This chapter analyzes papillary muscle mechanics for a mythical “PORVINE” heart created by superimposing PORcine and oVINE data. Porcine data were obtained from the LVP and papillary force curves in Figure 3 of Askov et al.\(^1\), digitized and interpolated with a cubic spline function. Ovine data are from our F10 heart, selected solely because the F10 LVP waveform was very similar to the LVP curve shown in Askov et al.\(^2\) Systolic duration was roughly matched by assigning a sampling interval of 15 ms to the ovine data, rather than the actual sampling interval of 16.67 ms. The porcine data were then sampled at these same 15 ms intervals. The resulting LVP, papillary force, and papillary length curves are shown in Figure 22.1, with magnitudes scaled or translated, as necessary, to fit the <0-9> ordinate. Additional ovine data, with time- but no magnitude-scaling, are shown in Figures 22.2, 22.5, and 22.6. Figure 22.7 shows the original data used to construct Figure 22.1.

This PORVINE construction had two purposes. The first was to emphasize a point made in Chapter 21, namely, that at the moment of mitral valve closure, with near-maximum LVP pressing on the closed leaflets, the chordae experience very little force, about 8% and 1%, respectively, of the maximum force developed in mid-systole by the anterior and posterior papillary muscles. Note, in Figure 22.1, that MVC is at 120 ms, but \(F_{\text{Ant}}\) is <1.5N and \(F_{\text{Post}}\) is <0.5N at this time. This supports the concept that the mitral valve leaflets in the closed valve are nearly self-supporting, without requiring major chordal/papillary forces to maintain valve closure.

The second reason for this PORVINE construction was a crude attempt to understand the behavior of papillary force-length loops in the beating heart. Figures 22.3 and 22.4 show these resulting loops for the anterior and posterior papillary muscles, respectively.

In Chapter 21, we showed (Table 21.1) that papillary muscle shortening in the F1-11 hearts ranged from 11-21%. By chance, heart F10, the one picked solely for its LVP wave-shape and analyzed in this chapter, exhibited 21% shortening in both papillary muscles. These values are large, but less than the values up to 30% measured by Grimm et al.\(^2\) using radiopaque marker pairs in tranquilized canines.

Slack sarcomere length in cardiac muscle is 1.9\(\mu\)m. Wu et al.\(^3\) found that the giant protein titin is the primary contributor to passive tension of cardiac muscle and that sarcomere lengths in cardiac muscle are limited by both collagen and titin to about 2.4\(\mu\)m (below the 2.5\(\mu\)m length where collagen is damaged). This suggests that the 21% papillary shortening in F10 is associated with sarcomeres operating over their full range of lengths (100*(2.4-1.9)/2.4)) and such proposed sarcomere lengths are shown at the top of Figures 22.3 and 22.4, assuming that maximum papillary length is associated with maximum \((i.e., 2.4\mu m)\) sarcomere length. Rodriguez et al.\(^4\) found that cardiac muscle sarcomeres in beating hearts can shorten from 2.4\(\mu\)m down to as much as 1.7\(\mu\)m (29%), but Wu et al.\(^3\) find that, below slack length, titin compression restores sarcomere lengths back to 1.9\(\mu\)m.

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CHAPTER 22 PAPILLARY CHIMERA

22-2

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Figure 22.3 "PORVINE" anterior papillary force-length loop. Numbers by data points=time(ms); IVC=isovolumic contraction, MVC=valve closure; IVR=isovolumic relaxation; MVO=valve opening. Sarcomere length estimates (top).

Figure 22.4 "PORVINE" posterior papillary force-length loop. Numbers by data points=time(ms); IVC=isovolumic contraction, MVC=valve closure; IVR=isovolumic relaxation; MVO=valve opening. Sarcomere length estimates (top).
CHAPTER 22 PAPILLARY CHIMERA

Figure 22.5 Left ventricular pressure-volume loop for the F10 ovine beat shown in Figure 22.2.

Figure 22.6 Enlarged scale display of the F10 ovine beat shown in Figure 22.2. Nomenclature as in Figure 22.2.

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Figure 22.7 (Left Panel) Anterior and posterior papillary muscle force in relation to LVP. Adapted from Fig. 3 of Askov et al.¹ (Right Panel) Anterior and posterior papillary muscle length in relation to LVP.