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An Approach to Robotic-Surgery System for Unroofing Myocardial Bridge: A Feasibility Study

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Abstract: Myocardial bridge is a congenital anomaly where a segment of the coronary artery tunnels through the myocardium instead of running on its surface. This paper reviews the clinical significance of myocardial bridging and explores various unroofing techniques aimed at alleviating associated symptoms and preventing complications. It examines the efficacy, safety, and outcomes of these interventions based on available literature and provides insights into future directions in this field. Myocardial bridge, characterized by the tunnelling of a coronary artery through the myocardium, poses challenges for conventional surgical techniques. This paper presents the design and development of a novel robotic-assisted surgery system tailored for myocardial bridge unroofing. The system integrates advanced robotic technology, specialized instrumentation, and intuitive control interfaces to enable precise and minimally invasive treatment of this condition. Feasibility testing in simulated and preclinical settings demonstrates the potential of the robotic system to enhance surgical outcomes and improve patient care.

***Keywords*:** Myocardial bridge, unroofing techniques, surgical intervention, minimally invasive procedures, robotic-assisted surgery, minimally invasive, surgical innovation, feasibility study.

1. INTRODUCTION

Typically, the coronary arteries lie on the surface of the heart. However, in people with myocardial bridges, one or more of the arteries goes through the heart muscle for a short distance. The flap of heart muscle that goes over this small section of artery forms a “bridge.”

So, Myocardial bridging occurs when the heart is malformed, with a bridge of muscle fibres overlying a section of a coronary artery, usually the left anterior descending (LAD) artery. When the heart beats, the artery is squeezed and normal blood flow is disrupted during both the pumping and relaxed cycles. Myocardial bridge refers to the myocardial tissue with which the coronary artery is partly covered. Though it has long been regarded to be benign, patients with myocardial bridges may present with myocardial ischemia, acute coronary syndromes, coronary spasm, sudden cardiac arrest or even sudden death

In most patients, a myocardial bridge is not treated if it is not causing any symptoms. In patients with symptoms, medicines such as beta-blockers and calcium channel blockers are usually the first line of treatment. In rare cases, patients need surgery to relieve their symptoms. Myocardial bridges have traditionally been considered a benign condition,

but recent studies have demonstrated that the clinical complications can be dangerous; these complications include acute coronary syndromes, arrhythmias (including supraventricular tachycardia and ventricular tachycardia)

However, vigorous exercise can increase the risk of adverse cardiac events in those with symptomatic myocardial bridges and documented ischemia, thus a surgical approach may be beneficial in athletes who wish to return to full participation. Patients often relate complaints of palpitations, exercise intolerance, fatigue and near- syncope or syncope, other non-specific symptoms such as headache and nausea may be present as well to varying degrees. Myocardial bridging is rare occurring in 0.5–16% in angiographic studies.

2. UNROOFING TECHNIQUES

2.1 Surgical Unroofing In this study, we propose a muscle coordination control method using attractor selection, a biologically inspired search method, for an antagonistic-driven musculoskeletal robot in which various muscles (monoarticular muscles and a polyarticular muscle) are arranged asymmetrically. First, muscle coordination control models for the musculoskeletal robot are built using virtual antagonistic muscle structures with a virtually symmetric muscle arrangement. Next, the attractor selection is applied to the control model and

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subsequently applied to the previous control model without muscle coordination to compare the control model's performance. Finally, position control experiments are conducted, and the effectiveness of the proposed muscle coordination control and the virtual antagonistic muscle structure is evaluated. robotic surgery offers the advantages of minimal trauma to neighboring structures, while the use of robotic tools provides the surgeon with the ability to operate precisely in limited spaces.

2.2 Minimally Invasive Techniques

Concurrent with developments in surgical robotic technology, catheter-based percutaneous procedures have also evolved and have become much more widespread. Development of multiple devices that can be delivered via catheter and development of delivery techniques have facilitated the application of this technology. Although, robotically assisted catheter-based interventions are not widely used in pediatric interventional cardiology practice, there are procedures in adults where robotic systems are utilized. Currently, there are two robotic catheter technologies available, electromechanically based systems and magnetically controlled systems The system may be delivered over an independent guide wire, but does not depend on that wire to maneuver.

