the leading cause of death worldwide and is projected to remain so for decades, according to the World Health Organization. Surgical intervention, including the implantation of artificial pacemakers, continues to be a life-safer for many patients.

Patients whose natural pacemaker cannot maintain an adequate heart rate due to problems with their heart's electrical conduction system often need an artificial pacemaker to be implanted. The pacemaker is typically surgically placed under the skin, where it is accessible for battery replacement (this is typically in the left shoulder area). Electrodes (pacemaker leads) run from the device to areas within the heart requiring the additional stimulus. The durability of the pacemaker lead is of great importance since damage to them can mean they no longer provide the life-saving electrical stimulus. Further, the pacemaker lead is meant to be a permanent implant, where it is expected to perform for many years without failure.

The SIMULIA Living Heart Human Model provides a unique testing environment where a pacemaker lead can be virtually inserted and mechanically deformed during the cardiac cycle. Once the mechanical deformation results are obtained, the long-term durability of the implant can be assessed. The virtual nature of the test provides a physiologically accurate methodology to test new and existing devices without exposing patients to un-necessary risk.

1. GEOMETRY AND MODEL

The pacemaker lead is a long flexible wire; therefore, it has been modeled as a beam structure of a length of 150 mm. A rigid tubular structure is also present in the model to act as a guide for the distal end of the pacemaker lead. This ensured that the tip of the pacemaker lead was located at the epicardial surface of apex of the right ventricle after the insertion process was complete (i.e. the lead was located within the heart where the electrical stimulus was needed). The lead assembly (lead & guide) was inserted at the appropriate position in the Assembly of the SIMULIA Living Heart Human Model (Heart Model) relative to the rest of the heart structure (refer to Figure 1).

2. MATERIAL AND GEOMETRIC PROPERTIES

The pacemaker lead is modelled using a beam element approximation. Representative quantities of the pacemaker lead cross-sectional and material properties in a consistent set of units are utilized:

Table1. Geometry and material properties of Lean

Parameter	Value
Density	6.96279e-10 (tonne/mm^3)
Area	3.0 mm^2
Moment of Inertia (I11)	0.5 mm^4
(I12)	0.0 mm^4
(I22)	0.5 mm^4
(J)	1.0 mm^4
Axial Behavior of Beam	9 N/mm
First bending moment behavior of beam (M1)	17 N mm^2
Second bending moment behavior of beam (M2)	17 N mm^2
Torsional behavior of beam	30 N mm /rad
Damping (alpha)	34 s^{-1}

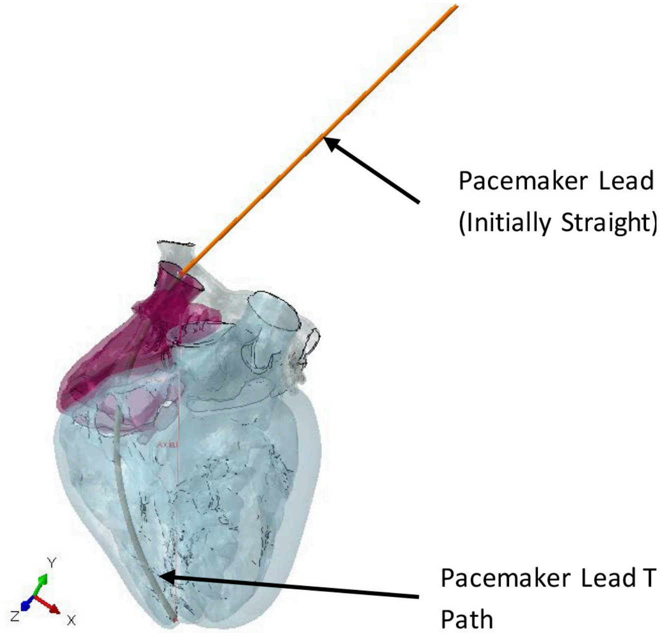

Figure1. Initial Pacemaker Lead Placement Relative to the Heart Model

3. ANALYSIS PROCEDURE

The mechanical portion of the Heart Model simulation utilized the Abaqus/Explicit solver in the 3DEXPERIENCE R2017x platform. The simulation begins with filling the heart with blood to a state consistent with being at 70% through the diastolic phase of the cardiac cycle. It is during this process, which lasts 0.3 seconds, the pacemaker lead is inserted into the right atrium and ventricle through the superior vena cava (refer to Figure 2). After the insertion process, the heart completes three cardiac cycles to reach cyclic stead-state of the Heart Model.

