Soft tissue biomechanics

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Relating to injury to the soft tissues (ligaments, tendons).

Biomechanical properties of soft tissue-

- Easily exposed to injury.
- Skin, then the underlying muscles. Systems that protect the internal organs.
- Understanding these baseline properties- Helpful in understanding the endurance of the tissue, the right level of tension, how sutures should be done during surgery.
- Composite material- New class of materials, used to make bicycles, aircrafts. Contain high strength fibers like carbon, Kevlar, which increase the strength of materials that they are embedded within (this is termed as the matrix). Light weight, high strength material.
- Soft tissue- Soft composite, collagen fibers. Anisotropic- Skin/ tissue behaves differently depending on the direction in which forces are applied to it. The behavior also varies depending on the location of the skin to which the force is applied.

Uniaxial test-

  - Tissue specimen obtained from fresh cadaver (less than 12-15 hours, as there would otherwise be extreme dehydration, which changes tissue properties).
  - Done using a UTM (universal testing machine). Has 2 clamps, bottom clamp is fixed, and the top moves at a specific speed, due to the rotation of a motor. This speed can be set (termed as displacement rate/ strain rate).
  - There is also a load cell, which shows the pull force being exerted on the tissue. Capped at a specific value of the force, which is the upper limit of the amount of force that can be applied.
  - For tissue testing, the force limit is generally 10 N. Using the force and displacement data, you can obtain the stress vs. strain curve.
  - Clamping done such that the load application is parallel to the length of the tissue (Quasi-static testing, longitudinal clamping).
  - Tissue tends to rupture after a certain level of strain, which leads to significant drop of load, and the test automatically ends (muscle fibers break).

Soft tissue exhibits different properties based on the phase.

- Phase 1- Almost linear curve, small region where there's a little bit of displacement. Fibers not aligned at all.
- Phase 2- Fibers totally aligned towards the direction of the load, highly non-linear curve. High amount of force for the same amount of displacement, due to the alignment of the fibers.
- Phase 3- Fibers completely aligned, and almost at capacity of stress that can be applied. Small amount of displacement possible, then the fibers break.

Planar biaxial test- Almost square piece of tissue.

- Apply forces in both directions.
- Use hooks to attach to the specimen if its size is very small, else, you can use clamps.
- Along each direction of load, one side is fixed, and the other is displaced at a certain rate, with the help of a motor.
- Equibiaxial- Same rate of displacement in both directions. Non-equibiaxial- Different rates in both directions.
- Human skin- In a state of biaxial free stress, which keeps the skin taut. With age, this tension reduces, which causes wrinkles. Not equibiaxial, which is why cuts in different directions take different amounts of time to heal. Strength of the collagen fibers, and the distribution of these fibers changes, which also leads to change in the amount of time required to heal from injury as well. This is one of the contributors to the anisotropic property of human tissue.
- Need to perform at least 3 iterations of any experiment, and use the average and standard deviation to come to the final plot, as the properties may vary, depending on the sample taken. So, for generalizable results, take average.

Internal organs- Fixed at certain locations, and loads at other locations. This is termed as multiaxial loading.

Langer line- Gives the direction in which the fibers run in our body. Parallel to these line- The tissue is stiffer, harder to pull at, as we need to provide enough forces to stretch the fibers. Perpendicular to it- Easier to pull at.

Ultimate tensile strength- Maximum stress at which the fibers would fracture.

- Isotropic- Properties remain the same, regardless of the direction in which force is applied.
- Transverse isotropic- Isotropic within the same plane, not when you move to another plane when applying forces.

Muscle tissue- Not undergone uniaxial or biaxial testing. Rather, has been put through shear testing, which is why that is the only data available to us.

