Polymeric Medical Sutures: An Exploration of Polymers and Green Chemistry

Instructor Notes

Part I: Drawing Threads Using Poly(ε-caprolactone)

General Notes:

- Part I should take 45 minutes, depending on the depth of the introduction to the lab. The introduction takes about 15 minutes, the melting of the poly(ε-caprolactone) takes about 15 minutes, and the drawing of the threads takes about 15 minutes.
- Consider including a demonstration during the introduction that mimics the entanglement of polymers of varying molecular mass with strings cut to varying lengths.
    - **Prep:** Have 6-10 small (3-5 inches) pieces of yarn cut up and 6-10 large (24 inches) pieces of yarn cut up. Arrange all the small pieces in a pile and the large pieces in a separate pile.
    - **Demonstration:** Attempt to pull a piece of yarn out of each of the piles to show how larger polymers can entangle easier than small polymers. Discuss what might happen when 14K, 45K, and 80K polymers are pulled into a suture and how their entanglement will affect the quality of the suture.
- Part I includes showing students an example of real sutures. There are many possible options for sutures, including those suggested below. A minimum of one type is necessary for the purpose of this experiment.
- Plastic bags can be used for ease of collecting and storing the sutures. Have students label the plastic bags using labeling tape and a permanent marker so the bags can be reused each year.
- The 80K poly(ε-caprolactone) can be drawn into lengthy sutures. You may consider having a drawing contest to see which students can draw the longest sutures. Carefully drawn sutures may even extend the length of the classroom.

Expected (Typical) Results:

Data and Observations Part I:

Table I. Observations of Actual Medical Sutures

Name/Type	Gauge (Thickness)	Observations (How it feels, thickness, stretch, color, weave, etc...)
Nylon	4-0	Black, smooth, thicker than nylon 5-0, feels like fishing line, strong, not very stretchy
Nylon	5-0	Black, smooth, thinner than nylon 4-0, feels like fishing line, strong, not very stretchy
Polygalactic Acid (PGA)	4-0	Blue, smooth, thicker than PGA 5-0, feels like thread, strong, not very stretchy
Polygalactic Acid (PGA)	5-0	Blue, smooth, thinner than PGA 4-0, feels like thread, strong, not very stretchy
Natural/Chromic Gut (PCM)	4-0	Brown, smooth, thicker than PCM 5.0, feels like hair, strong, not very stretchy

Natural/Chromic Gut (PCM)	5-0	Brown, smooth, thinner than PCM 4.0, feels like hair, strong, not very stretchy

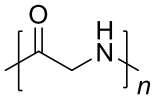
Table II. Observations of Drawn Poly(*ε*-caprolactone) (PCL) "Suture" Threads

Molecular Mass of PCL	Time Required for Melting	Qualitative Observations	Draw-Ability (easy, medium, difficult, impossible)	Quality of Sutures (low, medium, high)
80K	Most Time (typically 5-10 minutes)	Melted slowly, turned from white to clear upon melting, very thick, draws into very long sutures	Easy	High/Medium
45K	Medium Time (typically 3-5 minutes)	Turned from white to clear upon melting, draws into shorter sutures	Easy/Medium	High/Medium
14K	Least Time (typically 1-3 minutes)	Melted quickly, turned from white to clear upon melting, very thin, unable to draw a suture from	Difficult/Impossible*	N/A

*Students will not be able to draw the 14K poly(ε-caprolactone) into a suture. Do not allow them to waste too much time attempting to do this.

