The Alginate Solution: Dissolvable Sutures from Popping Boba
CYSF Project by Karen Attri

Research Question:

How can we develop a viable alternative to dissolvable sutures and lower healthcare inequalities across the globe?

Background:

Historical evidence for the widespread use of sutures for rudimentary surgery began around 3000 BCE (Carrington College, 2024) and often involved the use of plant-fiber based sutures and bone-needles. Fast forward to the 2nd century AD, evidence from Rome points to the first use of “catgut” sutures by Galen of Pergamon (Scheepers, 2014). Contrary to the name, this suture thread was often made from cattle, sheep, or goat intestines that had been dried and stretched.

A particular advantage for the use of catgut is the fact it is dissolvable and can be safely absorbed by the body after a wound is healed. Of course, catgut has become the forefather of contemporary synthetic dissolvable sutures made from biodegradable polymers like Polylactic acid (PLA) and Polyglycolide (PGA) which are also able to safely degrade in the body (Parthasarathy et al., 2017). Dissolvable stiches offer several benefits, including a reduced risk of infection, minimizing discomfort and inconveniences, as well as their biocompatibility (Universal Sutures, 2023).

These advantages are particularly pertinent to those in impoverished countries without much access to medical care. For one, the elimination of the need for suture removal for someone who already has limited access to healthcare increases the practicality and effectiveness of the sutures. This saves both the patient and the healthcare provider time and resources by allowing for greater access for the former and allow the latter to divert it to others. Additionally, reduced infection rates due to the lack of a second potential of exposure upon removing the stitches can also mean the difference between life and death for those who already have significantly reduced access to medical care.

And it truly is a matter of life or death for some. In Sierra Leone the maternal mortality ratio is 2 100 deaths per 100 000 live births, while in Ireland the ratio is 1 maternal death per 100 000 live births (Venkatapuram et al., 2013). What accounts for these huge discrepancies? Paul Farmer points to the lack of sutures, sterile drapes, and anesthesia is one of the many reasons for this outrageous maternal death ratio (2008). This sentiment is echoed by hundreds of other papers, all pointing to the lack of sutures as a primary cause of maternal death from complications arising from childbirth. These deaths can be prevented with increased access to sutures, particularly dissolvable sutures, especially in consideration of maternal deaths in which dissolvable stiches are often used.

Moreover, some of the reasons following the lack of use of these dissolvable sutures come from their higher cost. This is due to the high cost of the specialized synthetic materials used to derive the sutures as well as with the increase of cost that comes from its sophisticated chemical synthesis and processing. This drives the cost of dissolvable sutures up making this even more inaccessible for impoverished countries.

This investigation will be focusing on the development of a viable alternative to conventional dissolvable sutures. One of the major factors that contribute to healthcare inequalities when it comes to dissolvable sutures comes from the high cost of manufacturing contemporary dissolvable sutures and thus prevents this essential healthcare tool from being accessed by impoverished countries.

Some of the elements that will designate a "viable" alternative will include biocompatibility, cost-effectiveness, practicality (tensile strength, knot security, absorbability), and ease of access. As such, these elements will be investigated to determine a viable alternative to dissolvable stitches.

Methods:

Determining a Viable Suture Material:

Materials for an ideal biocompatible suture thread were investigated. It was important that this material be both biocompatible and dissolvable but also have a certain degree of stability in high temperatures and in watery environments.

However, for the creation of the sutures using cellulose cannot be considered as it cannot be broken down by the body (and it is what non-dissolvable sutures are made of). Other materials can include collagen-based materials, like gelatine or alginate (a polysaccharide that can crosslink in the presence of calcium ions), that can be used for the creation of the dissolvable surgical sutures.

PLA and PGA polymers:

Commercial sutures are typically made form Polylactic acid (PLA) and Polyglycolide (PGA), while certainly biocompatible and dissolvable, are not ideal due to limited access and complicated procedural methods. These sutures involve complicated processes to crosslink the polymers including "Ring-Opening Polymerization of Lactide" which is a relatively slow process that poses environmental and health concerns from the toxic catalysts used to cross link the polymer for the sutures (Samui et al., 2019). These factors increase the price of these dissolvable sutures, thus for the reasons discussed above, PGA and PLA will not be used for sutures in this project.