In open-heart surgical procedures, the grasping is usually performed with standard surgical instrument, such as forceps or hooks, and the two tissue sections fixed together by sutures or clips. Currently, there are no catheter-based instruments or techniques for tissue approximation other than clips or staples that snap together, trapping tissue in between the jaws of the clip. One specific example of tissue approximation is during PFO closure. Current approaches to closure include open-heart surgery, and catheter-based deployment of an occluder device. However, experience with device closure, shows that serious complications, such as major haemorrhage, cardiac tamponade, the need for surgery, pulmonary embolism and death occur in 1.5% of patients, and minor complications (arrhythmia, device fracture or embolization, air embolism, femoral hematoma and fistula) in another 7.9% . Results with open-heart surgery indicate a significantly lower risk of complications and no recurrence at 23 months of follow-up. A device and technique of PFO closure that mimics surgical closure was developed and tested in large animal studies. The two tissue layers are first pierced at the location where approximation is desired. During robotic deployment, a sharpened stylet inserted through the robot was used in place of the cannula. Not shown in the figure, the robot produces appropriate overlap of the septum secundum and primum by first piercing the secundum and then dragging it laterally to achieve the desired overlap with the septum primum. The robot then punctures the second layer and proceeds with device deployment.

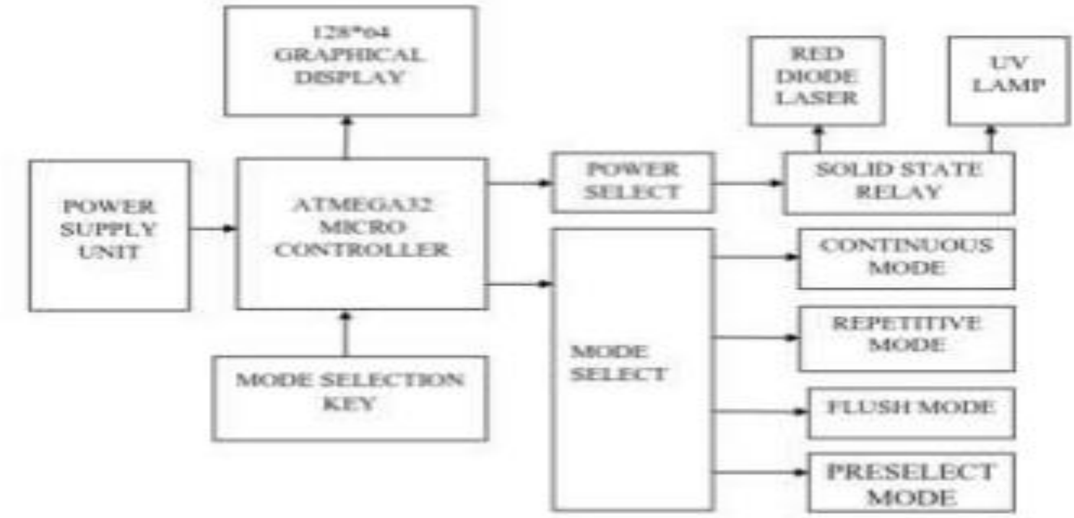
2. DESIGN CONCEPT

An alternative approach that mimics surgical tissue removal is under development. It utilizes the concentric tube robot described above, with an integrated tissue removal tool. In this case, the robot enters the heart percutaneously from the right internal jugular vein and passes through the tricuspid valve into the RV. From there, the robot can be steered to the RV outflow tract and the cutting tool can be employed to sculpt away excess tissue. The cutting tool provides integrated irrigation and aspiration in order that the morselized debris can be transported out of the heart through the lumen of the robot. Irrigation using a hepatized normal saline solution facilitates transport while minimizing both blood loss and device clogging due to emboli formation. shows results from *ex vivo* experiments on two types of tissue. Near the top, removal of the fibrous endocardial surface layer was performed with a gentle sweeping motion along the surface exposing the underlying myocardium. Removal of myocardial tissue is also possible, as shown. In this case, a cavity was milled into the tissue by plunging the tool roughly at a normal angle to the surface and sweeping it in a small circular pattern as it descended into the tissue. While the majority of cutting debris was aspirated through the robot lumen, a downstream embolization filter may need to be deployed into the main pulmonary artery to collect any particulate emboli that may be dislodged by the process of tissue removal.

