# BDL/Aneuvas 3D Print Testing

# Testing Plan Assignment

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# 1 Design Requirements Summary

Paying close attention to the design requirements is important in making sure that the design will satisfy the client's wishes in the future. These design requirements are split into the two sections, the customer requirements, and the engineering requirements. The customer requirements are specific requests from the client on how they want the final product to be. The engineering requirements are the values that can be compared and calculated, helping in the verification of the customer requirements. The customer requirements are as follows:

- Size (CR-1)
- Easy to Connect (CR-2)
- Soft Exterior/Hard Interior (CR-3)
- Lightweight (CR-4)
- Material Selection (CR-5)
- Retains Shape (CR-6)
- Similar Properties to Organic Tissue (CR-7)
- Cost Within Budget (CR-8)

Similarly, the engineering requirements are as follows:

- Stiffness (ER-1)
- Thickness (ER-2)
- Compressive Modulus (ER-3)
- Frequency (ER-4)
- Poisson's Ratio (ER-5)
- Compliance (ER-6)
- Angular Acceleration (ER-7)
- Radial Force (ER-8)
- Layering (ER-9)
- Pressure (ER-10)
- Shear Modulus (ER-11)
- Hardness (ER-12)
- Strain (ER-13)
- Coefficient of Friction (ER-14)

# 2 Top Level Listing Summary

## *2.1 Tests vs. Relevance*

Table 1 below provides the list of all eight tests that were performed during the length of the school year. These tests are that of shear, compression, hardness, Poisson's ratio, radial force, tension, compliance, and lubricity. Each of these tests corresponds with certain design requirements that were set in place, whether that was set by the client or by other engineering requirements. The table displays which design requirements were satisfied for each of the eight tests performed.

Table 1: Tests vs. Relevance

| Experiment/Test | Relevant DRs |
|---|---|
| T1 - Shear | CR-5, CR-6, CR-7, ER-4, ER-7, ER-11 |
| T2 - Compression | CR-5, CR-6, CR-7, ER-2, ER-3, ER-4, ER-7 |
| T3 - Hardness | CR-5, CR-6, CR-7, ER-12 |
| T4 - Poisson's | CR-5, CR-6, CR-7, ER-4, ER-5, ER-7 |
| T5 - Radial Force | CR-5, CR-6, CR-7, ER-4, ER-7, ER-8 |
| T6 - Tension | CR-5, CR-6, ER-2, CR-7, ER-1, ER-4, ER-7 |
| T7 - Compliance | CR-5, CR-6, CR-7, ER-2, ER-6, ER-10 |
| T8 - Lubricity | CR-5, CR-6, CR-7, ER-7, ER-14 |

# 3 Testing Plans

## *3.1 Test/Experiment Summary*

The eight tests that will be performed and analyzed are used to assist the team in seeing if the chosen design complies with the Design Requirements (DR) set by the client. Each test is used to determine if the chosen design fulfills a certain DR. Most of the DR have a specific test that is used to determine if it has been fulfilled by the test and will be further described later in the section.

Here are the eight tests that will be conducted:

- Shear
- Compression
- Hardness
- Poisson’s Ratio
- Radial Force
- Tension
- Compliance
- Lubricity

All of the equipment for the tests is provided by BDL and the team rents out the equipment needed for the certain tests they are performing on that day. The general equipment needed for seven of the tests are the Rheometer, the specific Rheometer fittings for certain tests, test tubes, syringes to transfer fluid, surgical scissors, a catheter, suture, and saline (PBS). Only the compliance test requires different equipment: the fluoroscope, Conray, Syringes, Suture, scissors, and gloves. Safety equipment for the fluoroscope is provided: radiation detector, lead vests, and thyroid covers.

The only variable that will be isolated for the tests are the two chosen ratios that the printed samples are since the characteristic of those ratios are what is being tested. In all the preformed tests, there will be two ratios being tested, with each sample of either ratio being soaked in a solution for four days. This is to ensure that the tests performed are correct and supply relevant data relating to the ratio changes.