Black line in the graph on different soft tissues- Error bar. **Memorize which tissues are the hardest, which are intermediate and which are soft.**

- Soft tissue- A lot of internal organs.
  - Tonsils
  - Brain- Softest among the soft tissues.
  - Lungs
  - Tongue
  - Stomach
  - Spleen
  - Esophagus
  - Breast- Hardest among the soft tissues
- Intermediate tissues-
  - Liver
  - Kidney
  - Uterus- Hardest among these
  - Gallbladder- Large variation, possibly due to limited sampling available for testing.
- Hard tissues- Those tissues that have a lot of contracting and relaxing functionality (like heart and intestine, or are protective, like the skin).
  - Heart
  - Skin- Hardest among these
  - Oral cavity
  - Small intestine
  - Urinary bladder- Softest among these
  - Colon
  - Vagina
  - Muscle
  - Nasal cavity

Tissue testing- Hard to obtain consent to obtain tissue from cadavers. Need to get access to diversified kinds of tissue, for which we work on artificial tissue development. Biomechanical mimics of every tissue, to test them without ethical issues. In India, very hard to even procure skin samples (success rate of only 5% in getting consent for viable cadavers).

Modulus of elasticity of the soft tissue- Based on phase 1 testing, which is the only extent of testing that a lot of tissues have undergone.

Development of artificial tissue- To simulate different situations, by developing a dummy using it. For instance, car crashes, bullet wounds and bomb blasts.

Haptics- Used to run simulations and showcase the movement of different parts.

- Used to aid with robotic surgeries. Need a lot of experience for this to be tried out.
- Training- Needs to be done either on cadavers, where consent issues still exist, or on surgical models, which may not be structurally accurate, and they're not materially accurate, which means that the amount of force needed to perform a particular action would be different.
- Here, tissue property identification is helpful, to develop materials that closely mimic all human tissues, to create artificial cadavers, on which such procedures and techniques can be practiced.

3D printing- Complex moulds for tissue and organ fabrication.

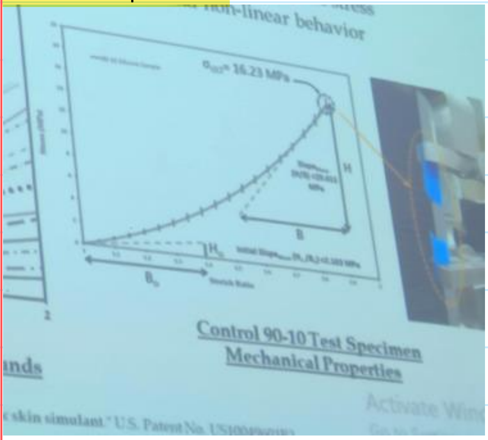
- Plantar fascia- If we want to print this (the arch of our foot), create a mould of this, and then pour in the fluid, that will set to give us the required structure.
- Most 3D printing- Very complicated, especially if we want to represent arterial structures (very intricate).

- In the absence of artificial substitutes for human skin- Pig/ porcine skin and cow/ bovine skin is used for testing. But the properties of porcine skin are significantly different from those of human skin. Deer skin is also used for the testing, and it also faces the same issue, it is quite different from human skin.
- Non-lethal ballistics- Used in general for crowd control. Need to test whether it is actually non-lethal or not. As per the NIJ (National Institute of Justice) standards, 10% gelatine is a fair metric for this testing. But gelatine actually has gel-like properties, and is much softer (lower modulus of elasticity) than human skin.
- Gels, polyurethanes- Gelatinous base.
- Artificial skin- Also used to identify the best kind of suturing, depending on the size, location and kind of wound. Simultaneous testing on actual skin and the artificial skin, to see the extent to which properties match.

- Stretch ratio= Strain + 1.
- Testing done by changing the levels of silicon in the artificial skin, and then comparing it with human skin, which has properties on a spectrum, which lie between an upper and a lower bound, as it depends on the location from which we've picked the skin, and the direction in which the sample has been cut/ forces are being applied to it.

Repeatable- When the same sample is tested multiple times, would it replicate the results that were produced originally? It also applies for different batches of the same composition.
Reproducibility- Can the composition allow a different individual to generate a sample, that generates similar properties as the original one.

Difference in the way the materials broke- As skin is anisotropic, whereas this developed material is isotropic. But the stress at which it broke was similar to that of the skin.
Control specimen- Retain 1 batch at the same composition, and perform repeated testing on it. Here, that sample is called the 90-10 test specimen.



