LECTURE 16: Sustainable Materials for Healthcare

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Sustainable Materials, Fall 2024

Artwork made using Gemini,
a Large Language Model by Google.
Generated June 4, 2024.

Announcements

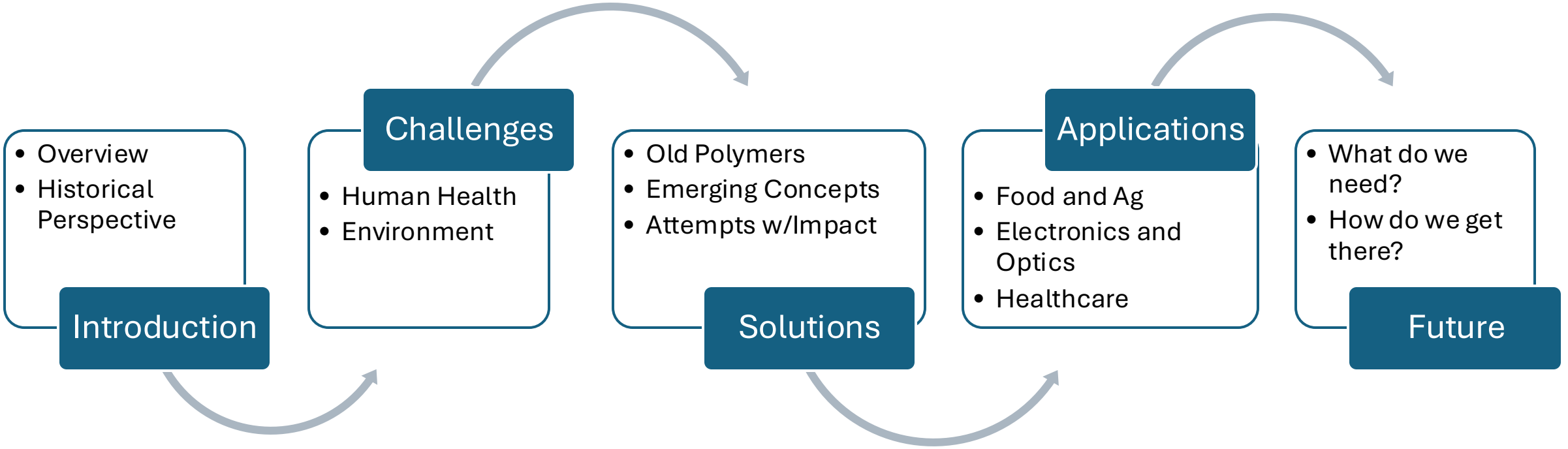
- **Assignment 5** is live due on 11/20/24. Please follow the instructions from Artem's last class for the assignment

- **Project Checkpoint #5** will be live next week (due on 11/27) – LCA Analysis of your projects

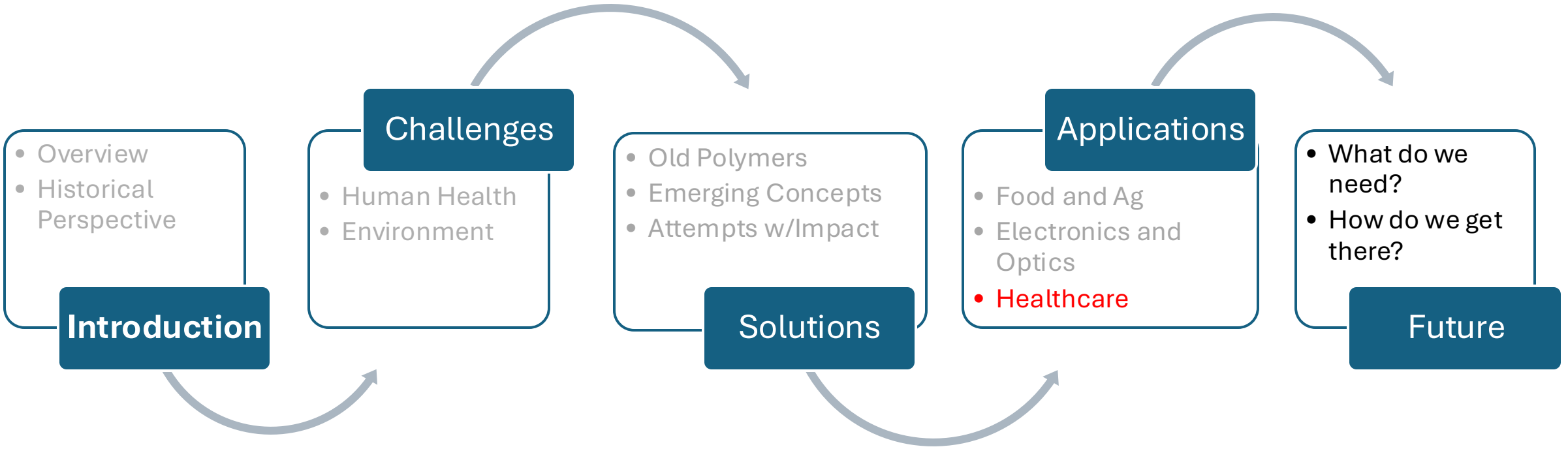
- **Lab Demonstrations next week:**
  - We will meet in class at 3 pm on Monday and Wednesday. Please be on time!
  - Class will split into 4 groups of 6-7 students
  - There will be 4 different demos covered across both classes in different parts of the Kaplan Lab

- **Finals:**
  - Presentations on Dec 2, 4 and 9th. Slots will be communicated via email
  - Please upload slides the night before on canvas.
  - Final report due Dec 16th