The variables that need to be calculated from the results of these tests are the shear modulus, frequency, compressive modulus, coefficient of friction, compliance, stiffness, angular acceleration, hardness modulus, strain percentage, Poisson's ratio, and the radial force of the samples. The desired range of these variables was put in place by our client and each test will show if the chosen ratios place the samples within the desired range or bring them closer than previously performed tests.

## *3.2 Procedure*

## *3.3 Tests and Relations*

Listed below are the tests being conducted by Team BDL/Aneuvas in accordance with the initial project proposal and standard operating procedures (SOPs) used by BDL for each test. The SOPs help to ensure the quality and replicability of tests being conducted. The customer requirements and engineering requirements (CR/ERs) are in accordance with the client meetings, House of Quality, and design analysis conducted Fall 2021. The SOPs are multi-page procedures provided by BDL and are being summarized below. These SOP synopses and ER/CRs met are from our Final Proposal Report Fall '21, where each of the original five tests are discussed in more detail.

### 3.3.1 Shear Test

#### *3.3.1.1 CR/ERs Met*

The results of the shear test will validate that our design is feasible by comparing the mechanical properties of the donor research with our studies. By varying the ratios of the polymers, it is possible to tweak the mechanical properties and even mimic the mechanical properties of human tissue. Several of our clients' requirements have been met here, including the specimen retaining its shape after testing, using the right material to make the specimen our client wanted, and becoming closer to being like organic tissue [1]. The engineering requirements that this test meets are seeing if the measured shear modulus lies within a range of 5 to 30 KPa and the frequency range of 0 to 20 rad/s.

- Shear Modulus (KPa)
- Frequency (rad/s)

#### *3.3.1.2 Standard Operating Procedure(s)*

To perform this test, a small piece of sandpaper will be placed into the rheometer and a disk sample will be placed on top of it. The rheometer will then apply a continuous oscillating force or direct shear to the sample. By measuring the shear modulus of the sample, it can be compared to the shear properties of human vessels and changes can be made accordingly [1][2].

### 3.3.2 Compression Test

#### *3.3.2.1 CR/ERs Met*

The results of the compression tests will validate that our design is feasible by comparing the mechanical properties of the donor research with our studies. Several of the same client requirements as stated above are met by this test, as well as meeting the engineering requirements of seeing if the measured compressive modulus lies within the range of 90,000 to 500,000 KPa and has a frequency range of 0 to 20 rad/s [1].

- Compressive Modulus (KPa)
- Frequency (rad/s)

#### *3.3.2.2 Standard Operating Procedure(s)*

To perform this test, a small piece of sandpaper will be placed into the rheometer and a disk sample will be placed on top of it. The rheometer will then apply an axial force of 0.9-1.4 N onto the sample,

measuring how resistant the sample is to the force. By measuring the elastic modulus of the sample, it can be compared to the shear properties of human vessels and changes can be made accordingly [1][2].

### 3.3.3 Lubricity Test

#### *3.3.3.1 CR/ERs Met*

The results of the lubricity tests will validate that our design is feasible by comparing the mechanical properties of the donor research with our studies. By varying the ratios of the polymers, it is possible to tweak the mechanical properties and even mimic the mechanical properties of human tissue. Several of our clients' requirements have been met here, using the right material to make the specimen our client wanted and becoming closer to being like organic tissue [1]. The engineering requirements that this test meets are seeing if the measured coefficient of friction measured lies within the range of 0.15 to 0.5.

- Coefficient of Friction

#### *3.3.3.2 Standard Operating Procedure(s)*

Before the test can proceed, a table must be placed perpendicular to the rheometer with a plastic container containing a 3D printed wheel placed some distance away, the desired distance of the container changes depending on the sample, and a clamp on the clamped to the other end of the table. A syringe filled with water will be used as a weight and will freely hang off the clamp when the wire is tied to it. A tube-shaped sample is secured to the wheel and surgical wire is connected to the rheometer, through the sample and connected to a syringe, creating two triangle shapes. Once everything is set up, the test can begin. The rheometer will gently pull on the wire and measure the amount of resistance the wire is experiencing while moving, allowing the friction of the interior of the sample to be found. By finding the friction property of the sample, it can be compared to the friction property of the human vessels to see if there are any similarities or if any changes need to be made to help the sample values get closer to the human values [1][2].