Gelatine:

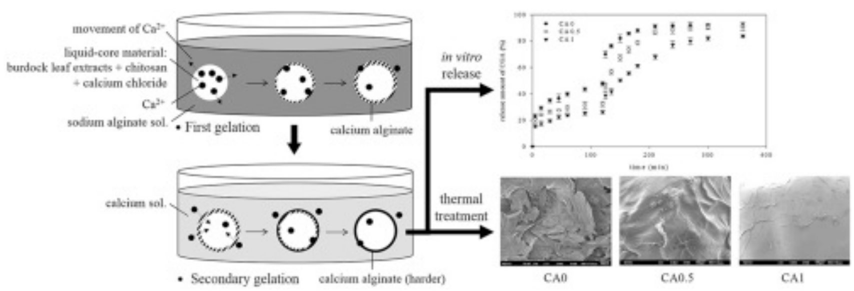
When looking at biocompatible materials with the restriction that they can be dissolved by the body, it is pertinent to look at hydrogel materials such as gelatine. Gelatine possesses high biocompatibility, and it has been used in many slow-release drug delivery systems as well as in bandages and internal scaffolding for the body (Choi et al, 2021).

However, some of the issues that arise from collagen-based sutures is its ability to rehydrate and hydrate, which can decrease its overall stability. The collagen bonds are held together by hydrogen bonding from the water and thus, upon heating of the solution, the bonds have a high chance of breaking upon hydrolysis (Rather et al., 2022). This diminishes its overall effectiveness, as it is possible that upon contact with bodily fluids and high temperatures from the body the sutures may come undone or break. Gelatine has been shown to denature at around 37°C (Farrugia et al., 1999) which coincidentally is the same temperature of the human body. This means that the sutures are likely to dissolve at contact with the human body, rendering it impractical for dissolvable sutures.

For this reason, and based on previous study, sutures made from gelatine will not be considered. Thus, while gelatine is both inexpensive and biocompatible, it does not meet the standard for stability and will not be considered in this investigation.

Alginate:

Alginate or alginic acid is a naturally occurring polysaccharide derived from brown seaweed (Lee et al, 2012). Commercially, it has been used in the popular popping boba or popping pearls drink with the specification process. When exposed to a solution of calcium ions, the calcium ions replace the sodium ions, allowing for the alginate molecules to bind together and cross-link. This chemical reaction creates a thin membrane that encapsulates the liquid drop (Tsai et al., 2017).



(*Alginate polymer formation*, Tsai et al., 2017)

Alginate is used in many biomedical applications, including wound dressing (by companies like Algicell™, Sorbsan™, etc.) and healing, drug delivery, and tissue engineering (Lee et al., 2012) and has been studied extensively as a biocompatible, non-toxic material. In addition, alginate is also non-immunogenic, meaning that the material has an antigen that will not trigger an immune response in the body (Raus et al., 2021). This is incredibly important, as rejection of the suture that triggers inflammation and the immune system can increase risk for infection as well as delay the healing process.

Regarding alginate's stability, it has been shown that alginate microbeads are stable for over 6 weeks in several tissue locations with minimal change to volume and diameter of the beads (Moya et al., 2012). Additionally, due to alginate's innate property of crosslinking in the presence calcium ions it can maintain its structural integrity with the calcium ions in the body. As calcium ions are essential for coagulation factors in blood clotting, and thus when the body senses injury, it will send calcium ions to the cite to facilitate wound healing. Alginate likewise uses calcium to crosslink itself, and the sutures can be strengthened by the body's natural response of sending calcium ions to a wound site.

In addition, cost-effectiveness studies show that alginate is generally more cost effective. For example, with the use of alginate in silver dressing to treat pancreatic cancer, the cost of treatment was shown to cost almost $90 (USD) less than its component silver-zinc sulfasalazine cream (Chuangsuwanish et al., 2013). Its ease of access due to its use in food is also benefit, as it available in many commercial stores.

For these reasons alginate-based sutures will be the primary focus for this investigation as it meets the elements that designated a viable alternative including biocompatibility, cost-effectiveness, and ease of access.

Investigating the Properties of Alginate:

As the material for the sutures has been determined, additional investigations will discern the practicality of this solution between various concentrations of the alginate gel sutures. Various concentrations of the alginate solution will be prepared and dried to create the suture thread and tested for various indicators of practicality including tensile strength, knot security, and absorbability.