Course Overview



Course Overview



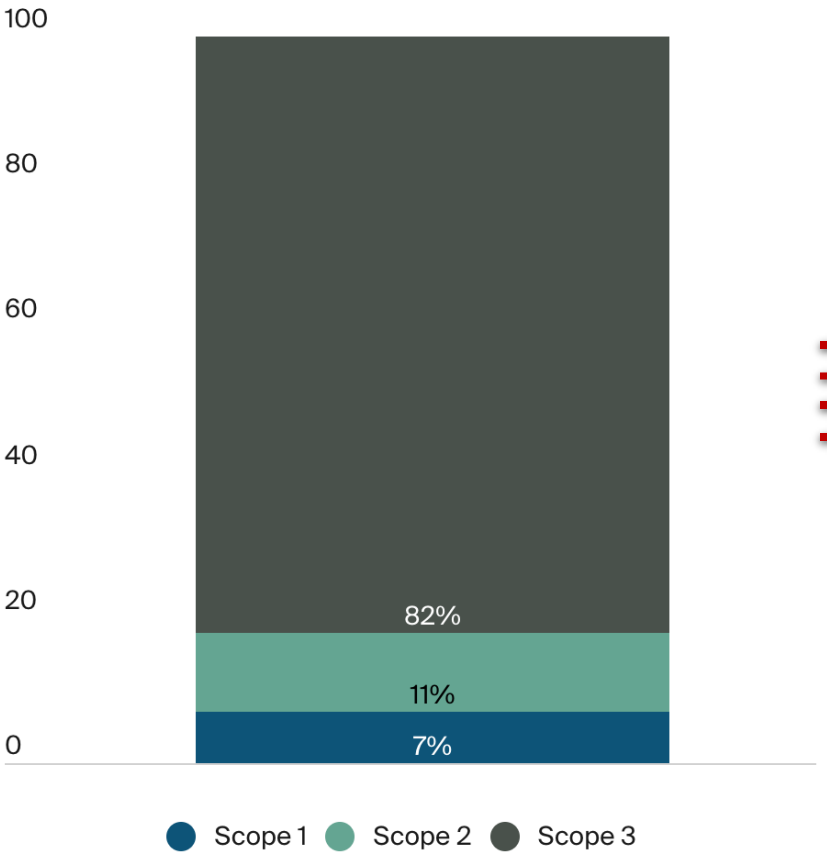
What are your favorite applications so far from what we've discussed?

Overview

- The environmental impact of healthcare
- Evolution of Healthcare: A material science perspective
- Design challenges for healthcare materials
- Sustainable Approaches
- Innovations in sustainable materials for healthcare

Healthcare has Adverse Ecological Impact

Greenhouse gas emissions, 2018



Scope 3

All other supply-chain emissions including:

- Water and waste
- Energy
- Transport
- Finance, insurance, administration, and public health
- Testing and research
- Construction
- Other manufacturing
- Information and computer technology, equipment, and services
- Plastics, rubber, textiles, and paper
- Medical supplies
- Medical devices
- Pharmaceuticals and chemicals
- Food
- Other

Scope 2

Emissions from direct purchases of energy

Scope 1

Direct emissions from health care facilities

- Worldwide health sector contributes 4.6% to the total GHG emissions
- Majority of the emissions come through the production and transportation of goods
- Medical consumables further contribute to waste streams

Source: https://www.commonwealthfund.org/publications/explainer/2022/apr/how-us-health-care-system-contributes-climate-change

Types of Material Waste Generated by Healthcare

- **Consumables:** single use catheters, IV, syringes and needles etc
- **PPE:** Gloves, masks, head covers, scrubs, lab coats etc.
- **Packaging:** Drug and consumable packaging

Source: https://www.commonwealthfund.org/publications/explainer/2022/apr/how-us-health-care-system-contributes-climate-change

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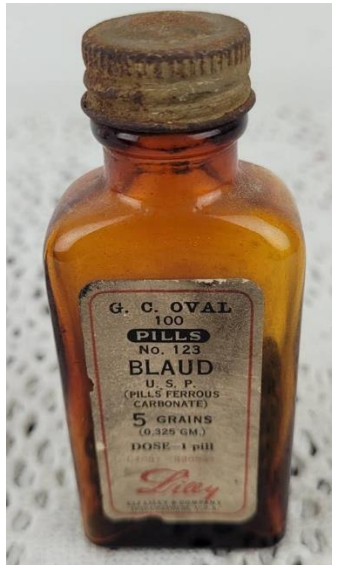
Medical Equipment Evolved from Reusable to Single-use



- Medical equipment and PPE was made of reusable materials like glass, metals and cotton

Medical Equipment Evolved from Reusable to Single-use

- Medical equipment and PPE was made of reusable materials like glass, metals and cotton
- It is now replaced by synthetic single-use materials

Key Advantages of Synthetic Materials in Biomedical Applications

- Low cost
- Sterility
- Comfortable/ easy to use
- Higher patient compliance
- Safety
- Biocompatibility/ non-immunogenic
- Higher shelf-life of stored patient samples and drugs
- Easy transport

Sterility is the Biggest Concern with Reusable Materials

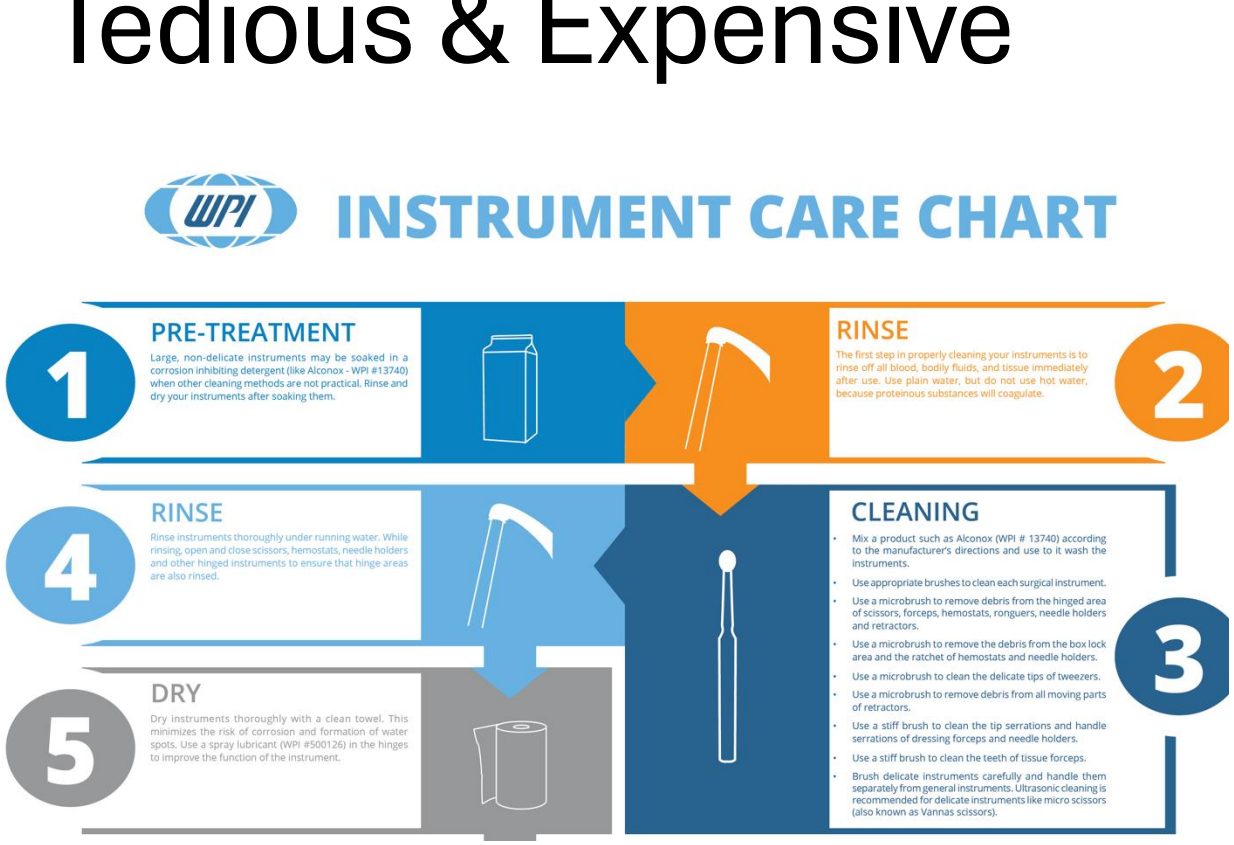
- ALL surgical equipment must be free of –
  - Human fluids/ tissue remains
  - Pathogens
  - Cytotoxic or immunogenic chemicals