### 3.3.4 Compliance Test

#### *3.3.4.1 CR/ERs Met*

The results of the compliance tests will validate that our design is feasible by comparing the mechanical properties of the donor research with our studies. By varying the ratios of the polymers, it is possible to tweak the mechanical properties and even mimic the mechanical properties of human tissue. This test meets all the same client requirements as stated above as well as meeting the engineering requirements of seeing if the measured compliance lies within a range of 0 to 0.006 cm^3/mmHg and the pressure is within a range of 80 to 320 mmHg [1].

- Compliance (/mmHg)
- Pressure (mmHg)

#### *3.3.4.2 Standard Operating Procedure(s)*

To perform this test a tube-shaped sample will be secured a pressure transducer and syringe, one on either side. The sample will be filled with thick liquid until there is no air left inside and placed under the fluoroscope. Slowly fill the sample with more liquid until the pressure gage reads 80mmHg, take a picture with the fluoroscope and then increase the pressure by 40mmHg, take another picture. Repeat this step until the pressure has reached 280mmHg. Send the images taken during this process to the rheometer in the lab. This helps see how much the sample can swell from internal pressure. By doing this procedure, the compliance properties of the sample can be compared to the properties of the human vessel and necessary changes can be made [1][2].

### 3.3.5 Tension Test

#### *3.3.5.1 CR/ERs Met*

The results of the tension tests will validate that our design is feasible by comparing the mechanical properties of the donor research with our studies. By varying the ratios of the polymers, it is possible to tweak the mechanical properties and even mimic the mechanical properties of human tissue. This test meets all the same client requirements as stated above [1]. The engineering requirements that this test meets are to see if the measured stiffness (E) lies within a range of 100 to 20,000 KPa and the angular acceleration is within 0 to 20 rad/s.

- E (KPa)
- ω (Rad/s)

#### *3.3.5.2 Standard Operating Procedure(s)*

To perform this test, a rectangular sample is secured in the rheometer and pulled until it experiences an axial force of 100mHg. The procedure is done again but this time the sample will experience an axial force of 160mmHg. Measuring the tension properties of the samples informs the team on how close the prototypes are to the properties of human vessels [1][2].

### 3.3.6 Hardness Test

#### *3.3.6.1 CR/ERs Met*

The results of the hardness tests will validate that our design is feasible by comparing the mechanical properties of the donor research with our studies. By varying the ratios of the polymers, it is possible to tweak the mechanical properties and even mimic the mechanical properties of human tissue. Several of our clients' requirements have been met here, including the specimen retaining its shape after testing, aiming for a specific stiffness and compressive modulus values, using the right material to make the specimen our clients wanted, and becoming closer to being like organic tissue [1]. The engineering requirements that this test meets are seeing if the measured Hardness modulus lies within the range of 1,000 to 5,000 KPa and the strain is within 55 to 90%.

- Modulus (KPa)
- Strain (%)

#### *3.3.6.2 Standard Operating Procedure(s)*

To perform this test, a metal ball is attached to the 8mm plate to create an indenter. The rheometer is then loaded to 0.9-1.0N of Force. The researcher then conducted the test by allowing the rheometer to compress the sample at a given rate. The release of energy as the sample is destroyed is recorded for the sample hardness [1][2].

### 3.3.7 Poisson’s Ratio Test

#### *3.3.7.1 CR/ERs Met*

The results of the compliance tests will validate that our design is feasible by comparing the mechanical properties of the donor research with our studies. By varying the ratios of the polymers, it is possible to tweak the mechanical properties and even mimic the mechanical properties of human tissue. The same clients' requirements as said above have been met here [1]. The engineering requirement that this test meets is to see if the measure Poisson’s ratio lies within the range of 0.30 to 0.50.