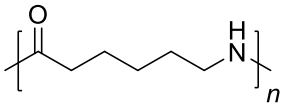
Answers to Pre-Lab Questions:

1. Examine the structures of the four polymers below:



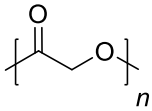
polyglycine

melting point 290 °C



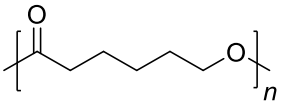
nylon 66

melting point 265 °C



polyglycolide, PGA

melting point 220 °C



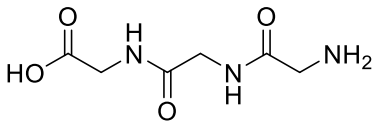
polycaprolactone

melting point 60 °C

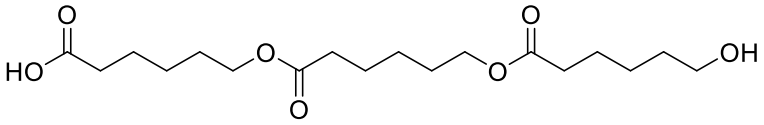
a. What similarities and differences exist in the molecular structures?

Polyglycine and nylon 66 have oxygen and nitrogen heteroatoms along with C & H, whereas polyglycolide and poly(ε-caprolactone) have C, H, and O. only. Also the chain lengths differ. Longer chains has a lower boiling point in each series.

b. Draw the entire polymer that would be represented by polyglycine where *n* is equal to 3. Assume one terminus group of the "trimer" is a carboxylic acid (CO_2H) and the other an amine (NH_2).

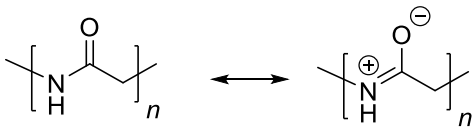


c. Draw the entire polymer that would be represented by polycaprolactone where *n* is equal to 3. Assume one terminus group of the "trimer" is a carboxylic acid (CO_2H) and the other an alcohol (OH).



d. What types of intermolecular forces are possible for each molecule ignoring the end groups?

The polyglycine and nylon 66 have an N-H bond which can be used for hydrogen bonding. The bond is actually an amide bond so very polar. The ester polymers can have dipole-dipole interactions but no H-bonding except on the end groups.



e. How might the intermolecular forces identified above affect the properties of the polymer?

Stronger bonds (H-bonds) lead to higher melting points and intermolecular interactions.

Answers to Post-Lab Questions:

1. Compare the thickness, texture, strength, stretchiness, etc. of the poly(ε-caprolactone) threads to an actual suture. Describe any similarities or differences observed.

   Answers will vary depending on the sutures used for comparison, but likely students will notice that the poly(ε-caprolactone) threads are stretchy and not as strong as the actual sutures.

2. What is the relationship between the molecular mass of poly(ε-caprolactone) and the draw-ability and quality of the threads? Propose a reason for this observation.

   As the molecular mass of the poly(ε-caprolactone) increases, the draw-ability of the suture increases. Larger polymer chains are generally able to entangle with other molecules easier than smaller polymer chains, and therefore are easier to pull into sutures.

Materials:

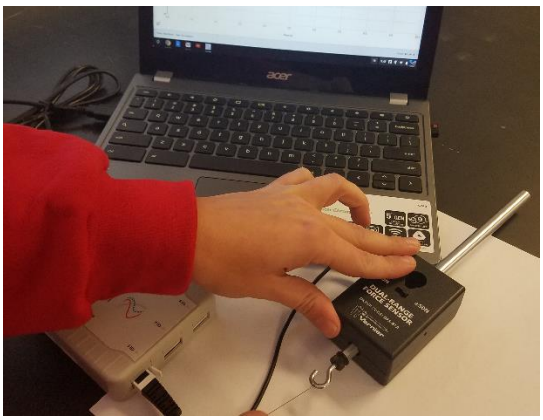
Item	Suggested Supplier	Estimated Cost*	Number of Class Periods the Materials Cover
Aluminum dish (100 pk)	Flinn Scientific (AP6390) VWR (25433-016)	$10.30 $25.78	3
poly(ε-caprolactone) 80K (250 g)	Sigma Aldrich (440744)	$110.50	16
poly(ε-caprolactone) 45K (250 g)	Sigma Aldrich (704105)	$99.90	16
poly(ε-caprolactone) 14K (250 g)	Sigma Aldrich (440752)	$120.50	16
Some Options for Actual Sutures			
4-0 PGA (12 sutures)	AD Surgical (#M-G418R19)	$31.50	24**
5-0 PGA (12 sutures)	AD Surgical (#M-G518R19)	$31.50	24**
4-0 Nylon (12 sutures)	AD Surgical (#M-N418R19)	$17.50	24**
5-0 Nylon (12 sutures)	AD Surgical (#M-N518R19)	$17.50	24**
4-0 PMC (12 natural sutures)	AD Surgical (PMC-418R19)	$31.60	24**
5-0 PMC (12 natural sutures)	AD Surgical (PMC-518R19)	$31.60	24**

