# Fiber pattern in heart valve leaflet material controls valve shape and stresses

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**Introduction:** Aortic valve leaflets are known to exhibit anisotropic mechanical response due to collagen fibers running in a preferred direction. Prosthetic valves and leaflet grafts for valve repair often incorporate leaflet materials with such reinforcement fibers for their load-bearing effects. We hypothesize that important features of the closed, loaded valve can be controlled by varying global patterns of these reinforcement fibers, and we use a finite element model of the aortic valve to study the effect of different fiber patterns on valve coaptation and leaflet stress.

**Materials and Methods:** We used a dynamic finite element model of the aortic valve [1] that incorporates a nonlinear anisotropic constitutive law for the leaflet material. Three different leaflet fiber patterns were modeled: (1) a pattern of straight fibers parallel to the leaflet free edge, (2) a pattern of concave-up fibers opening toward the free edge (Fig. 1A), and (3) a spatially varying pattern with concave-up fibers in the top portion of the leaflet gradually changing to concave-down fibers near the bottom (Fig. 1B). The finite element model was used to simulate the state of the closed valve under end-diastolic pressure. The simulated closed state of the valve was assessed by computing the area of leaflet coaptation and the stresses in the leaflets.

**Results and Discussion:** In the model with the concave-up pattern, the fibers tend to straighten as pressure loads the leaflets, causing in-plane deformation of the leaflet midline toward the free edge. This results in 12 % greater area of leaflet coaptation than in the model with straight fibers as well as a flatter closed valve surface corresponding to more efficient valve function. However, it also introduces a stress concentration at the point of attachment of the bottom of the leaflet to the aortic root (Fig. 1C). In the model with the spatially varying pattern, the concave-up fiber pattern near the free edge increases the coaptation area by 13% compared to the model with straight fibers while the concave-down pattern near the bottom of the leaflet removes the stress concentration at the point of attachment, moving it toward the center of the leaflet (Fig. 1D) where it can be counteracted by a local increase in leaflet thickness.

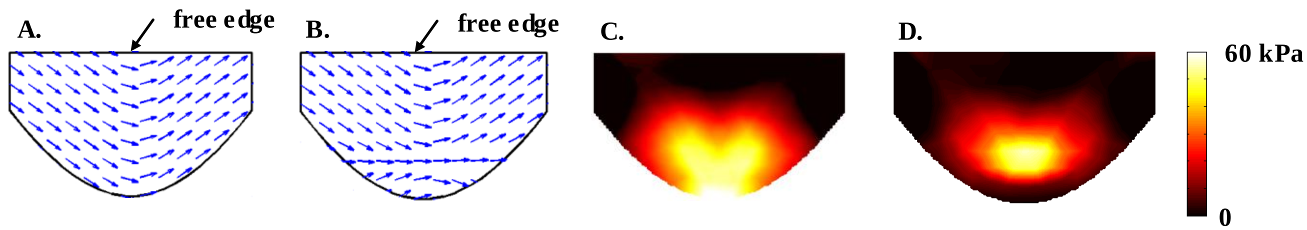


Figure 1. (A) Outline of one leaflet of the aortic valve model illustrating the concave-up fiber pattern. (B) Outline of one leaflet of the aortic valve model illustrating the spatially varying fiber pattern, with fibers becoming concave-down near the bottom of the leaflet. (C) Stress in a single leaflet of the closed model corresponding to the concave-up fiber pattern is mapped to color and plotted on the flattened, undeformed leaflet. (D) Stress in a single leaflet of the closed model corresponding to the spatially varying fiber pattern. Stress shown is the component of the second Piola-Kirchhoff stress tensor that is perpendicular to the fiber direction.

**Conclusions:** Specific fiber patterns in heart valve leaflet material can be exploited to control the shape of the valve under pressure load and the stress field within the leaflets. This represents a potent and previously unreported mechanism that can be used in the design of prosthetic heart valves and in the design of leaflet grafts to be used in surgical repair of valves.

**Acknowledgement:** This work was supported by NIH grant R01 HL073647-06.

**References:**

[1] Hammer PE et al. Ann Biomed Eng 2011; 39(6):1668-1679.