- Single-use materials are sterilized and packaged in a way to maintain sterility

- FDA has strict regulations for single-use items that are reused

- Reusable materials must be decontaminated and sterilized prior to each use

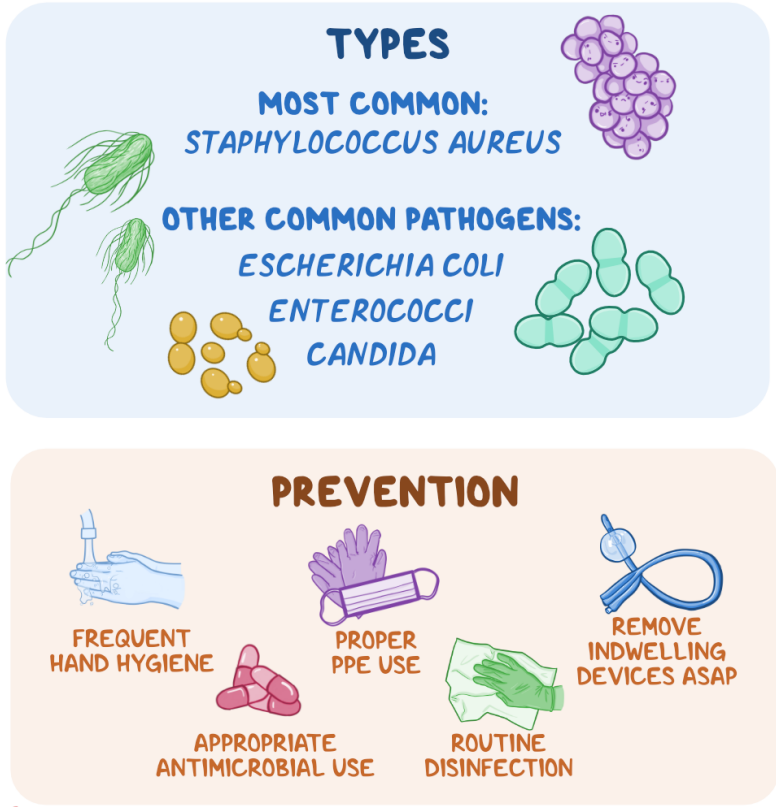
Sterilization of Reusable Medical Devices is Tedious & Expensive

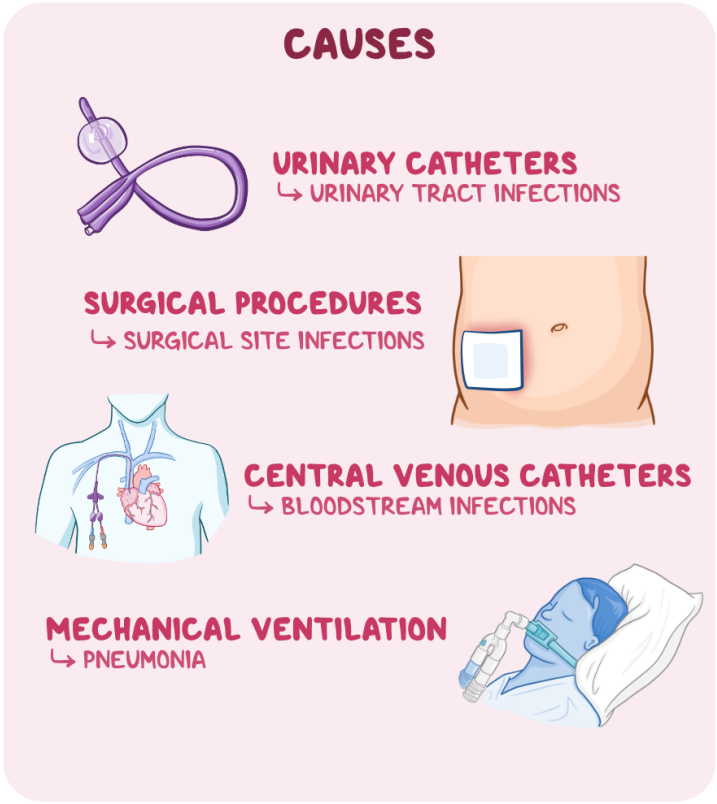


- Multiple steps involved in the sterilization process must be rigorously checked for quality control
- Energy and cost intensive

