Damped and Ventricularized Coronary Pressure Waveforms

Lloyd W. Klein, MD and Divya Korpu, MD

ABSTRACT: Although the terms ventricularization and damping are commonly used in the cath lab and are widely recognized as indicating possible flow limitation due to catheter position, their hemodynamic origins and mechanism have not been well studied. Often, they are thought to be synonymous terms. Both patterns are due to distortion of the normal harmonic frequencies of wave conduction. Pressure damping is seen when the outer diameter of the catheter is larger than the ostial diameter or when the tip of the catheter is pressed against the vessel wall. It is characterized by an abrupt decline of mean coronary pressure with narrow pulse pressure and delayed upstroke and downstroke. Conversely, ventricularization is seen when the catheter tip is advanced into an ostial stenosis, partially obstructing flow, and is characterized by a steep decline of pressure in diastole with large pulse pressure, absence of the dicrotic notch, and appearance of presystolic positive deflection. A ventricularized pressure waveform can be considered a hybrid between coronary arterial pressure and coronary wedge pressure.

KEY WORDS: hemodynamics, harmonics, pressure damping, ventricularization, diagnostic catheterization

Early recognition of an altered pressure waveform helps to avoid catheter-related coronary dissection and ischemia during coronary angiography. These artifactual pressure waveforms are often referred to as “damped” or “ventricularized.” When the pressure transmission is compromised from either a coronary stenosis surrounding the catheter tip, or the tip is not coaxially located but rather rests against the vessel wall, the aortic waveform may be distorted. Clinically, cath lab personnel often do not strictly distinguish between the resulting patterns, using these terms interchangeably. Indeed, both reveal possible flow limitation due to the catheter, indicating the potential for vessel damage; in either circumstance, the catheter should be immediately withdrawn.

This review considers the flow dynamics involved in producing these patterns and distinguishes between them in terms of their specific implications. A full comprehension of these abnormal waveform patterns requires a basic understanding of pressure recording and flow propagation.

Waveforms and Harmonics

Left ventricular (LV) contraction produces pulsatile flow in the arterial system, with each heartbeat generating a pulse wave. The pressure waveform produced repeats periodically, creating a sinusoidal wave pattern, with each pulse wave having a specific frequency. Energy is transferred between the flowing blood and the vessel walls during pulsatile blood flow, resulting in storage and dissipation of elastic energy. Each pulsatile flow generates vibrations in the arterial system, creating a state of harmonic motion in blood vessel walls throughout the arterial vasculature. A harmonic is a wave whose frequency is a positive integer multiple of the frequency of the original wave (the “fundamental frequency,” also called the 1st harmonic). A Fourier series can be used to represent the composition of any periodic waveform as a sum of fundamental and harmonic components. The first 4–5 harmonics contain most of the information in arterial waves.

Coronary arterial flow is influenced both by the diastolic pressure at the coronary ostium as well as the distal pressure (microcirculation) ends of the vessel. Distal pressure is generated by the effect of contraction and relaxation of myocardium on intramuscular small arteries and arterioles. Using wave-intensity analysis, each wave can be represented as a product of the change in pressure and flow velocity at any point in the cardiac cycle. Six waves have been identified within the cardiac cycle. These have been defined by their origin (proximal, forward-traveling waves or distal, backward-traveling waves) and effect on blood flow (expansion/suction waves or compression/pushing waves). Coronary blood flow peaks in diastole, attributable to the dominant backward-traveling suction wave generated by myocardial relaxation leading to microcirculatory decompression.

Fluid Pressure Recording

Accurately recording the pressure waveform requires a continuous column of liquid connecting arterial blood to a pressure transducer (hydraulic coupling). The catheter, tubing, fluid, and transducer together constitute the recording system. Every system has its own natural oscillatory, or resonant, frequency. The dynamic response of a hemodynamic-monitoring system is defined by its natural frequency and the damping coefficient. The natural frequency indicates how fast the pressure-monitoring system vibrates when detecting the signal of the arterial pressure pulse.

If the resonant frequency of the recording system coincides with one of the frequencies/harmonics comprising the arterial waveform, resonance and subsequent distortion of the signal
will occur. The components of an invasive arterial pressure monitoring are designed to maintain the natural frequency above 40 Hz, which is higher than the frequencies comprising the arterial waveform (10-30 Hz), thus minimizing resonance.