3. SYSTEM ARCHITECTURE

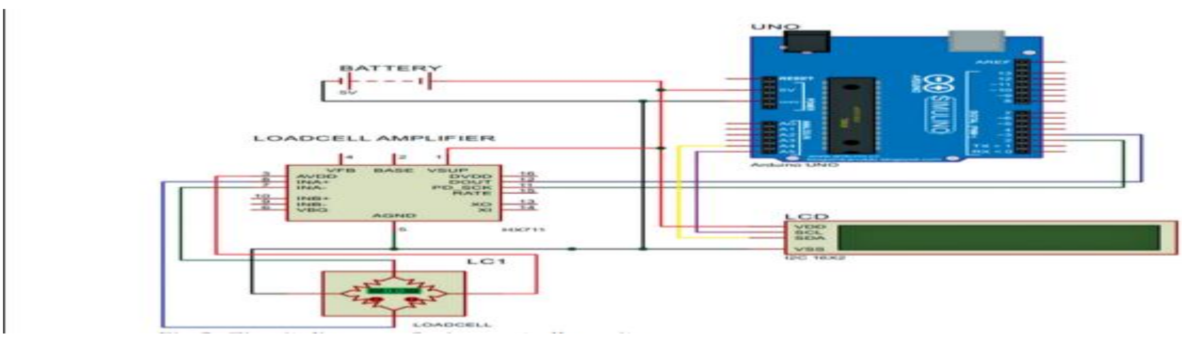
An alternative approach that mimics surgical tissue removal is under development. It utilizes the concentric tube robot with an integrated tissue removal tool. To remove abnormal obstructions from the RV outflow tract, a navigation route can be employed. In this case, the robot enters the heart percutaneously from the right internal jugular vein and passes through the tricuspid valve into the RV. From there, the robot can be steered to the RV outflow tract and the cutting tool can be employed to sculpt away excess tissue. The cutting tool provides integrated irrigation and aspiration in order that the morselized debris can be transported out of the heart through the lumen of the robot. In this case, a cavity was milled into the tissue by plunging the tool roughly at a normal angle to the surface and sweeping it in a small circular pattern as it descended into the tissue. While the majority of cutting debris was aspirated through the robot lumen, a downstream embolization filter may need to be deployed into the main pulmonary artery to collect any particulate emboli that may be dislodged by the process of tissue removal.

5. CONTROL SYSTEM



Lasers are devices that produce intense beams of light which are monochromatic, coherent, and highly collimated. The wavelength colour of laser light is extremely pure monochromatic when compared to other sources of light, and all of the photons that make up the laser beam have a fixed phase relationship with respect to one another. Light from a laser typically has very low divergence. It can travel over great distances or can be focused to a very small spot with a brightness which exceeds that of the sun. Because of these properties, lasers are used in a wide variety of applications in all walks of life. For cutting and engraving operation in an industrial application we propose a system to operate laser at different modes. Depending upon the metal, user can select power on laser through the panel keys, to reduce power consumption and wastage of material.

6. HUMAN-MACHINE INTERFACE



5. CONCLUSION

From the engineering perspective, while it is not easy to predict the ideal robotic image-guided intracardiac system of the future, we believe that it should possess certain key features. The robotic platform should enter the heart percutaneously and provide ergonomic control of both tools and imaging. Essential imaging features include high-quality real-time views of the entire heart volume as well as high-fidelity tool-tip views for visualizing the tool–tissue interaction. In combination with imaging, the incorporation of touch sensing, to monitor forces applied to the tissue, will be critical for safe and effective pediatric intracardiac interventions. These techniques can enhance the surgeon's ability to 'see' the robot tool position. This improved estimate of robot position can be calculated in real time during a procedure and superimposed on the live image to provide an augmented reality display for the interventionalist

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