The Risk of HAIs is a Serious Healthcare Concern

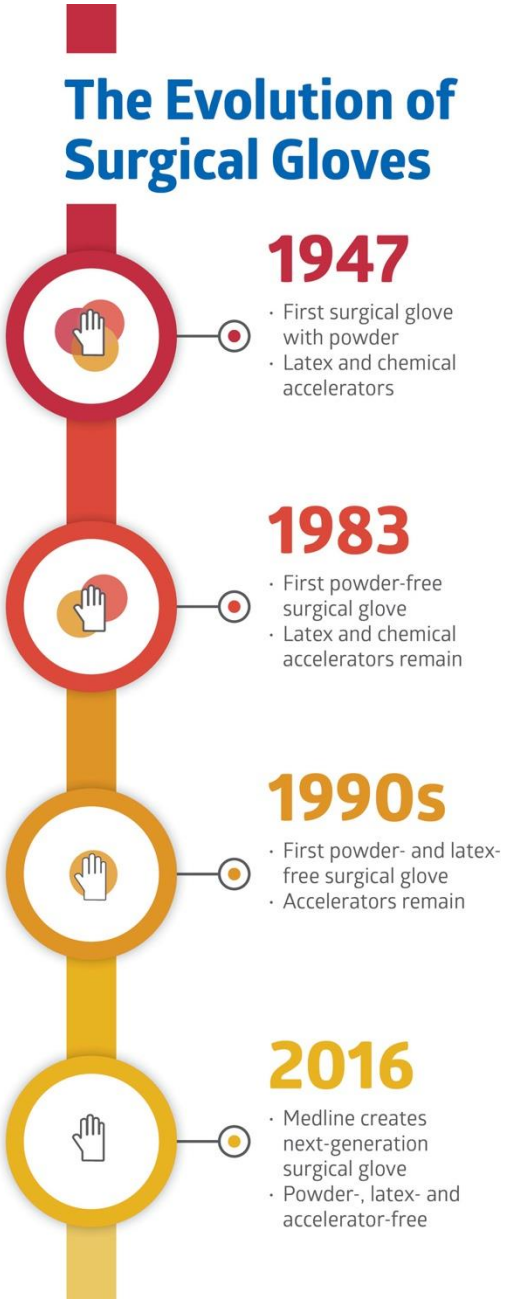
- **HAIs – Healthcare-associated infections** that patients get during or shortly after receiving healthcare
- Drug-resistant pathogens more likely to be encountered in healthcare settings
- Sterile equipment may be contaminated with pathogens





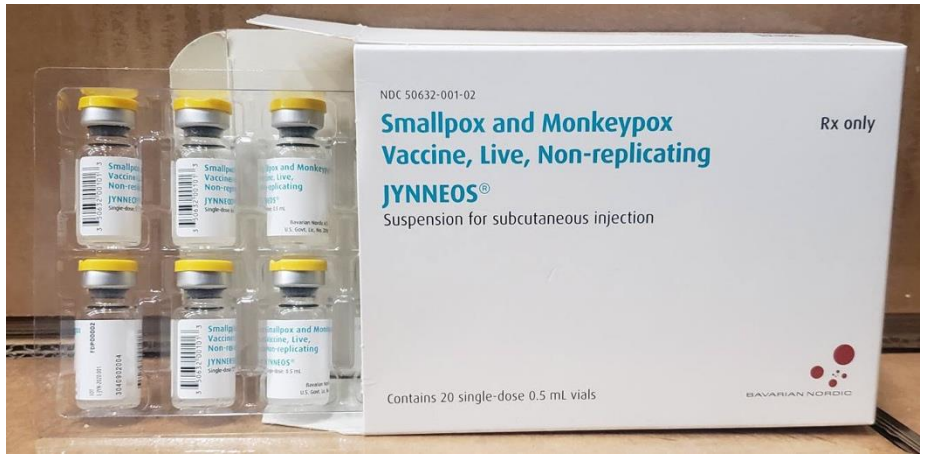
Risk of Immunogenicity Minimized use of Sustainable Materials

- Materials utilized in healthcare settings must be non-toxic and not cause immune reactions
- E.g – Latex gloves vs. powder-free nitrile gloves
- Natural materials such as latex may cause immune reactions in patients and healthcare works
- Powder gloves also cause increased sensitivity and greater risks for infections



Materials for Drug Packaging and Transport must ensure Stability and Efficacy

- Safe Transportation – shatter-proof, not sensitive to temperature and light
- Free of harmful chemicals that leach into drug – BPA
- Non-reactive to drug formulations
- Preserves efficacy
- Minimizes contamination



- **Most prescription medication containers are not recyclable due to risk of contamination**

Material Properties are Crucial for Performance of Medical Devices

- Material properties such as stiffness, transparency, charge, oxygen permeability, dictate their applicability for fabricating medical devices

- E.G – PVC blood bags vs. Glass
  - Flexible
  - Shatter-proof
  - Oxygen permeable
  - Sterile
  - Cheap

The Disposal of Medical Waste is Energy and Labor Intensive

- Medical waste is likely to be contaminated by –
  - Harmful chemicals (chemotherapy, drugs etc)
  - Pathogens
- Sorting of waste requires prior knowledge and care
- Waste sorted by contamination type and risk during disposal
  - E.g: Bio- sharps bins have to be incinerated while liquid waste is bleached
- Specialized equipment needed for decontamination
- Disposal post decontamination is single stream

Generator Responsibility

Step 2 - Packaging & Labeling

How do we Improve Sustainability in Healthcare?

- Reducing the bio-burden of medical equipment – Innovations to improve sterility
- Energy efficient decontamination processes
- Biodegradable packing materials for single-use consumables
- Use of bio-based polymers for medical applications

Class Discussion:

- Using sustainable materials in healthcare.