Harmonic distortion occurs when the recording system is faulty, causing its harmonic components to be differentially impacted. One distortion pattern is termed “damping.” Damping reduces the resonant frequency of the pressure-transducing system. An underdamped signal has increased resonance and exaggerates oscillations, often recognized as catheter “fling,” or spike-like signals. Overdamping is recognized when the signal takes a long time to reach its true pressure (equilibrium), and is characterized by undershooting the actual pressure and minimizing the oscillations of the wave. With an overdamped system, the waveform loses its characteristic landmarks and appears unnaturally smooth, with a diminished or absent dicrotic notch resulting in a rounded appearance. Air bubbles most often blunt, or damp, propagation of the signal, causing an overdamped waveform and erroneous pressure readings.4

Coronary Catheter Pressure-Wave Damping

As a principle of physics, what cardiologists in the catheterization laboratory call “damping” is in fact overdamping. Overdamping results in falsely low systolic and falsely high diastolic pressure readings.5 When the cause is not within the recording system but rather a signal of occlusion at the distal catheter end, damping is a sign of severe partial obstruction.

Pressure damping may occur when (1) the outer diameter of the catheter is almost as large, or larger, than the ostial diameter; or (2) when the tip of the catheter is pressed against the vessel wall. Severe obstruction at the distal end of the catheter produces flow limitation sufficient to decrease volumetric displacement of the fluid-filled pressure system, resulting in a diminution of its natural frequency and thus preventing all of the harmonics of wave propagation from being detected. Consequently, the normal arterial-wave pattern is distorted, with a narrow pulse pressure and a delayed upstroke and downstroke (Figures 1 and 2).

Her et al6 found that the incidence of pressure damping in 2926 consecutive patients was 2.3%, among whom the incidence of true atherosclerotic ostial stenosis was 40.8%. Catheter-induced coronary spasm was the most common reversible cause of damping.

Ventricularization

Ventricularization can be considered a less-severe degree of damping that results in a characteristic shape of the distorted wave where diastolic pressure drops to a greater extent than the systolic. It occurs when the catheter tip is advanced into an ostial stenosis and/or when the diameter of the coronary artery lumen matches, or is slightly larger than, the diameter of the catheter.7 It signifies partial obstruction to antegrade flow, such that the catheter tip is “wedged” inside the lumen.17 The origin of the pattern is that both systolic and diastolic flow are impaired, but there is substantial flow in systole. When the pressure transmission is compromised in this manner, the aortic waveform simulates a ventricular pressure waveform, with a large pulse pressure and low diastolic pressure (Figure 3).

Ventricularization is characterized by a steep decline of pressure in diastole with an absence of the dicrotic notch and an appearance of a presystolic positive deflection, which
FIGURE 3. Ventricularization occurred during left main catheterization in a 70% ostial stenosis and a 90% ostial left anterior descending stenosis distal to the catheter tip. Note a marked fall in diastolic pressure with a large pulse pressure.

is consistently related to atrial contraction. This “a” wave is generated by the motion of ascending aorta during atrial systole that is inconspicuous in normal ascending-aortic pressure tracings.1,7 It is easier to identify this waveform during ventricularization because the slope of intracoronary pressure is shallow at the time of appearance of this wave. Traditionally, it has been erroneously taught that this wave pattern is the LV pressure.7 Although the ventricularized pressure waveform resembles the LV waveform to a certain extent, it bears only superficial physiological correlation.1 Reproduction of this pattern was produced in an animal model by placing a balloon-tipped catheter into the left main coronary artery and inflating the balloon to produce partial occlusion.7 Thus, the cause of this pattern is “wedging” in part. However, it is not an accurate reproduction of the intramural pressure.1 The observed diastolic pressure is much higher than the true LV diastolic pressure with less systolic distortion.

The ventricularization waveform is actually a hybrid between coronary arterial pressure and the coronary wedge pressure. When the LV contracts, the muscles compress the arterioles. This produces a ventricular-type waveform, because it reflects the ventricle squeezing blood forward within the intramural arteries. Therefore, it is a hybrid pattern partially created by systolic flow due to myocardial contraction within the small arteries and arterioles.

Right vs Left Coronary Artery Obstruction Patterns

The normal right coronary artery pressure waveform has roughly equal systolic/diastolic flow because right-ventricle contraction does not create high resistance to systolic flow. Thus, myocardial flow is predominantly balanced proximally, and primarily diastolic distally. Hence, it is observed that at the right coronary artery ostium, damping is common but ventricularization is rare.

This explanation also accounts for why ventricularization occurs primarily in the left main rather than in the right coronary – because the LV has more muscle mass and thus more diastolic flow than the right coronary artery. This is why ventricularization is not often seen when the catheter tip is inadvertently advanced against the wall of the coronary artery.

Conclusion

Continuing to inject contrast despite damping or ventricularization may lead to ventricular fibrillation or dissection and thrombosis of the proximal coronary artery. When damping or ventricularization is noted, it is best to withdraw the catheter and reposition it or gently inject contrast while withdrawing the catheter. Precautions, like performing a non-selective aortic cusp “flush” injection, and minimizing the number of injections to assess ostial stenosis severity, may help to prevent complications.1,6,7 A gentle contrast injection as the catheter is being withdrawn may allow the stenosis to be safely identified.


References