- Poisson’s Ratio (Unitless)

#### *3.3.7.2 Standard Operating Procedure(s)*

To perform this test, the rheometer is equipped with DinoCapture and a mirror plate. The sample is placed in the center of the camera field of view and the camera is calibrated based on known measurements. The sample is then compressed with a known force over a known period. Axial displacement is measured by the calibrated DinoCapture program and results are filled into Excel for analysis. The sample must be wicked around with PBS to ensure that it stays wet and the bottom that touches the glass is clearly visible to the camera [1][2].

### 3.3.8 Radial Force Test

#### *3.3.8.1 CR/ERs Met*

The results of the radial force tests will validate that our design is feasible by comparing the mechanical properties of the donor research with our studies. By varying the ratios of the polymers, it is possible to tweak the mechanical properties and even mimic the mechanical properties of human tissue. The same client requirements as stated above have been met here [1]. The engineering requirement that this test meets is seeing if the measured radial force lies within the range of 0.003 to 0.01 N/mm.

- Radial Force (N/mm)

#### *3.3.8.2 Standard Operating Procedure(s)*

To perform this test, a tube sample is placed centered on the rheometer. The gap must be set to touch the top of the tube. Then the rheometer will compress the tube to 50% of the total exterior diameter. The radial force is determined by dividing the force at 50% compression by the length of the tube [1][2].

## *3.4 Results*

With each one of the tests, the team is looking to see if the plastic to polymer ratios that were chosen for this project better match the properties of human blood vessels than the previously tested ratios from past projects. From there, if the chosen ratios do match the desired properties more than the previous samples, then the team looks at the results to see which of the two ratios better matches the desired ranges to find the official ratio for the final model.

Compliance values when comparing both samples (30a-50a and 40a-60a) are less than 10% of difference (0.01) and this is found to be statistically significant as compared to the pervious VC-A30-30A design, which have a p value range of 0.00019 to 0.069 when compared to donors 1-3. We also noticed a smaller percentage difference when compared to the donors with an average of 72% while designs like the previously mentioned VC-A30-30A has an average difference of 92% when compared to donors 1-3. Which what the team is looking for, which is to make a model which has to mimic anatomical mechanical properties and handle various loads during multiple tests, this discovery proves that those requirements can be validated.

Looking at the Poisson's ratio for both samples (30a-50a and 40a-60a) after a 4-day bath, we see that the mean Poisson’s ratio for the 30-50 and the 40-60 are 0.25 and 0.26 respectively. This is found to be statistically different from the donor samples which ranged from 0.37 to 0.51 for donors 1-3. Our samples’ mean Poisson’s ratio were also smaller than silicone models (mean Poisson’s ratio = 0.35).

To ensure that the values found during the testing are providing accurate results, the thickness and area of the samples have to be relatively similar to their respective human vessels. The samples printed have a diameter is 8 mm and the area if calculated from there using the equation for an area of a circle. Tests than use a cylindrical tube sample instead of a puck have the length of the tube (~10 mm) included in the area equation [2]. The area that is found is then multiplied by physiological pressure (roughly 100 mmHg to 160 mmHg) to determine the application forces so that the sample won’t get destroyed in testing [2]. Once all these values are found, all further calculations and measurements are found by the rheometer and transferred into a data file that is then analyzed and compared to donor samples by the team. The ranges

of desired values were given by our client based on previous testing done with donor samples.

### *3.5 Conclusion*

After all eight of the tests have been completed and analyzed, along with careful discussion with the client, the team has concluded that the research that has been made has been successful in the advancement of obtaining material that behaves similarly to that of real human tissue. These results can be found in table # of section 4.2 below, which show the numbers that the team has found compared to the target values (human tissue values). Though the team's design does not have the exact same characteristics as that of human tissue, the research has shown improvement compared to that of previous research, which supplies client satisfaction. This improvement has shown that the research is going in the right direction so that further research can be conducted in the hopes of hitting those future goals.

# 4 Specification Sheet

## *4.1 Customer Requirements*

The list of customer requirements can be found in table 2 below. These requirements were specifically given by the client, to make sure that the project satisfies certain areas of research. The eight of the customer requirements the team has been asked to focus on are size, the connection to remain easy, having a soft exterior and a hard interior, remaining lightweight, to focus on material selection, retaining similar shapes, aiming towards similar properties to human tissue, and finally to keep the design cost within budget. Table 2 also states the details of the design that verify whether or not the customer requirements can be satisfied.

