CHAPTER 15 ANNULAR AND ANTERIOR LEAFLET AREA AND PERIMETER

Figure 15.1 shows mitral annular and anterior leaflet areas throughout sequential cardiac cycles for hearts H1-H6. The mitral annular area displayed in these figures is the projected annular area in the X-Y plane with the best-fit annular plane clamped to the X-Y axis for each frame. It is calculated as the sum of all the triangular areas from adjacent annular marker projections to the projection of the annular midpoint in that frame.

Note that annular area, greatest in diastole, begins to fall in all hearts well before the onset of left ventricular pressure rise and valve closure. This pre-systolic event is well-known and discussed in some detail in the next chapter. Here, we only mention that it results from annular contraction triggered by atrial excitation.

During systole, annular area may increase (H5, H6), decrease (H3, H4), or remain nearly unchanged (H1, H2). Tsakiris et al.\(^1\) showed, long ago, that annular area excursions throughout systole depend on specific hemodynamic conditions. In the next chapter we explore some of the balance-of-force mechanisms that may underlie this finding.

Annular area begins to increase well before mitral valve opening. In these six hearts, annular area started to increase an average of 67 ms (range 17-100 ms) before mitral valve opening, as left ventricular pressure is falling rapidly during isovolumic relaxation. We also discuss some of the mechanisms likely to underlie this phenomenon in the next chapter.

Appendix C provides the algorithm used to compute anterior leaflet area for each frame. In all six hearts, as shown in Chapter 10, anterior leaflet area was found to be constant to within a few percent throughout ejection. That leaflet 3D geometry is rather constant during ejection (as we have shown in previous chapters) makes this measurement possible and perhaps reasonably reliable throughout ejection, provided we are not missing too many regions of unmeasured curvature with our sparse marker arrays. If leaflet geometry is not constant, as is true anytime the valve is open throughout diastole, leaflet area is almost impossibly difficult to measure at the present time. This can be seen as the reproducible, but very noisy leaflet area computation during diastole, at a time when external forces are highly unlikely to be changing leaflet area in the open valve. To measure leaflet area reliably throughout diastole will require measuring many hundreds of specific points on the leaflet surface with a 3D resolution of about 0.1 mm at each site. Any studies of leaflet stretching or growth involving leaflet area measurements during diastole in the beating heart must be treated with the utmost skepticism.

The noisy area measurements observed during diastole in all six hearts in this study certainly reflect leaflet shape change, far more than leaflet area change, as the leaflet cracks like a whip, doubles back on itself, and flips curvatures on a ms time scale. The problem of diastolic leaflet area measurement is not unlike measuring the surface area of a flag waving and cracking in a stiff breeze blowing in random directions.

Note that leaflet and annular area time-histories are not correlated. This highlights an important fact, namely that the mitral annulus and anterior leaflet are almost completely uncoupled. The only place they are coupled is at the trigone hinge, and this hinge is almost unmoving. This independence of leaflet and annulus mechanics almost dooms attempts to link leaflet stresses or strains to annular shape and motion.

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Figure 15.1 Mitral annular and anterior leaflet areas. LVP = left ventricular pressure.
Figure 15.2 Mitral annular trigone and contractile region perimeters and anterior leaflet edge perimeters for hearts H1-H6. LVP=left ventricular pressure.
Figure 15.2 shows annular trigone perimeters, annular contractile region perimeters, and anterior leaflet edge perimeters for hearts H1-H6. Trigone-trigone annular perimeters (Markers #29-15-39-22-23-21-24 path) are almost invariant, as are anterior leaflet edge perimeters (Markers #29-42-43-44-38-45-46-47-24 path). Annular contractile perimeters (Markers #29-16-28-17-27-18-26-18-25-20-24 path), in contrast, are quite mobile, increasing in length from systole to diastole by some 12-19% with the same timing (described above) as mitral annular area change. Once again, note that variations in annular contractile perimeters and anterior leaflet edge perimeters are uncorrelated, further emphasizing the disconnect between the mitral annulus and the anterior mitral leaflet.

Figure 15.3 compares the length-variations throughout the cardiac cycle of 16 regions around the mitral annular perimeter. The markers defining these regions are numbered in Figure 15.4 and the annular regions defined by these markers in Table 15.1. In each heart, 3D marker coordinate data were used to compute regional lengths between each adjacent pair of annular markers around the annular perimeter. The three-beat mean and standard deviation for the length of each region was obtained, then the coefficient of variation (standard deviation divided by the mean) computed.

As can be seen in Figure 15.3, regional annular length changes displayed two peaks, a sharp peak for regions 3 and 4 in all hearts, and a more diffuse peak for regions 7 and 8. The annular location of the first peak, surrounding Marker #17, is shown in red in Figure 15.4; the second, surrounding Marker 19 in blue. We will discuss these regions further in future chapters, but will only indicate here that the first (red) region is close to the interface between posterior leaflet P1 and P2 scallops and the second (blue) region near the interface between posterior leaflet P2 and P3 scallops. The dynamics of these interface regions likely play a role in the peak length changes in these regions. Note the relatively lower length changes of regions 10-16 and 1, comprising the entire annulus from Marker #20 counterclockwise to Marker #16, strongly suggesting the influence of the relatively immobile trigone region. Note also the relatively lower length changes in regions 5 and 6, on either side of Marker #18, possibly reflecting the fact that this region includes the central meridian of the central posterior leaflet scallop.

Table 15.1

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Figure 15.3 Annular perimeter segmental coefficients of variation. See text.