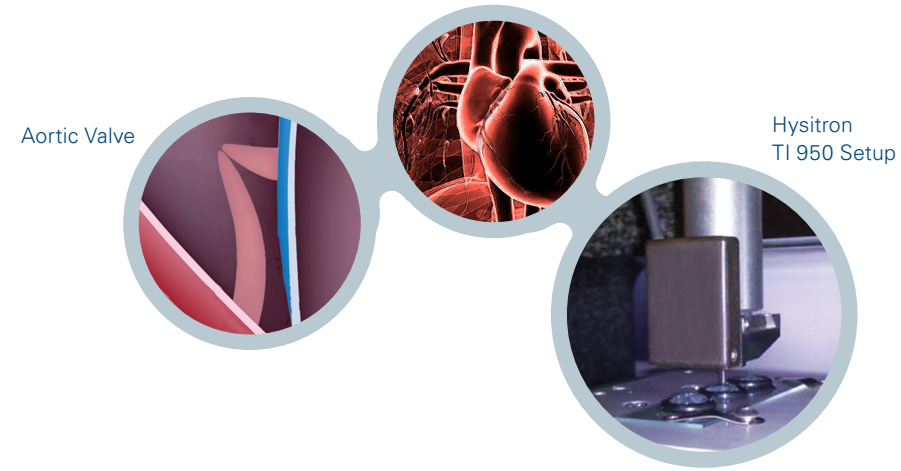

Application Note #1524

Highly Localized Characterization of Aortic Valve Tissue

When a patient has a failing aortic valve that cannot be repaired, a cardiac surgery, known as aortic valve replacement, is used to replace the damaged valve with an alternate, healthy valve. The two common types of valve conditions are known as stenosis (valve does not open properly) and regurgitation (valve does not close properly). Currently there are two types of open heart replacement surgeries that can be performed on a patient in order to replace faulty valves. The first type of surgery uses mechanical valves that are made of synthetic materials. These valves are made to outlast the patient's life; however, blood tends to stick to these mechanical valves and anticoagulants (blood thinning medication) are required for the duration of the patient's life. The second type of surgery uses biological valves, commonly known as tissue valves, to replace the faulty valve. These tissue valves are taken from animals, donated human tissue, or sometimes from the same patient. Tissue valves do not require additional medication, but they eventually will wear out and need replacement; this life cycle is typically 10-15 years in less active people with low blood demands. Very little is known about the mechanical properties of aortic valve tissue. A better understanding of these tissues can lead to general understanding of each tissue component, knowledge that can later be used to create biomimetic tissues. This application note discusses how accurate measurement of the mechanical properties of the valves can help acquire this knowledge, leading ultimately to the creation of more accurate models.

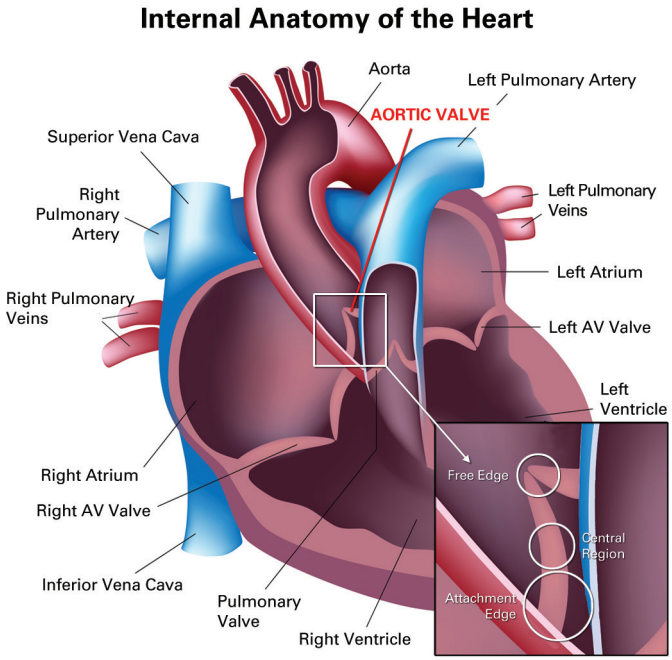

Figure 1. Cross-sectioned human heart schematic showing the location of the aortic valve. The three regions (Attachment Edge, Central Region, and Free Edge) are shown.

Methods

A Hysitron® TI 950 TriboIndenter® equipped with an xZ 500 Extended Displacement Stage was used to perform micro-indentation tests on three porcine aortic valve samples. The tissues were sectioned into 500 µm thick leaflets and adhered to microscope slides using CellTak (BD Biosciences)

adhesive. All testing was performed in-vitro using phosphate buffered saline (PBS) fluid. All tests were performed in displacement-controlled feedback mode using a diamond fluid cell Berkovich probe to reach approximate peak displacements of 15 µm. Each test began with the probe out of contact with the sample in the PBS solution in order to determine the precise point of contact with the tissue. A hold segment of 20 seconds was used for all tests. Three regions were tested on each valve, as seen in Figure 1. Indent locations were selected using the TriboIndenter's optical microscope. The first region tested, the Attachment Edge, is where the valve attaches to the vessel wall. The function of the second area tested, the Central Region, is to withstand the pressure that is caused when the valves open and close. The third region tested was the Free Edge, whose main purpose is to seal the valve.