Table 2: Customer Requirements

| **Customer Requirements** | | **Client Acceptable (Y/N)** | **Notes / Verification** |
|---|---|---|---|
| CR -1 | Size | Y | Anatomically similar CAD & Layering. |
| CR -2 | Easy to Connect | Y | UV Cured Printing (integrated) W/ original base. |
| CR -3 | Soft Exterior, Hard interior | Y | 20%-80% Layer |
| CR -4 | Lightweight | Y | Design <500g, CW <200g, Samples <5g each. |
| CR -5 | Material Selection | Y | Aguilus & VeroClear |
| CR -6 | Retains Shape | Y | Unless plastically deformed. |
| CR -7 | Similar properties to human tissue | Y | Test results: closer values- not exact. Improved. |
| CR -8 | Cost within Budget | Y | Test & Sampling <$600, Approx. $400 remaining. |

## *4.2 Engineering Requirements*

The list of engineering requirements can be found in table 3 below. These requirements were specifically chosen to help satisfy the customer requirements. These 14 requirements: stiffness, thickness,

compressive modulus frequency, Poisson's ratio, compliance, angular acceleration, radial force, layering, pressure, shear modulus, hardness modulus, strain, and coefficient of friction. Table 3 also states the details of the design that help verify whether or not the engineering requirements can be satisfied. If the calculated values are within the target ranges decided for each of the engineering requirements it will help verify whether or not the engineering requirements can be determined as acceptable.

Table 3: Engineering Requirements

| Engineering Requirements | | Units | Target Range | Tolerance | Measured / Calculated Value | ER Met (Y/N) | Client Acceptable (Y/N) | Test / Method Associated |
|---|---|---|---|---|---|---|---|---|
| ER -1 | Stiffness/ E | Kpa | 100 to 20,000 | 100 | 30-50: 70,000 to 120,000; 40-60: 90,000 to 160,000 | N | Y | Tension |
| ER -2 | Thickness | mm | 1.2 | 0.05 | CAD: 1.2mm; Capiler: 1.2mm | Y | Y | N/A |
| ER -3 | Compressive Moduless | KPa | 90,000 to 500,000 | 50 | 30-50:500,000 to 680,000; 40-60: 590,000 to 810,000 | N | | Compression |
| ER -4 | Frequency | rad/s | 0 to 20 | 0.01 | Rheometer controlled | Y | Y | Most |
| ER -5 | Poisson's ratio | unitless | 0.30 to 0.50 | 0.05 | 30-50:0.18 to 0.29\| 40-60: 0.21 to 0.30 | N | Y | Poison's Ratio |
| ER -6 | Compliance | cm^3/mmHg | 0 to 0.006 | 0.0001 | 30-50: 0.00052 to 0.00066 40-60: 0.00034 to 0.00046 | | Y | Compliance |
| ER -7 | Angular Acceleration | rad/s | 0 to 20 | 0.01 | Rheometer controlled | Y | Y | Most |
| ER -8 | Radial Force | N/mm | .003 to .01 | 0.001 | 30-50: 0.03 ; 40-60: 0.03 | N | Y | Radial Force |
| ER -9 | Layering | mm | 0.96, 0.24 | 0.01 | CAD measured; printer tolerance | Y | Y | N/A |
| ER -10 | Pressure | mmHg | 80 to 320 | 5 mmHg | Pressure Gauge; Pressure Transducer (readings varied) | Y | Y | Compliance |
| ER -11 | Shear Modulus, E | KPa | 5 to 30 | 5 | 60-50:70,000 to 145,000; 40-60: 90,000 to 150,000 | N | Y | Shear |
| ER -12 | Hardness, Modulus | KPa | 1,000 to 5000 | 100 | 30-50: 5478.26 40-60: 829041.9 | Y/N | Y | Hardness |
| ER -13 | Strain | % | 55 to 90 | 1 | Rheometer controlled | Y | Y | Hardness |
| ER -14 | Coefficient of Friction | unitless | 0.15 to 0.5 | 0.01 | 30-50: 0.3351 40-60: 0.3353 | Y | Y | Lubricity |

