CHAPTER 30  ACTIVE ANTERIOR LEAFLET

Mitral valve leaflets have long been considered as passive flaps. The findings described in Chapter 29 suggest otherwise, but the possibility that the large stiffness of the anterior leaflet arises simply from leaflet residual strains that place passive leaflet elastic elements into the post-transitional nonlinear region of their stress-strain curves must be considered. In the nonlinear stress-strain curves obtained by May-Newman and Yin from excised mitral leaflets (Figure 29.1) this requires residual stretch of roughly 15% or more for the anterior leaflet.

For many reasons, we do not think that the behavior of hyperelastic (nonlinear) passive leaflet elements, with stress-strain relations such as those in Figure 29.1, can accommodate the findings in Chapter 29. One of these involves the leaflet stiffness response to neural stimulation; the STIM experiment of Itoh et al., as discussed in Chapter 29.

Because the saddlehorn stimulation (near Marker #22) was, by design, sub-threshold in intensity and too rapid for the heart to follow, the STIM pulses did not alter left ventricular hemodynamics (Figure 30.1) or mitral annular dimensions (Figure 30.2), but they nearly doubled both circumferential stiffness (Figure 30.3) and radial stiffness (Figure 30.4) throughout the entire anterior leaflet. While this alone strongly suggests active behavior (characteristic of contractile tissues), the maximal principal strain response to STIM poses an additional problem for any attempt to explain this result by invoking passive nonlinear elastic elements stretched into the post-transitional region. Note that maximal principal strain (Figure 30.5) was reduced by almost half with STIM. In Figure 29.1, passive stiffness is only increased if stretch is increased. With the STIM experiment, however, stiffness was nearly doubled with a reduction in strain by nearly half. This is typical behavior of active tissues, such as muscles, but incompatible with passive soft tissues having hyperelastic stress-strain curves similar to those displayed in Figure 29.1.

Further, Krishnamurthy et al. computed circumferential and radial moduli during 4 time-intervals during isovolumic relaxation for 3 beats in each of 8 hearts. Each time interval was analyzed independently, thus the results represented 192 separate, independent inverse finite element solutions, with no requirement for the combined time-steps to exhibit linear behavior. But the linearity of the stress-strain curve for each beat, characterized by the correlation coefficient \( r^2 \) associated with a linear regression analysis of each curve, was \( 0.995\pm0.003 \) (SD) for the circumferential curves and \( 0.994\pm0.003 \) (SD) for the radial curves. While this linear behavior is at odds with post-transitional elasticity of passive biological tissues (which is highly nonlinear as shown in Figure 29.1), and thus does not support the concept of passive hyperelastic leaflet tissue, it is even more remarkable because it strongly suggests that leaflet stiffness is insensitive to pressure and time-invariant during isovolumic relaxation. This is consistent with the virtually invariant anterior leaflet shape during IVR discussed in Chapter 9 and the nearly invariant anterior leaflet area during IVR discussed in Chapter 10. In many ways, then, the anterior leaflet is behaving much like a canvas sail that can bend to its near-final shape in a light breeze, yet hold this shape, with very little displacement or surface strain, in a gale. This behavior may contribute to the remarkable ability of this thin membrane-like anterior leaflet to withstand the high systolic pressures generated by the millions of contractile cells in the \(~1cm\)-thick left ventricular myocardium without buckling.

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**Figure 30.1** STIM experiment group mean (±SD) left ventricular hemodynamic parameters CTRL (before) and STIM (during) sub-threshold 320 min⁻¹ saddlehorn electrical pulse stimulation (N=7).

**Figure 30.2** STIM experiment group mean (±SD) mitral annular dimensional parameters CTRL (before) and STIM (during) sub-threshold 320 min⁻¹ saddlehorn electrical pulse stimulation (N=7).

**Figure 30.3** Individual and group mean (±SD) circumferential anterior leaflet moduli, CTRL (before) and STIM (during) sub-threshold 320 min⁻¹ saddlehorn electrical pulse stimulation. (N=7).

**Figure 30.4** Individual and group mean (±SD) radial anterior leaflet moduli, CTRL (before) and STIM (during) sub-threshold 320 min⁻¹ saddlehorn electrical pulse stimulation. (N=7).
FIGURE 30.5 Group mean anterior leaflet maximum principal strains before (CTRL) and during (STIM) sub-threshold electrical pulse saddlehorn stimulation at 320min⁻¹. (N=7).