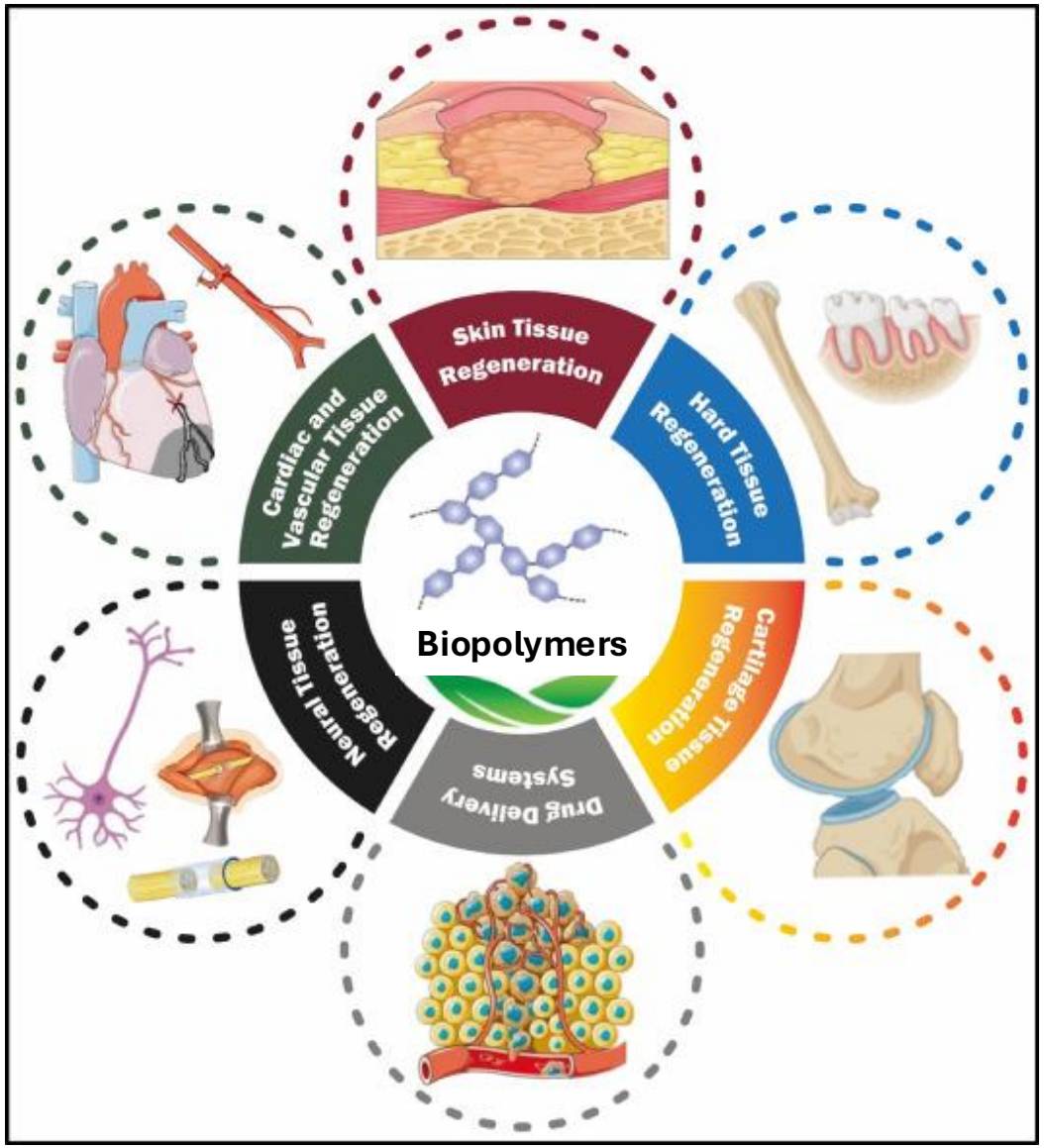
- Discuss the following in groups:

  - What are some biomedical applications where sustainable materials may be introduced?
  - What types of sustainable materials may be utilized for biomedical applications?
  - What are the salient features of these materials?
  - What are some limitations that need to be addressed?

- Discuss with the class

Bio-based Polymers are Promising Alternatives

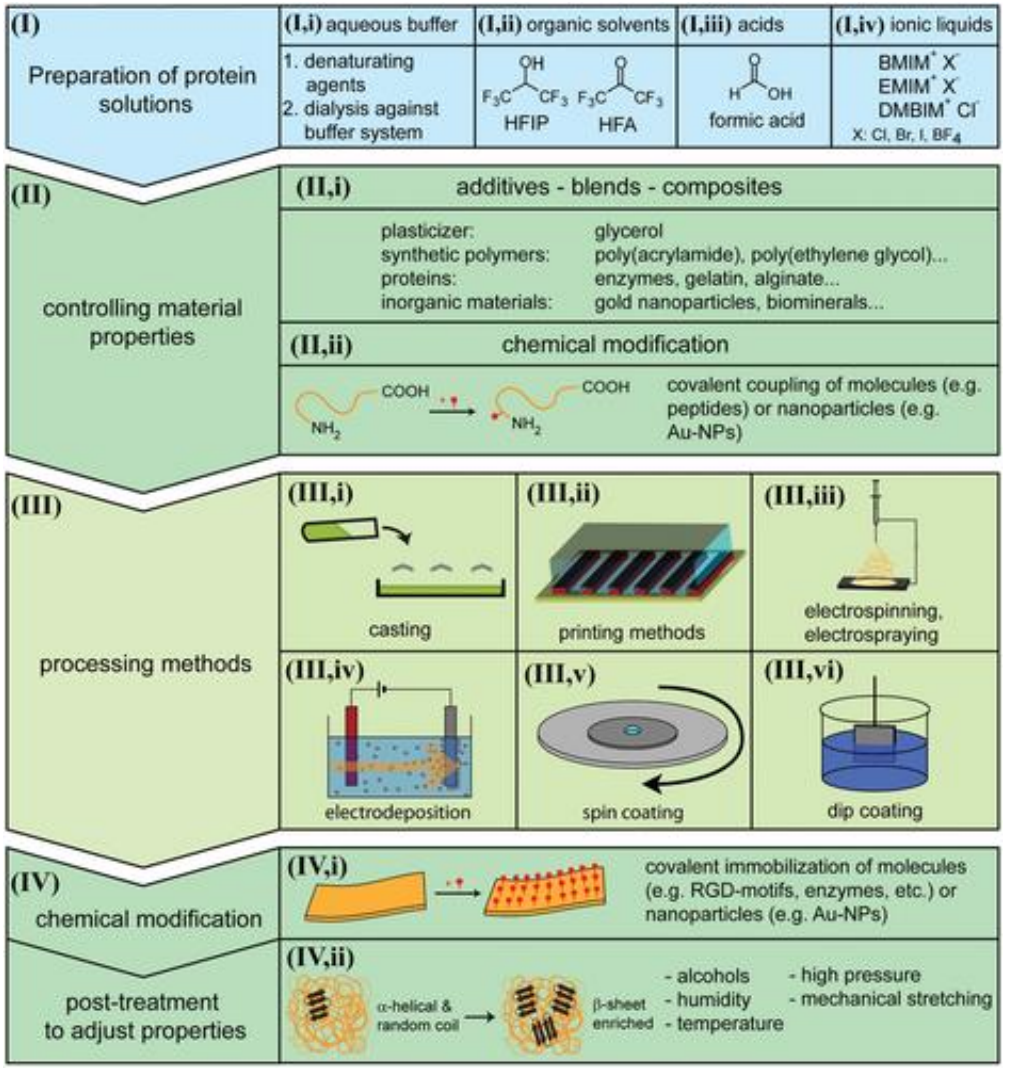
- Biopolymers are biodegradable and bioresorbable
- Water-based, non-toxic processing strategies
- Biocompatibility and low immunogenicity
- Versatile functionality possible



Sustainable Materials may be Engineered to Impart Favorable Material Properties

- Physical or chemical modifications, use of bio-based additives, novel processing and fabrication methods to achieve desired properties