Larger Table included in **Appendix A.**

# 5 QFD

The House of Quality is included in **Appendix B.** Every engineering requirement has a targeted value or a goal to maximize or minimize that value. The targeted values are the frequency, angular acceleration, radial force, and the pressure the material needs to withstand and that of the Poisson's ratio, where, if met, provides proof in comparing the similar properties to that of the organic tissue. The values that the team wants to maximize to meet the customer requirements are the compressive modulus, the compliance, and the layering process. The compressive modulus and the compliance relate to the amount of force the material can withstand and retain its shape and characteristics. Therefore, the higher the value is, the higher quality results the team will see. The last requirement that looks to maximize the value is the layering requirement. With most of the project focused on the hard interior and soft exterior and the similarities in properties, the ways the material is layered must be maximized. Lastly, the values that the team wants to minimize to meet the customer requirements are the stiffness characteristic and the overall thickness of the design. Decreasing both values will help obtain characteristics like organic tissue, which in turn obtains successful results [1]. The primary connection between all the tests is using human physiological conditions such as blood pressure (120-200 mmHg), vascular stress and strains, and previously measured mechanical properties to compare polymer capability of replication. Each Engineering requirement is carefully tailored to suit these conditions and measure the stability and potential of the polymer to not only withstand the same forces but also to perform similarly. Forces in Newtons are converted to blood pressure using sample size and conversion equations of force.

# 6 References

[1] I. Smith, L. Nelson, K. Nelson, and A. Ponugupaty, *Northern Arizona University*, “Final Proposal,” Rep. Nov. 2021.

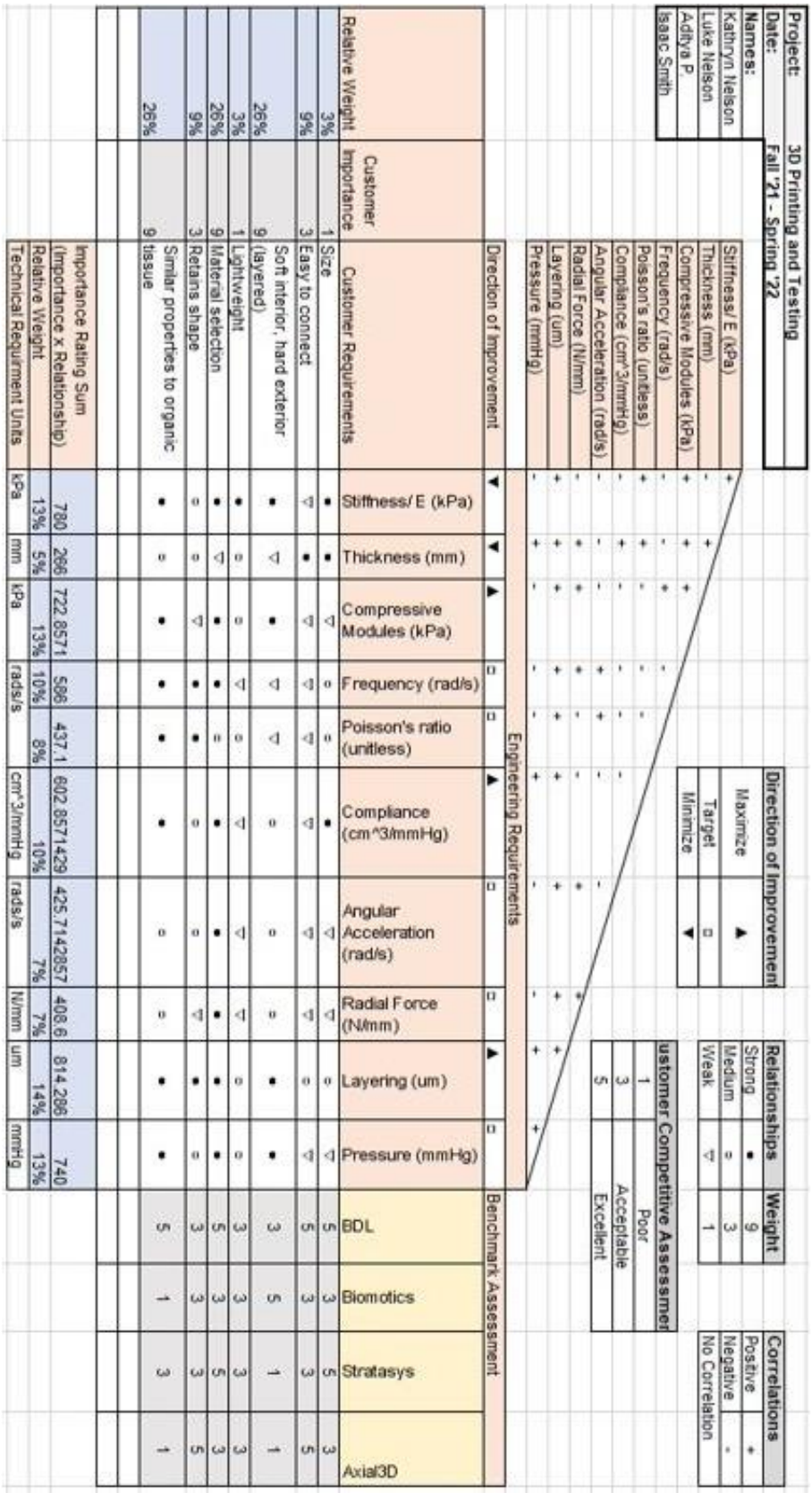
[2] N. G. Norris, W. C. Merritt, and T. A. Becker, "Application of nondestructive mechanical characterization testing for creating in vitro vessel models with material properties similar to human neurovasculature," *Journal of biomedical materials research. Part A*, 17-Sep-2021. [Online]. Available: https://pubmed.ncbi.nlm.nih.gov/34617389/. [Accessed: 13-Oct-2021]

