Research paper

Application of finite element analysis to the design of tissue leaflets for a percutaneous aortic valve

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ABSTRACT

Percutaneous Aortic Valve (PAV) replacement is an attractive alternative to open heart surgery, especially for patients considered to be poor surgical candidates. Despite this, PAV replacement still has its limitations and associated risks. Bioprosthetic heart valves still have poor long-term durability due to calcification and mechanical failure. In addition, the implantation procedure often presents novel challenges, including damage to the expandable stents and bioprosthetic leaflets. In this study, a simplified version of Fung’s elastic constitutive model for skin, developed by Sun and Sacks, was implemented using finite element analysis (FEA) and applied to the modelling of bovine and kangaroo pericardium. The FEA implementation was validated by simulating biaxial tests and by comparing the results with experimental data. Concepts for different PAV geometries were developed by incorporating valve design and performance parameters, along with stent constraints. The influence of effects such as different leaflet material, material orientation and abnormal valve dilation on the valve function was investigated. The stress distribution across the valve leaflet was also examined to determine the appropriate fibre direction for the leaflet. The simulated attachment forces were compared with suture tearing tests performed on the pericardium to evaluate suture density. It is concluded that kangaroo pericardium is suitable for PAV applications, and superior to bovine pericardium, due to its lower thickness and greater extensibility.

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1. Introduction

Conventional heart valve replacement surgery involves opening the chest via a sternotomy, stopping the heart and placing the patient on a cardiopulmonary bypass. The invasive nature of open heart surgery often requires a lengthy and difficult recovery period, with a high risk of fatality in older and very ill patients. The percutaneous transcatheter aortic valve replacement involves a minimally invasive technique whereby the valve is placed in position inside the aorta with a catheter through a small insertion in the femoral artery, and expanded into contact with the host annulus by a balloon. The result is a far shorter recovery period and potentially less risk for the patient.