Results

Representative force versus displacement curves from each region of Valve 1 are shown in Figure 2. Each region required significantly different forces to displace the probe to similar depths. Figure 3 displays the reduced modulus values of all three valves as a function of testing region. Average reduced modulus results for each region of the three valves are displayed in Table 1.

Overall, micro-indentation tests performed in the Free Edge region of all three valves yielded lower reduced modulus values. The highly elastic nature of the Free Edge can be attributed to the valve-sealing function of this region, which requires substantial flexibility over millions of cardiac cycles.

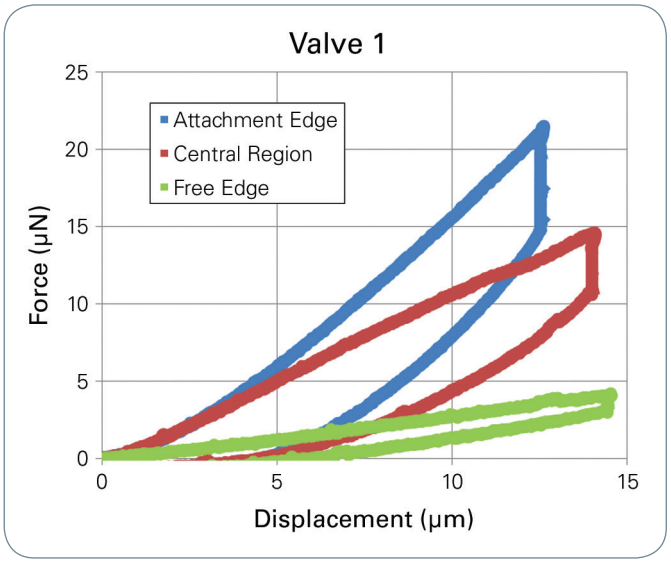

Figure 2. Representative force versus displacement curves from each region of Valve 1.

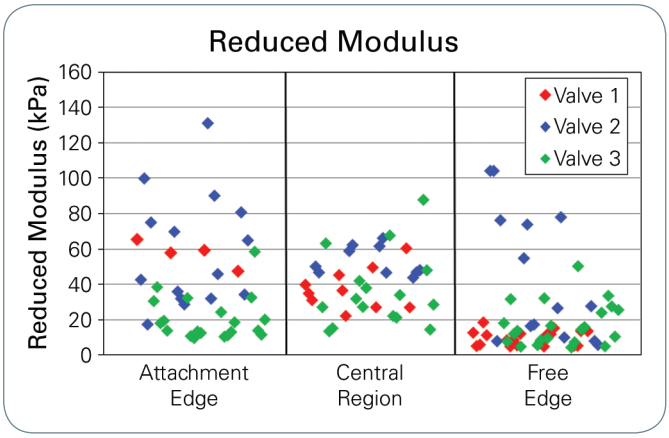

Figure 3. Reduced modulus values from the series of indents on each region of Valve 1, Valve 2, and Valve 3.

Reduced Modulus (kPa)	Attachment Edge	Central Region	Free Edge
Valve 1	57.42 ± 7.37	37.26 ± 11.75	9.82 ± 4.21
Valve 2	58.64 ± 32.06	53.07 ± 8.16	43.72 ± 36.75
Valve 3	20.56 ± 12.41	36.36 ± 21.04	17.24 ± 11.99
All Samples	38.99 ± 28.76	41.25 ± 17.26	21.21 ± 23.72

Table 1. Average reduced modulus values for the series of indents in each region of Valve 1, Valve 2, and Valve 3.

Valve 2 yielded higher mechanical properties than the other two samples. The variability from sample-to-sample was expected, due to the variability of fiber alignment from valve-to-valve. A larger sample size would be necessary to confirm or refute trends in the data.

Conclusion

This preliminary study on porcine aortic valve specimens yielded promising results towards determination of a practical test method to understand mechanical behavior of soft tissues in small volumes. The reduced modulus values collected were in the range of ~5 to 100 kPa, which are in-line with modulus values of 2 to 14 kPa collected previously using tensile testing in both the radial and circumferential directions.[1]

The minimal sample preparation required and the ability to test in fluid makes nanoscale-to-microscale indentation a suitable testing procedure for these very soft tissues. In addition to the calculation of reduced modulus, nanoscale and microscale indentation can also be used to study the stress relaxation properties, hysteretic material behavior, or time-dependent properties of aortic valve tissues.

References

1. Vesely, I., et al, *J. Biomec.*, **25** (1992) 101-109 + 111-113.

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