# 7 Appendix

## *7.1 Appendix A: Engineering Requirements Chart*

| Engineering Requirements | | Units | Target Range | Tolerance | Measured / Calculated Value | ER Met (Y/N) | Client Acceptable (Y/N) | Test / Method Associated |
|---|---|---|---|---|---|---|---|---|
| ER -1 | Stiffness/ E | Kpa | 100 to 20,000 | 100 | 30-50: 70,000 to 120,000; 40-60: 90,000 to 160,000 | N | Y | Tension |
| ER -2 | Thickness | mm | 1.2 | 0.05 | CAD: 1.2mm; Capiler: 1.2mm | Y | Y | N/A |
| ER -3 | Compressive Modulus | KPa | 90,000 to 500,000 | 50 | 30-50:500,000 to 680,000; 40-60: 590,000 to 810,000 | N | | Compression |
| ER -4 | Frequency | rad/s | 0 to 20 | 0.01 | Rheometer controlled | Y | Y | Most |
| ER -5 | Poisson's ratio | unitless | 0.30 to 0.50 | 0.05 | 30-50:0.18 to 0.29\| 40-60: 0.21 to 0.30 | N | Y | Poison's Ratio |
| ER -6 | Compliance | cm^3/mmHg | 0 to 0.006 | 0.0001 | 30-50: 0.00052 to 0.00066 40-60: 0.00034 to 0.00046 | | Y | Compliance |
| ER -7 | Angular Acceleration | rad/s | 0 to 20 | 0.01 | Rheometer controlled | Y | Y | Most |
| ER -8 | Radial Force | N/mm | .003 to .01 | 0.001 | 30-50: 0.03 ; 40-60: 0.03 | N | Y | Radial Force |
| ER -9 | Layering | mm | 0.96, 0.24 | 0.01 | CAD measured; printer tolerance | Y | Y | N/A |
| ER -10 | Pressure | mmHg | 80 to 320 | 5 mmHg | Pressure Gauge; Pressure Transducer (readings varied) | Y | Y | Compliance |
| ER -11 | Shear Modulus, E | KPa | 5 to 30 | 5 | 60-50:70,000 to 145,000; 40-60: 90,000 to 150,000 | N | Y | Shear |
| ER -12 | Hardness, Modulus | KPa | 1,000 to 5000 | 100 | 30-50: 5478.26 40-60: 829041.9 | Y/N | Y | Hardness |
| ER -13 | Strain | % | 55 to 90 | 1 | Rheometer controlled | Y | Y | Hardness |
| ER -14 | Coefficient of Friction | unitless | 0.15 to 0.5 | 0.01 | 30-50: 0.3351 40-60: 0.3353 | Y | Y | Lubricity |