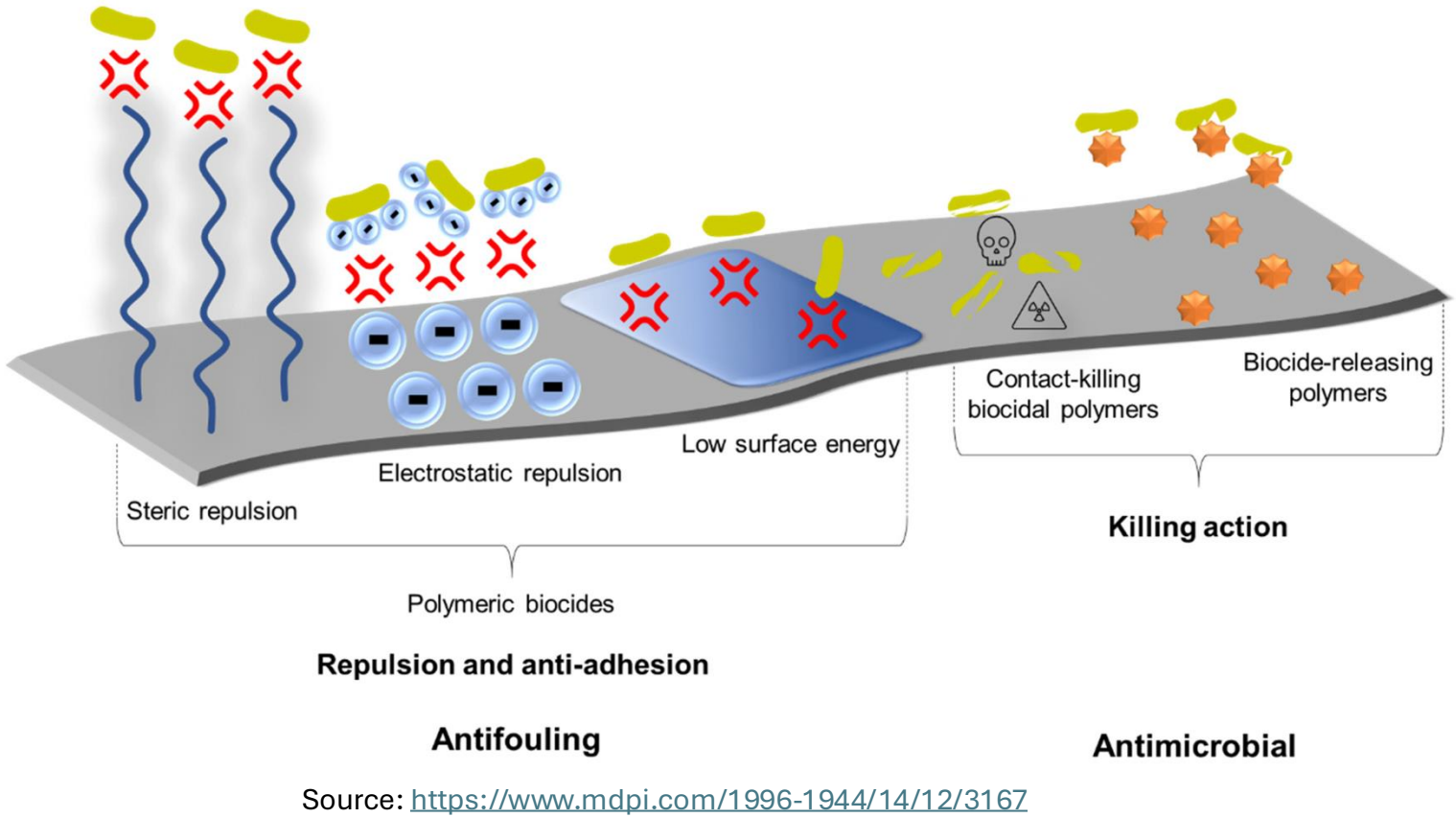
- **Ideal Strategies must be –**
  - Fossil-fuel free/ reduced
  - Energy efficient
  - Biodegradable
  - Biocompatible
  - Non-toxic
  - Sterile/ sterilizable



Source: https://onlinelibrary.wiley.com/doi/full/10.1002/adsu.202000167

Sustainable Materials that Enhance Sterility

- Materials that minimize microbial contamination by preventing adhesion, killing on contact or release antimicrobial agents
- Minimize the risk of HAIs
- Reduced need for lengthy and tedious sterilization processes
- Energy efficient



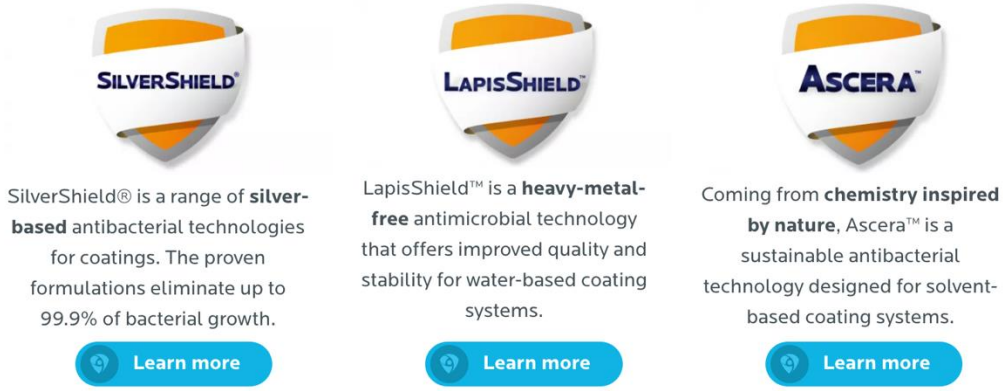
Source: https://www.mdpi.com/1996-1944/14/12/3167

Antibacterial Surfaces are Increasingly Common

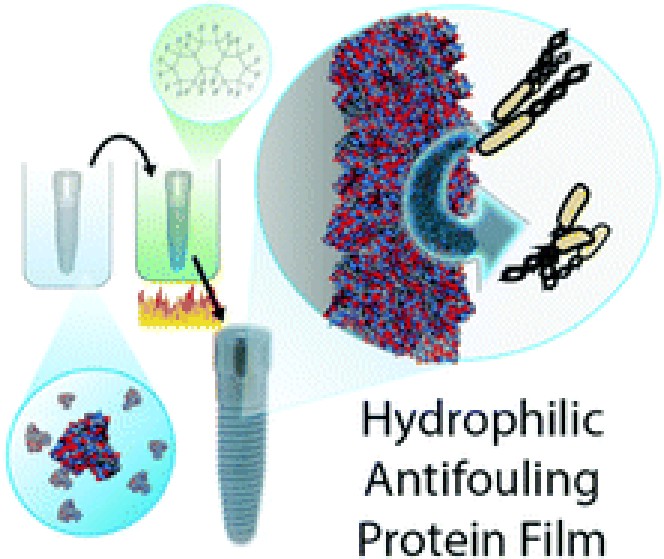
- Contains antimicrobial agents in the paint –
  - Copper/ silver
  - Antimicrobial polymers
  - Naturally antimicrobial additives (phytochemicals)