Bottom line- Low strain slope, top line- high strain slope.

Silicon based material- Mechanically similar to skin, but did not feel like skin.
Hydrogel- 90% water, class of material that mimics the feel of skin. Eg.- Agar is a type of hydrogel. The mechanical integrity is very different from skin.

Artificial artery- Arteries are not flat, they are circular, and generally have 3 layers (layer names not that important), each having their own specific thickness and fibre distribution. Coaxial in 1 layer, longitudinal in the other 2. Goal of making these mimics- Stent testing (done in balloon angioplasty, where a deflated stent is inserted, and then inflated to open up the artery).

- Oversized stent- Scratches the surface of the artery, which leads to infection, and hence thrombosis (ingrowth of tissue, which blocks the stent, thus creating another clot).

Make an arterial replica, that is accurate to the individual for whom the stent needs to be placed, to accurately determine stent size.
Take a series of MRI images (termed as Z-stack) in all 3 planes (coronal, sagittal, transversal). Use these images to create a 3D model of the artery. It is termed as the arterial lumen model (where the lumen is the hollow section of the artery).

Creating the layers around the 3D print of this hollow section- Controlled dipping. Try out different durations of dipping the mould into the material, and see when we are able to attain the required thickness.

Artificial brain tissue- To test and simulate for traumatic brain injury.

Calcaneal fat pad- Main tissue under the heel, cushioning for the entire body weight, undergoes a lot of wear and tear. If damaged, need surgery to insert a gel, to provide the cushioning again, or using an external insole.
Testing by UTM (single loading), or by multiple cycles of loading and unloading- Multiple cycles more realistic to simulate the potential forces acting on the calcaneal fat pad (termed as cyclic loading and unloading strain tests).

Diabetic foot condition- Hard, stiff fat pad.
Plantar fasciitis- Poor condition of the foot arch (Plantar fascia).

Study of properties on healthy, diabetic foot and plantar fasciitis affected heel pads. Then, develop own compositions of gels, to match plots with each of these compositions, to have a representative material for testing, without having to obtain cadaveric heel pads. **Testing- Compression test.**

Artificial heel surrogates- Analyse their structure and the nature of their surface.

Tribology- Study of friction and lubrication.

Heel system- Surface of the heel + the bone structure + fluid in between them for lubrication. We study the interaction of this system with the ground.
Walking fast- Less portion of the heel in contact with the ground, which could potentially cause slipping.

Different wound shapes and the appropriate way on how to suture them. Developing a skin simulant (skin phantom), and then observe these properties on them. Injured skin- Weaker (lower modulus of elasticity) than non-injured skin. Suturing- Makes the properties shoot back up, but it may exceed the properties of normal skin, thus showing that there is some residual tension (over suturing).

DIC- Digital Image Correlation.

High strain zone surrounded by a low strain zone- Region where the fracture is most likely to happen.

Cuts/ incisions to be made at locations where there is not high strain. During surgery, this is optimal, to minimize the strain put on the sutures, to reduce rupture/ risk of infection.

Skin grafting- When there is significant loss of skin, you take a healthy portion of skin from another location of the body, which is easy to heal (generally from the thighs). Process this skin through a machine that puts cuts in it, that allows it to stretch and cover a larger area of skin. Cel proliferations- Lead to faster wound healing, while reducing the risk of infection.

Challenges-

- Skin is very expensive.
- Body rejection of skin not from the same body. So, cadaveric skin, or skin from other animals cannot be used.
- Need to use a very small piece of skin to replace a large portion. Right now, the maximum possible is 3:1 (stretch the sample to cover 3 times its original area).
- Poisson's strain- Must be negative for metamaterials (expand when you pull at them, instead of curving).

Speckles- Must stand out, differently coloured.

Hernia- An organ around the abdominal region protrudes out. Put back using hernial mesh (made of polypropylene). Mesh often fails. Want to mimic its interaction with abdominal tissue, to see which aspect of the interaction leads to its failure. Structure of the mesh needs to be tweaked to minimize the stress exerted on the mesh.