*The estimated cost does not include shipping costs and costs were obtained July 2016.
**If the suture portion of the experiment is done as a demonstration, less than half of a suture should be consumed per class period meaning the sutures will last for 24 class periods.

Part II: Tie-Ability and Tensile Strength Testing

General Notes:

- Part II takes about 25-30 minutes.
- Only one type of real suture is required, but more can be purchased for deeper exploration. If the tie-ability and tensile strength test of the experiment is done as a demonstration, less than half of a suture should be consumed per class period meaning the sutures will last for 24 class periods.
- Vernier Dual-Force Probe with interface is recommended as the tensile strength tester, but if probe equipment is not available, a simple trigger pull scale or spring scale could work but will give less quantitative data.
- If students are going to collect and compare data as a class, a consistent procedure must be used across the entire class.



Vernier Dual-Force Probe

Trigger Pull Scale

Expected (Typical) Results:

Data and Observations Part II:

Table III. Tensile Strength and Tie-Ability

Thread/Suture	Force (Newtons)	Qualitative Observations
45K PCL	Low (typically <1 N)	Hard to tie, breaks when tied
80K PCL	Low (typically 1-5 N)	Hard to tie, stretchy
Actual Suture: Nylon 4-0	High (typically ~12-15 N)	Easy to tie, hard to break
Actual Suture: Nylon 5-0	High (typically 10-12 N)	Easy to tie, hard to break
Actual Suture: PGA 4-0	High (typically ~12-15 N)	Easy to tie, hard to break
Actual Suture: PGA 5-0	High (typically 10-12 N)	Easy to tie, hard to break
Actual Suture: Natural 4-0	High	Easy to tie, hard to break

	(typically ~12-15 N)	
Actual Suture: Natural 5-0	High (typically 10-12 N)	Easy to tie, hard to break

Answers to Post-Lab Questions:

1. Does the type and thickness of material impact the tie-ability and tensile strength of a suture? Explain why or why not.

   The type of material impacts the tie-ability. The poly(ε-caprolactone) threads were less tie-able than the other sutures indicating the type of material matters. The type and thickness of material both impact the tensile strength. The thicker the material the greater the tensile strength. The poly(ε-caprolactone) had less tensile strength than the other sutures indicating the type of material matters.

2. How did the poly(ε-caprolactone) threads compare in thickness and in strength to the actual sutures? Would they make good commercial products? How might they be improved?

   The poly(ε-caprolactone) threads are not as strong as actual sutures and would not make good commercial products as a result. The threads could be improved by increasing their strength. This could be done by drawing thicker sutures or braiding sutures together. Students might speculate that a PCL of even higher molecular mass than 80K might have better properties.

Materials:

Item	Suggested Supplier	Estimated Cost*
Dual Range Force Sensor	Vernier (DFS-BTA)	$109
LabQuest 2 (or another Vernier interface)	Vernier (LabQ2)	$329

*The estimated cost does not include shipping costs and costs were obtained July 2016.

Part III: Degradability Testing

General Notes:

- Part III takes about 25-30 minutes.
- Only one type of real suture is required, but more can be purchased for deeper exploration. If the degradation test is done as a demonstration, less than half of a suture should be consumed per class period meaning the sutures will last for 24 class periods.