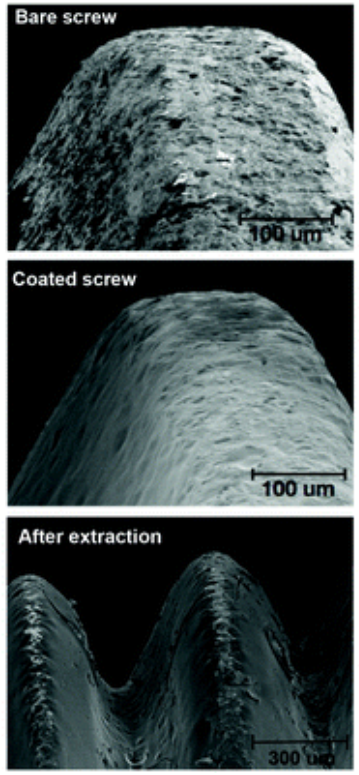
- Ideal for hospitals and high contact areas to reduce airborne and surface-borne pathogens

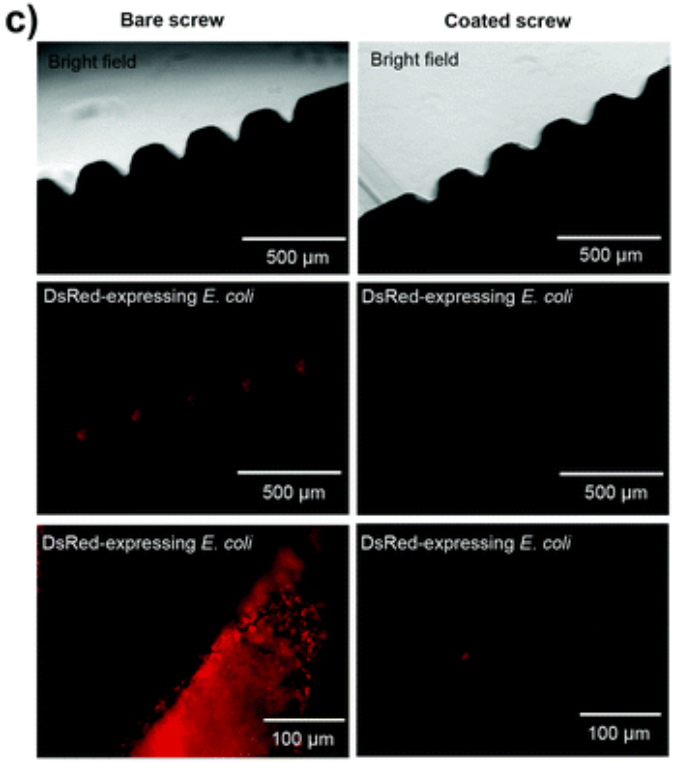
- Features:
  - Low cost
  - Easy to clean
  - Durable
  - Reduced decontamination needs



Surgical Screws Coated with Anti-Fouling Protein, Prevents Bacterial Contamination



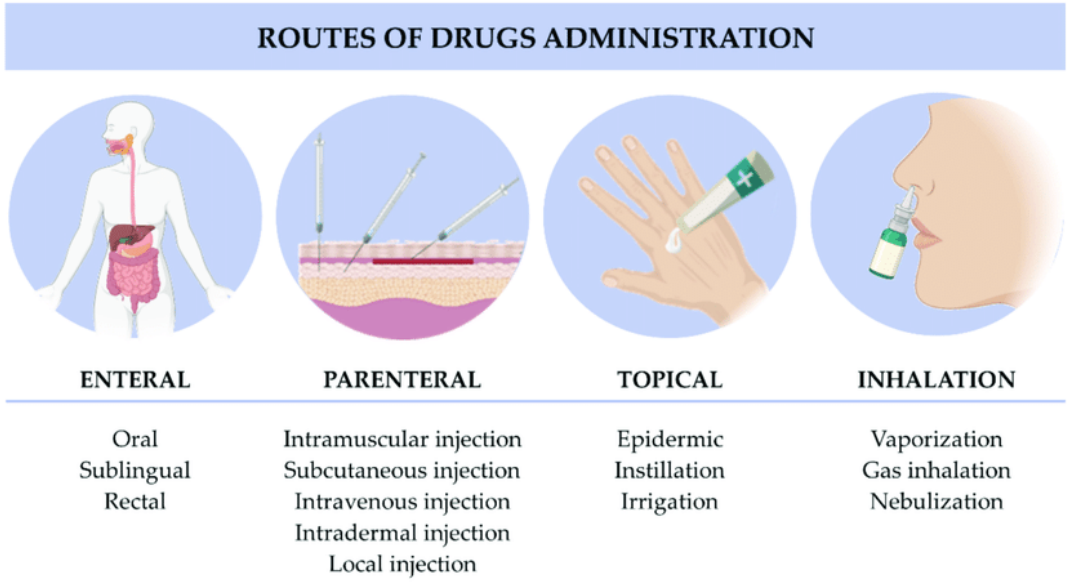




- Protein-based material is biocompatible and biodegradable
- Minimizes contamination and the need for sterilization techniques
- Green processing and packaging options

Sustainable Materials to Improve Shelf-life and Administration Strategy

- **Shelf-life:**
  - Reduce packaging needs
  - Prolong storage duration
  - Minimize need for cold storage
  - Maintain efficacy



- **Administration Strategy:**
  - Minimize dosages – smart/ programmable delivery
  - Minimal material usage
  - Optimize route of administration – better patient compliance