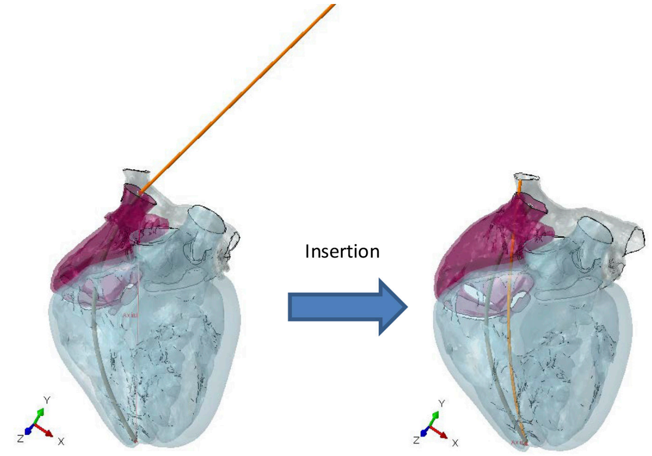

Figure2. Pacemaker Lead Insertion Process

4. BOUNDARY CONDITIONS AND LOADS

In order to facilitate the insertion of the pacemaker lead, an Axial connector element was connected to the distal end of the lead and the epicardial surface of the right ventricle apex. During the blood filling portion of the simulation, the connector element was shortened to a final length near 0 mm. This effectively pulled the pacemaker lead tip from the superior vena cava to the right ventricle apex. During the cardiac cycle, the distal end of the pacemaker lead was affixed to the epicardial surface of the right ventricle, and the proximal end was Pinned.

5. INTERACTIONS

The interaction between the pacemaker lead and the heart model utilized General Contact. Specifically, contact between the pacemaker lead and the epicardial surfaces of the right atrium and ventricle was specified. Further, contact between the pacemaker lead tip and the pacemaker lead path structure was also defined to ensure the proper final location of the pacemaker lead tip.

6. RESULTS AND DISCUSSION

The pacemaker lead is a thin flexible wire, and during the cardiac cycle the main mode of deformation is bending. Therefore, the curvature changes of the pacemaker lead throughout the cardiac cycle is an output quantity of primary interest. In the Explicit solver, the appropriate output is the section curvature (SK), which is given in terms of curvature change about two orthogonal planes (SK1 and SK2). Figure 3 is contour plots of the curvature at various points throughout the cardiac cycle.

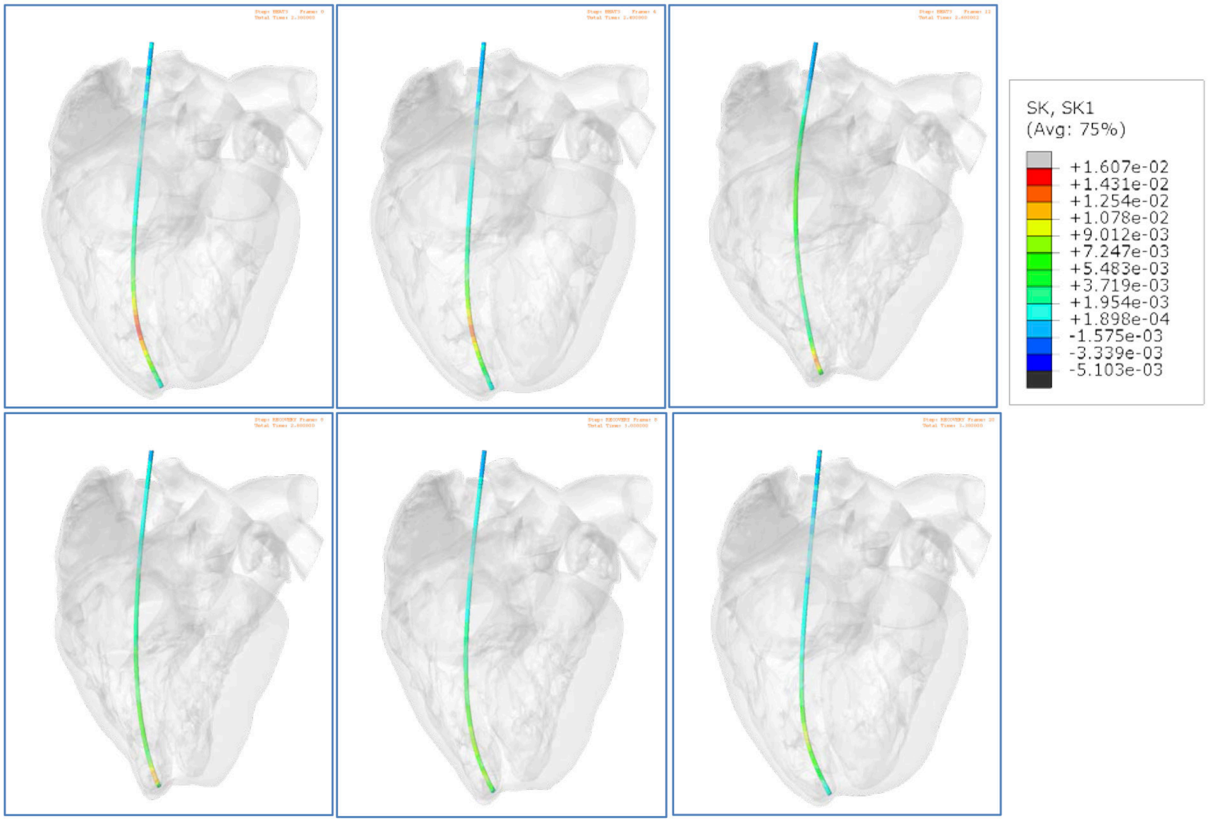

Figure3. Curvature Contour Plots during the Cardiac Cycle.