Safety Considerations:

Table 1: List of chemicals used and associated WHMIS and Hazards Identification

Chemical	Nature of Hazard	Symbols
Sodium Alginate	None	N/A
Calcium Chloride ($CaCl_{2\,(s)}$)	May form combustible dust concentration in air, eye irritation	

First Aid:

Table 3: First Aid treatment for various routes of exposure for chemicals used

Route of Exposure	Treatment	Applicable Chemicals
Inhalation	Move to fresh air	$CaCl_{2\,(s)}$
Skin Contact	Rinse with water for 15 minutes	$CaCl_{2\,(s)}$
Ingestion	Do not induce vomiting. Get medical attention.	$CaCl_{2\,(s)}$
Eye Contact	Rinse with water, remove contact lenses	$CaCl_{2\,(s)}$

Environmental and Disposal Considerations:

Dispose of Calcium chloride in household hazardous waste site at a designated Calgary fire station. Dispose of Sodium Alginate in a plastic bag and put into the garbage, do not pour down the drain.

Materials:

- 1x Sodium Alginate
- 1x Calcium Chloride
- 1x Distilled Water
- 2x Bowls
- 1x 3mL syringe
- 1x Blender
- 1x Stir Stick
- 1x Ruler
- 1x Balance
- 2x Beakers
- 50x quarters (4.5g)

General Procedure for Suture Preparation:

This procedure was developed through trial and error. It was inspired by the process of synthesizing catgut sutures. This method was used as spinning a fibrous thread like PLA or PGA using the alginate was not feasible with alginate.

1. Measure out 5.0g of calcium chloride with the balance
2. Dissolve the calcium chloride with 500mL of distilled water
3. Measure out desired mass of sodium alginate
4. Blend the sodium alginate in 500mL of distilled water
5. Allow the sodium alginate solution to rest for at least 3 hours to remove any air bubbles from blender
6. Take calcium chloride solution and place it in a long container
7. Use the syringe to draw up the sodium alginate
8. In a swift linear motion, place pressure on the syringe top release the sodium alginate into the calcium chloride bath
9. Wait about 3 minutes for the membrane to form. Rinse the polymer in a water bath
10. Leave the polymer on a counter under a heat source for 2 hours when the alginate has hardened and shrunk

Table 3: Independent, dependent and controlled variables including methodology and impact

Independent Variable	**Range and Scope**	**Methodology**
Mass of Sodium Alginate (±0.1g)	0.5 - 4.0% percent by mass by 0.5% increments	Mass measured with a balance
Dependent Variable	**Device, Precision**	
Tensile Strength (±0.1g)	• Force that the threads can withstand will be calculated by measuring the mass it can hold before breaking when held from certain height • Standardized masses that will be used are quarters each measured to 4.5g per unit • Three trials per alginate suture concentration will be taken	
Tensile Strength of Knots (±0.1g)	• Force that the thread with one knot in it can withstand will be calculated by measuring the mass it can hold before breaking • Standardized masses that will be used are quarters each measured to 4.5g per unit • Three trials per alginate concentration will be taken	
Tensile Strength after Hydration	• Force that the thread in a water bath can withstand will be calculated by measuring the mass it can hold before breaking	

(±0.1g)	• Standardized masses that will be used are quarters each measured to 4.5g per unit • Three trials per alginate concentration will be taken

Controlled Variable	Effect on Dependent variable	Methodology
Concentration of calcium chloride	The concentration of calcium chloride is directly related crosslinking of alginate solution. If the concentration of calcium chloride is increased, then the alginate will become more crosslinked impacting it's tensile strength.	• Concentration of calcium chloride measured with a balance • Calcium chloride bath replaced after each increment of percent mass alginate concentration
Type of syringe used	Size of extrusion hole on the syringe impacts the diameter of alginate that is extruded. Thicker alginate extrusion is more prone to breakage and take longer to dry out and become the thread.	• The same syringe will be used throughout the investigation • Syringe will be cleaned after each use to prevent shrinking of extrusion hole
Type of water	Tap water (especially in Calgary) contains lots of minerals (including Calcium) which can gel the alginate before introduction to the bath. It also can change the concentration of calcium in the bath.	• Distilled water will be used in this investigation to prepare both solutions
Temperature of water of the calcium chloride bath	The temperature of the bath has been shown to impact the formation of alginate (Indrani, 2013). This is because the crosslinking also depends on the energy of the surrounding system, and colder temperatures can slow the bonding of the alginate.	• The temperature of the solution will be controlled to room temperature (about 20°C) using a temperature sensor
Masses used for Force calculation	Variations in the size and shape of the masses can influence gravitational pull and thus it's mass, ultimately impacting the force calculation.	• Quarters determined to be the same mass will be used • Quarters are all the same shape, size, and mass
Type of Knot	Different knot types can place pressure on the threads, also impacting the breaking point.	• The Square knot will be used for each trial • This is because it the most common surgical knot (especially for C-sections)
Method of extruding the sodium alginate	Kinks or variations of the extruded alginate polymer can create breaking/weak points in the thread.	• Use a swift motion to make the thread over a large and long container with the calcium chloride bath • Exclude polymers that are kinked from trials as they would be an outlier and not meet the objective