Expected (Typical) Results:

Data and Observations:

Table IV: Degradability of Threads/Sutures

Suture	Time to Dissolve (min)	Qualitative Observations
45K PCL	Low (typically <1 min)	Dissolves quickly
80K PCL	Low (typically 1-3 min)	Turns clear and then dissolves
Actual Suture: Nylon 4-0	Never	Does not change
Actual Suture: Nylon 5-0	Never	Does not change
Actual Suture: PGA 4-0	Low (typically 1-3 min)	Turns clear and then dissolves
Actual Suture: PGA 5-0	Low (typically 1-3 min)	Turns clear and then dissolves
Actual Suture: Natural 4-0	High (typically 5-7 min)	Slowly curls, turns clear, and then dissolves
Actual Suture: Natural 5-0	High (typically 5-7 min)	Slowly curls, turns clear, and then dissolves

Answers to Post-Lab Questions:

1. Does the type, strength, or thickness of material impact the degradability of a suture? Explain why or why not.

   Answers will vary depending on the sutures tested. The type of material impacts the degradability of a suture. Some materials are degradable and others are not. The thickness of the material impacts the time required to degrade the suture. Thicker sutures generally take longer to degrade.

2. When would it be important or not important for sutures to dissolve in the human body? Explain.

   It would be important for sutures to dissolve when they are used inside the body so that the body wouldn't have to be opened to remove the stitches.

3. Which of the sutures that you tested would be appropriate for use as stitches that were designed to dissolve or not dissolve in the human body?

Answers will vary depending on sutures tested, but sutures that degrade can be used as sutures designed to dissolve and sutures that do not degrade can be used a sutures designed to not dissolve in the body.

Part IV: Guided Inquiry with Polylactic Acid (PLA)

General Notes:

- Part IV takes 50-60 minutes, but more time can be provided to allow students to investigate their questions more thoroughly.
- PLA cups for this experiment can be found at Greenware, WorldCentric, or another source.
    - Greenware website: http://www.fabri-kal.com/product/greenware-cold-drink-cups/
    - Worldcentric website: http://worldcentric.org/biocompostables/cups
- To incorporate PLA into the poly(ε-caprolactone), cut the PLA cups (or other source) into small pieces (~1 cm^2) and add them to aluminum dish with the poly(ε-caprolactone)
    - Note that the aluminum dishes will not be able to be reused once the PLA has melted.
    - To improve the melt blending of PLA and poly(ε-caprolactone), make sure to stir the mixture with a glass stir rod
- The level of inquiry can be adjusted based on time and level of students. For example, for open inquiry students can develop their own testable question regarding PLA and sutures. Or for more guided inquiry student groups can be assigned a question to test. Here is a list of possible questions:

    - Does the incorporation of PLA with 14K poly(ε-caprolactone) create a quality, drawable suture?
    - Does the incorporation of PLA into a suture (14K, 45K, or 80K) increase the degradability?
    - Does the incorporation of PLA into a suture (14K, 45K, or 80K) increase the tensile strength?
    - What effect does the incorporation of PLA with 45K poly(ε-caprolactone) have on the sutures?
    - What effect does the incorporation of PLA with 80K poly(ε-caprolactone) have on the sutures?
    - Does the source (blueberry container, plastic cup, etc.) of PLA have an effect on suture quality?
    - What would happen to the quality of the suture if you braided the sutures together?

Materials:

Item	Suggested Supplier	Estimated Cost*
6 oz. PLA Cups (pack of 50)	World Centric	$3.14

*The estimated cost does not include shipping costs and costs were obtained July 2016.

- **Results:** Student conclusions from the guided-inquiry Part IV consistently stated that the melt-blended threads with PLA and PCL mixed were stronger. These results were supported by their tensile testing and visual observations.