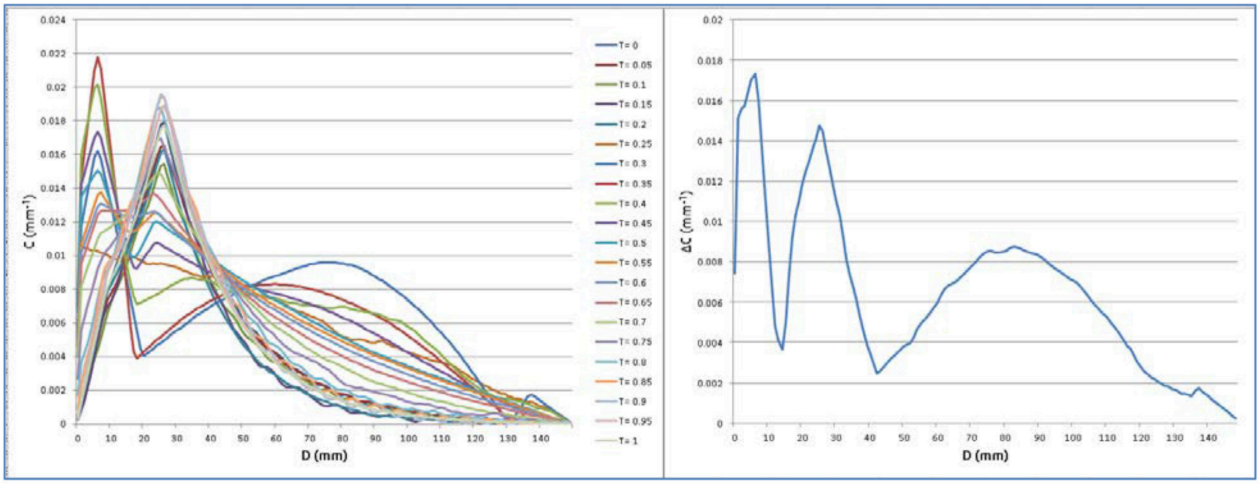

Figure4. Curvature Path Plots of the Pacemaker Lead Throughout the Cardiac Cycle

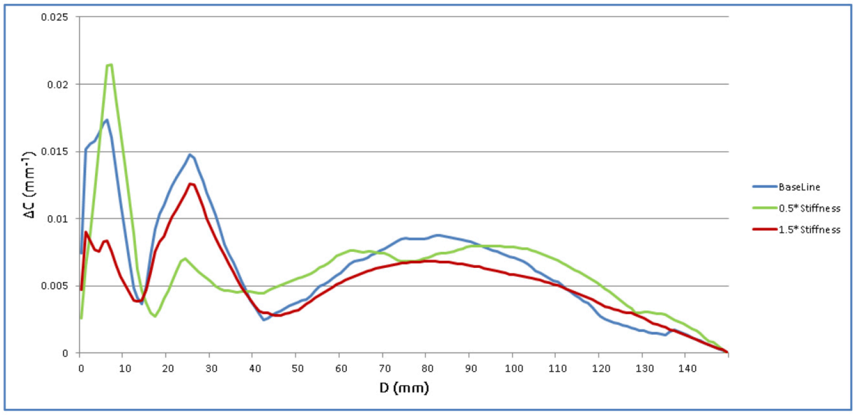

Figure5. Impact of the Lead Stiffness on Curvature during the Cardiac Cycle

The plot on the left of Figure 4 shows the curvature change along the length of the pacemaker lead at ten frames throughout the cardiac cycle. The plot on the right of Figure 4 represents the maximum difference in curvature at all the time points listed on the plot on the left (i.e. a representation of the alternating curvature along the length of the pacemaker). Plots such as this make it easier to determine how the curvature changes spatially (i.e. along the length of the pacemaker lead) and temporally throughout the cardiac cycle.

The SIMULIA Living Heart Human Model allows for "what-if" studies to be completed very easily. For example, Figure 5 shows the impact of increasing and decreasing the lead stiffness by 50% from the baseline values presented above. When the stiffness was reduced by 50% from the baseline, the curvature increases for the first peak and reduces for second peak. Alternatively, when stiffness was increases by 50%, the curvature reduced for both peaks.

7. SUMMARY

In this technology brief, we demonstrate that Heart model can be used to model the behavior of pacemaker lead with in the SIMULIA Living Human Heart Model. The virtual nature of the simulation allows you to evaluate these life-saving devices in a safe and efficient manner.

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