Time in the calcium chloride bath	More time in the bath allows for more access to the calcium ions and thus more crosslinking of the alginate	• Wait about 3 minutes for the alginate to solidify into a polymer • Use a timer on a phone
Time in water bath for rehydration	A longer time in the rehydration can impact how much water is able to renter into the polymer, thus impacting its strength	• Allowing it to soak in the water bath for 10 minutes
Time drying on counter	A longer drying time can influence how brittle or soft the alginate sutures become.	• Timing the drying time to be 2 hours under a constant heat lamp source.

Raw Quantitative Data:

Table 4: Mass of sodium alginate and qualitative observations of the alginate solution before calcium chloride bath

Mass of Sodium Alginate (±0.1g)	Qualitative Observations
2.5	Solution is slightly more viscus than water
5.0	More viscous than previous solution, slight tinge of color and cloudiness
7.5	Similar to previous solution, more of a tinge of color and cloudiness
10.0	Significantly more viscous, little flow, cloudier and greyer colored
12.5	Glue-like viscosity, traps large air bubbles, cloudier and greyer
15.0	Thick glue-like viscosity, traps small air bubbles, cloudier and greyer. Sticky and cannot flow off stir stick
17.5	Thick slime-like viscosity, traps small air bubbles, cloudier and greyer. Sticky and cannot flow off stir stick
20.0	Slime-like consistency, breaks rather than flows, grey and quite cloudy, traps small and large air bubbles

Table 5: Number of Quarters alginate suture held before breaking point over three trials for simple tensile strength, tensile strength with a knot, and rehydrated tensile strength

Mass of Sodium Alginate (±0.1g)	Tensile Strength (Number of Quarters)			Tensile Strength with Knot Number of Quarters			Tensile Strength once Rehydrated (Number of Quarters)		
	Trial 1	Trial 2	Trial 3	Trial 1	Trial 2	Trial 3	Trial 1	Trial 2	Trial
2.5	9	8	8	3	9	5	5	6	4
5.0	14	25	31	20	36	38	39	22	35
7.5	34	13	23	25	32	17	25	27	30
10.0	13	7	12	5	11	13	10	6	14
12.5	9	11	8	7	4	4	3	2	5
15.0	4	2	5	2	1	0	5	2	0
17.5	3	3	3	1	0	0	2	2	1
20.0	1	0	0	0	0	0	1	0	3

Processed Data:

Percent Mass For sodium alginate Solution for 2.5g of sodium alginate:

$$\frac{Solute\ Mass}{Solution\ Mass}\times\ 100\% = \frac{2.5g}{500g}\times\ 100\% = 0.5\%$$

Uncertainty:

$$RU_{solute} = \frac{0.1g}{2.5g} = 0.04 \qquad RU_{solution} = \frac{25\ g}{500\ g} = 0.05$$

$$AU = (0.04 + 0.05)(0.5\%) = 0.045\%$$

$$\therefore Percent\ Mass = 0.50 \pm 0.05\ \%$$

Sample Calculation for average number of coins for 2.5g of sodium alginate standard tensile strength:

$$A = \frac{1}{n}\sum_{i=1}^{n} a_i$$

$$a_i = data\ set\ values$$
$$A = arithmetic\ mean$$
$$n = number\ of\ values$$

$$= \frac{9+8+8}{3} = 8.333\ldots\ coins \times\ 4.5g = 37.5g$$

Uncertainty:

$$RU_{mass} = \frac{0.1g}{4.5g} = 0.0222\ldots$$

$$AU = (0.0222\ldots)(37.5g) = 0.833\ldots g$$

$$\therefore Mass\ of\ Coins = 37.5 \pm 0.8\ g$$

Sample Calculation for Force withstood by 2.5g of sodium alginate standard tensile strength:

$$F = ma = (0.0375\ kg)\left(\frac{9.81m}{s^2}\right) = 0.368\ N$$

Uncertainty:

**Note: gravitational acceleration is a referenced value and therefore as an unknown uncertainty that cannot be tabulated below.*

$$RU_{mass} = \frac{0.8g}{37.5g} = 0.0213\ldots$$

$$AU = (0.0213\ldots)(0.368N) = 0.007850\ldots N$$

$$\therefore Mass\ of\ Coins = 0.368 \pm 0.008\ N$$

Table 6: Mass alginate suture held before breaking point averaging three trials for simple tensile strength, tensile strength with a knot, and rehydrated tensile strength

Percent by Mass Alginate ($\pm$0.05 %)	Tensile Strength ($\pm 0.8\ g$)	Tensile Strength with Knot ($\pm 0.8\ g$)	Tensile Strength Rehydrated ($\pm 0.8\ g$)
0.50	37.5	25.5	22.5
1.00	105.0	141.0	144.0
1.50	105.0	111.0	123.0
2.00	48.0	43.5	45.0
2.50	42.0	22.5	15.0
3.00	16.5	4.5	10.5
3.50	13.5	1.5	7.5
4.00	1.50	0.0	6.0

Table 7: Force alginate suture held before breaking point for simple tensile strength, tensile strength with a knot, and rehydrated tensile strength

Percent by Mass Alginate ($\pm$0.05 %)	Tensile Strength ($\pm 0.008\ N$)	Tensile Strength with Knot ($\pm 0.008\ N$)	Tensile Strength Rehydrated ($\pm 0.008\ N$)
0.50	0.368	0.250	0.221
1.00	1.030	1.383	1.412
1.50	1.030	1.089	1.206
2.00	0.471	0.426	0.441
2.50	0.412	0.221	0.147
3.00	0.162	0.044	0.103
3.50	0.132	0.015	0.075
4.00	0.015	0.000	0.059

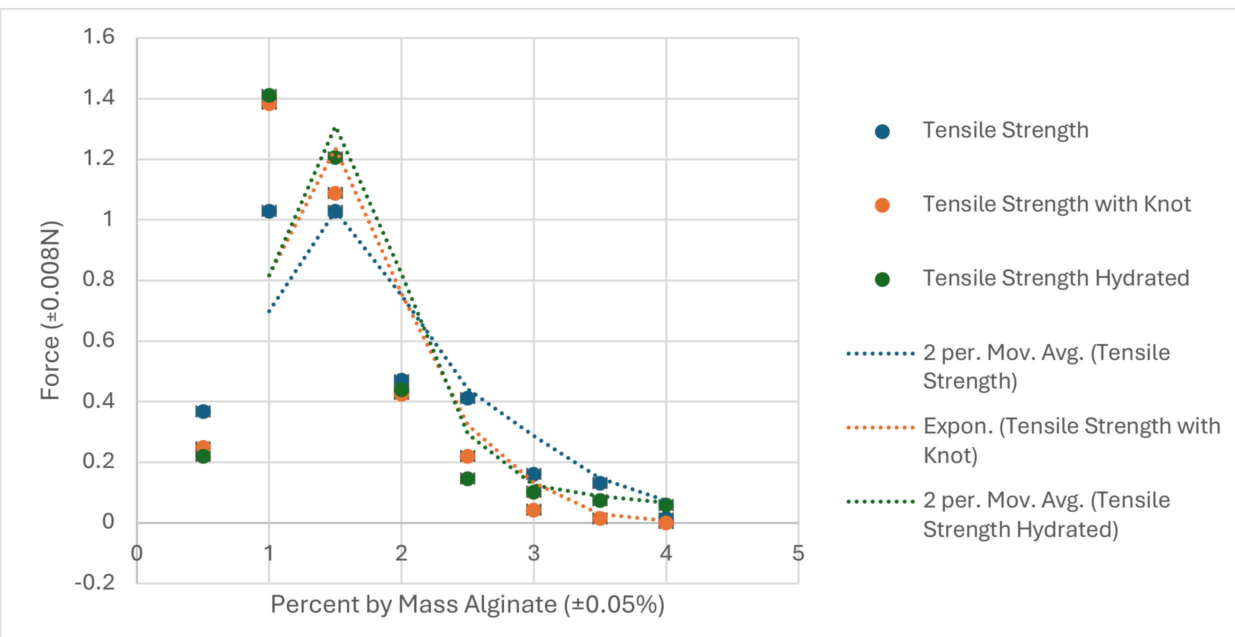


Figure 1: Force as a function of Percent by Mass alginate suture solution before breaking point for simple tensile strength, tensile strength with a knot, and rehydrated tensile strength

