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ADVANCES IN ANTICALCIFIC AND ANTIDEGENERATIVE TREATMENT OF HEART VALVE BIOPROSTHESES

Proceedings of the Fourth Scientific Meeting of the International Association for Cardiac Biological Implants

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CHAPTER 3

BIAXIAL MECHANICAL BEHAVIOR OF BIOPROSTHETIC HEART VALVE CUSPS SUBJECTED TO ACCELERATED TESTING

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Abstract

The effects of in vivo cyclic loading on the mechanical behavior of porcine bioprosthetic heart valves are largely unknown, and are undoubtedly related to their continued poor long-term durability. To elucidate the mechanisms that eventually produce failure in porcine bioprosthetic heart valves, tension-controlled biaxial mechanical tests were performed on the cuspal tissue following 0, 1.4, 5.7, 10.1, 50, 100, and 200 million cycles of accelerated testing. A microstructural constitutive model was employed to estimate the changes in the effective mechanical behavior of the collagen fibers. Under a 60-N/m equibiaxial tension state, a trend toward increasing circumferential extensibility was found, with no trend in the corresponding radial extension. Simulations using the microstructural model demonstrated that slight specimen misalignments with respect to the biaxial test axes can potentially cause large variations in the measured extensibilities. When the model was used to fit representative data from a nonfatigued and a 200 million cycle fatigued valve, the effective fiber stiffness for the fatigued specimen was markedly lower than the nonfatigued specimen. Histologic studies revealed delaminations but no evidence of damage to the collagen fiber structure, suggesting that tissue damage occurs on a subfibril structural level. Overall, our results imply that long-term cyclic loading produces a gradual weakening of the collagen fiber network, potentially facilitating calcification and ultimately valve failure.

Introduction

Although bioprosthetic heart valves remain a popular choice for heart valve replacement, they continue to suffer from limited long-term durability. The mechanisms of valve material degeneration, especially when related to calcification, are not well understood.[1] In vivo structural deterioration of porcine aortic valve

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bioprostheses (PBHVs) is strongly time-dependent
creasing rapidly after 10 years postimplantation.[1,2]
pecially in bending, is believed to potentiate minera
chemical aspects of mineralization and valve deterio
tensively,[5-7] little work has been completed on the
cyclic loading of chemically treated valve tissue.[8]

At present, "adequate" fatigue life of an intact valv
testing. In this procedure, the PBHV is cycled at 15
rate in a pulsatile flow loop using sterile saline as
magnitude and loading pattern are believed to ade
environment, with failure patterns generally similar
cal studies of explanted tissue. In general, the stud
valves requires an understanding of the gradual mec
complete valve failure. A study of the subfailure me
progression with time (number of opening and clos
lish a quantitative representation of the fatigue pr
elucidate the predominant mechanisms and mecha

Broom[8-10] completed a series of studies on the effec
sion and flexure on circumferential strips of glutar
porcine mitral and porcine aortic valves. The circu
ened markedly with as few as 2.3×10^6 cycles, and t
increased numbers of cycles.[8] Collagen disruption
nounced flexure by 300×10^6 cycles. In porcine
disruption increased with the number of cycles and
10^6 cycles.[9] Low pressure fixed porcine aortic valv
tained little damage, whereas high pressure fixed v
strate damage similar to the mitral valve tissue. A c
the native collagen fiber crimp was found in all but
in which the crimp pattern was already lost during

These uniaxial studies provide the only informatio
mechanical loading of heart valve tissue found in
tissue strips, however, cannot mimic the heteroger
combined loading sequences found in the physiolog
the collagen fiber architecture is disrupted in unia
plex interactions between the axes are lost. Accele
preserves the 2-dimensional fiber network. Althoug
dent upon the individual valve geometry and testi
directly measured, the cuspal stresses more closely re
experienced in vivo. Materials tests performed on t
mined accelerated testing intervals could provide a
valve tissue subjected to realistic purely mechanical
of time. However, the gains of intact fatigue cyclin
the mechanics of the intact valve tissue, are not pre
ing is performed to assess the mechanical property

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