## 7.2 Appendix B: HOQ



| Project: | 3D Printing and Testing |
|---|---|
| Date: | Fall '21 - Spring '22 |
| Names: | |
| Kathryn Nelson | |
| Luke Nelson | |
| Aditya P. | |
| Isaac Smith | |

| Direction of Improvement | |
|---|---|
| Maximize | ▲ |
| Target | □ |
| Minimize | ▼ |

| Relationships | | Weight |
|---|---|---|
| Strong | • | 9 |
| Medium | ○ | 3 |
| Weak | ▽ | 1 |

| Correlations | |
|---|---|
| Positive | + |
| Negative | - |
| No Correlation | |

| Customer Competitive Assessment | |
|---|---|
| 1 | Poor |
| 3 | Acceptable |
| 5 | Excellent |

| Relative Weight | Customer Importance | Customer Requirements | Direction of Improvement | | Stiffness/ E (kPa) | ▼ | Thickness (mm) | ▼ | Compressive Modules (kPa) | ▲ | Frequency (rad/s) | □ | Poisson's ratio (unitless) | □ | Compliance (cm^3/mmHg) | ▲ | Angular Acceleration (rad/s) | □ | Radial Force (N/mm) | □ | Layering (um) | ▲ | Pressure (mmHg) | □ | Benchmark Assessment: BDL | Biomotics | Stratasys | Axial3D |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 3% | 1 | Size | | | • | | • | | ▽ | | ○ | | ○ | | • | | ▽ | | ▽ | | ○ | | ▽ | | 5 | 3 | 5 | 3 |
| 9% | 3 | Easy to connect | | | ▽ | | • | | ▽ | | ▽ | | ▽ | | ▽ | | ▽ | | ▽ | | ○ | | ▽ | | 5 | 3 | 3 | 5 |
| 26% | 9 | Soft interior, hard exterior (layered) | | | • | | ▽ | | • | | ▽ | | ▽ | | ○ | | ○ | | ○ | | • | | • | | 3 | 5 | 1 | 1 |
| 3% | 1 | Lightweight | | | • | | ○ | | ○ | | ▽ | | ○ | | ▽ | | ▽ | | ▽ | | ○ | | ○ | | 3 | 3 | 3 | 3 |
| 26% | 9 | Material selection | | | • | | ▽ | | • | | • | | • | | • | | • | | • | | • | | • | | 5 | 3 | 5 | 3 |
| 9% | 3 | Retains shape | | | ○ | | ○ | | ▽ | | • | | • | | ○ | | ○ | | ▽ | | • | | ○ | | 3 | 3 | 3 | 5 |
| 26% | 9 | Similar properties to organic tissue | | | • | | ○ | | • | | • | | • | | • | | ○ | | ○ | | • | | • | | 5 | 1 | 3 | 1 |
| | | Importance Rating Sum (Importance x Relationship) | | | 780 | 266 | 722.8571 | 586 | 437.1 | 602.8571429 | 425.7142857 | 408.6 | 814.286 | 740 | | | | | | | | | | | | | | |
| | | Relative Weight | | | 13% | 5% | 13% | 10% | 8% | 10% | 7% | 7% | 14% | 13% | | | | | | | | | | | | | | |
| | | Technical Requirment Units | | | kPa | mm | kPa | rads/s | | cm^3/mmHg | rads/s | N/mm | um | mmHg | | | | | | | | | | | | | | |