Conclusion:

The main purpose of this project was to investigate ways to lower healthcare inequalities across the globe by developing a viable alternative to dissolvable sutures. Too many countries face issues regarding their inability to access the crucial medication and tools that is needed to save lives. Particular to sutures, a lack of accessibility to sanitary, effective, and inexpensive dissolvable sutures can prevent mothers from receiving life-saving cesarean operations that could prevent maternal mortality. Using research and some at-home-experimentation, an alternative has been developed that could change this narrative, allowing for greater access to this unalienable right.

To find a viable alternative to these dissolvable sutures' biocompatibility, cost-effectiveness, practicality (tensile strength, knot security, absorbability), and ease of access were all assessed. The following briefly analyzes the findings from these investigations.

Biocompatibility was difficult to experiment on directly, so research was imparted to draw conclusions to the effectiveness of alginate in the human body. From this research, seen in the background and methodology, it was discovered that alginate possesses significant non-toxic, biocompatible, and non-immunogenic properties. Moreover, alginate's current use in tissue scaffolding demonstrates its biodegradability within the human body in addition to its biocompatibility. Thus, alginate meets the biocompatibility and biodegradability aspects of this alternative.

As for cost-effectiveness, this can be determined by Chuangsuwanish's 2013 study which investigated the cost effectiveness of sodium alginate as a drug delivery system for cancer. In addition, considering its relatively inexpensive price online or in grocery stores, it could certainly be mass produced for a very little cost. In comparison to PGA gut dissolvable sutures that run for about $225 for a box of 12 (a little under $20 per unit), the alginate sutures could cost a fraction of that price as they don't require complicated manufacturing processes. Alginate sutures can also be made a lot more quickly in a matter of minutes, while typical absorbable sutures take around 64 hours to manufacture (Yanistsky et al., 1981).

With practicality, specifically focusing on the thread's tensile strength and knot security, it can be discerned from *Figure 1* that alginate concentrations from about 1-2% had the best tensile strength across all categories. This means that the suture thread will be able to stand about 1 Newton of force. While this tensile strength is not suited for sutures on the surface of the skin or on areas that may exert more force, it is well suited for cutaneous and soft tissue surgery, like the ones done in C-sections. Thus, it's practicality and suitability as a dissolvable suture alternative is there. Furthermore, more research and experimentation could be done to find ways to increase the tensile strength, perhaps by adding collagen to strengthen the sutures or otherwise.

Finally, regarding ease of access. Considering the creation of these sutures is incredibly easy as well as possible with household ingredients it can be concluded that these sutures are relatively easy to access overall. This ensures that it would be a viable alternative to those in impoverished countries as they would likely be able to manufacture the material themselves.

Limitations and Further Study:

Limitation	Impact on Investigation	Further Study/Improvement
Measurement of Tensile Strength	The measurement of tensile strength of the sutures using masses may have been inaccurate as one is calculating indirectly. In addition, the set up for seeing the mass that the thread sometimes caused the thread to slip and come loose, perhaps creating new breaks in the suture thread.	Using a force meter or a tensile strength device to get exact readings rather than calculated ones.
Materials Used (combine to be stronger)	Only alginate was investigated, however, many commercial products have mixtures of different materials, thus not all possibilities for alginate as a suture were explored which may have led to a lower force measurement than expected.	Continue research and experiments using collagen to make the alginate stronger and increase the tensile strength of the sutures.
Kinks and unevenness in extruded alginate suture	Unevenness in the surface of the alginate extrusions created weak spots that often broke when doing tensile strength tests.	Continue research on increasing the viscosity of the alginate (without making it more brittle). Better methods of extruding the alginate, potentially have it remotely controlled to always have an even pressure and speed and reduce kinks.

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