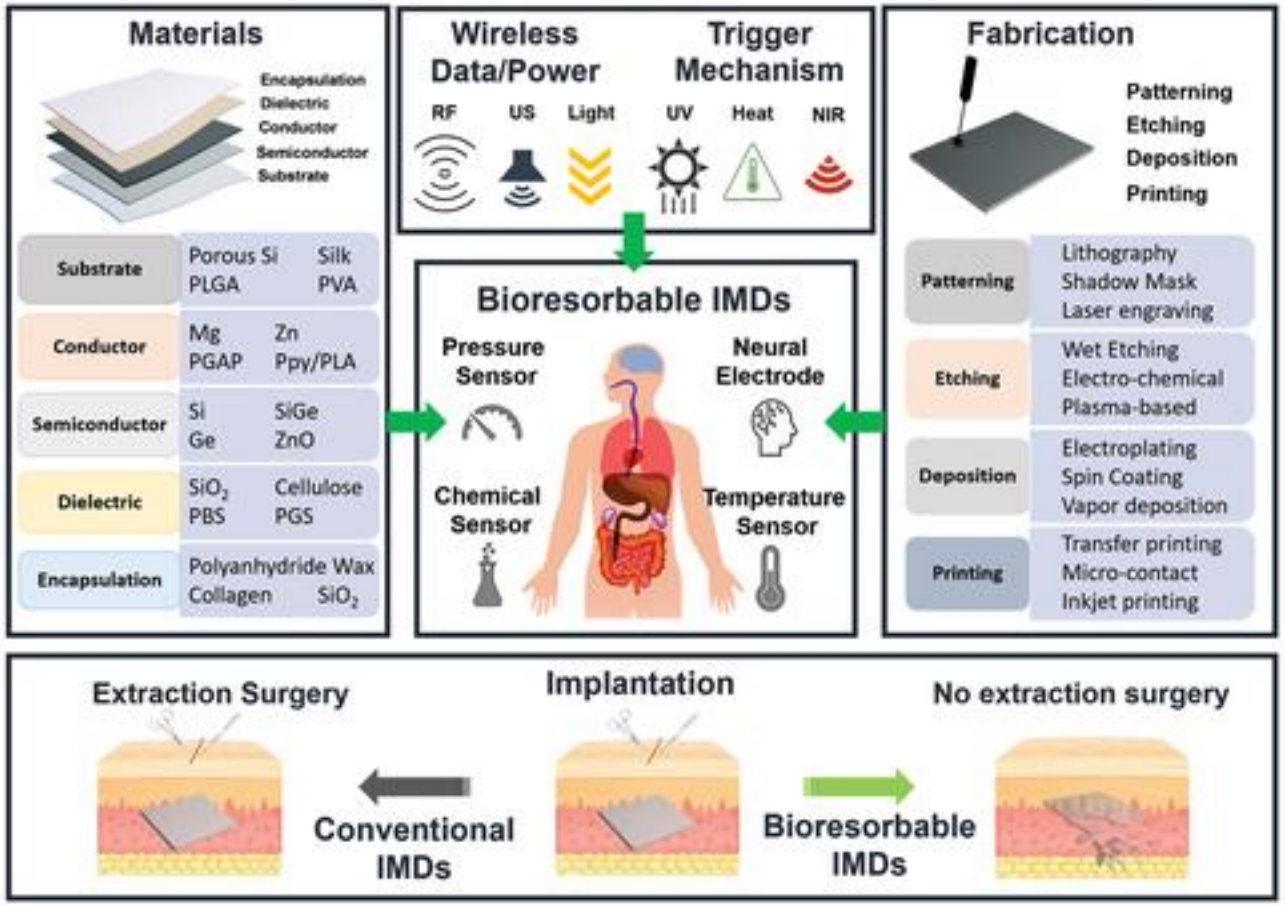
Silk Microneedles for Transdermal Vaccine Delivery and Improved Shelf-life

VAXESS technologies

- **Single dosage -** Microneedle delivery enables sustained release of vaccine ensuring effective immune response
- **Simplified shipping and storage –** silk protects sensitive compounds even at room temperature
- Biodegradable biopolymer-based approach

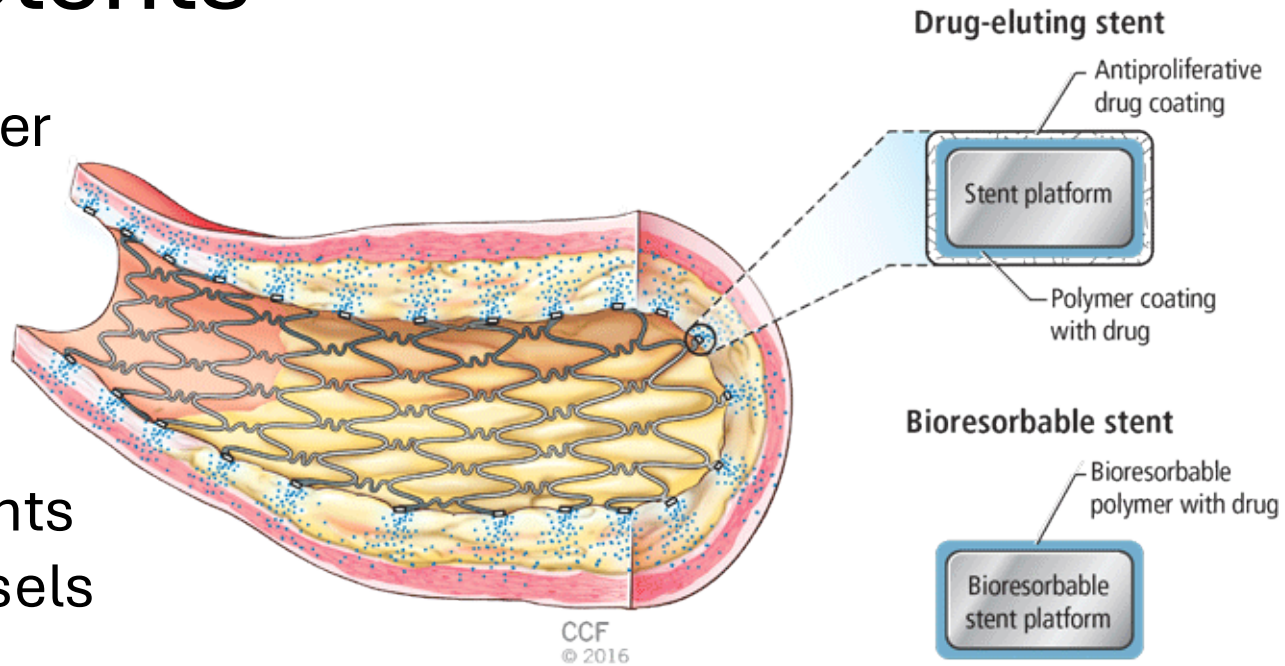
Bioresorbable Materials as Alternatives to Non-biodegradable Materials

- Bio-based fabrication strategies
- Fewer medical interventions
- Reduced likelihood of infections
- Improved wound-healing
- Improved patient compliance



Bioresorbable Cardiac Stents

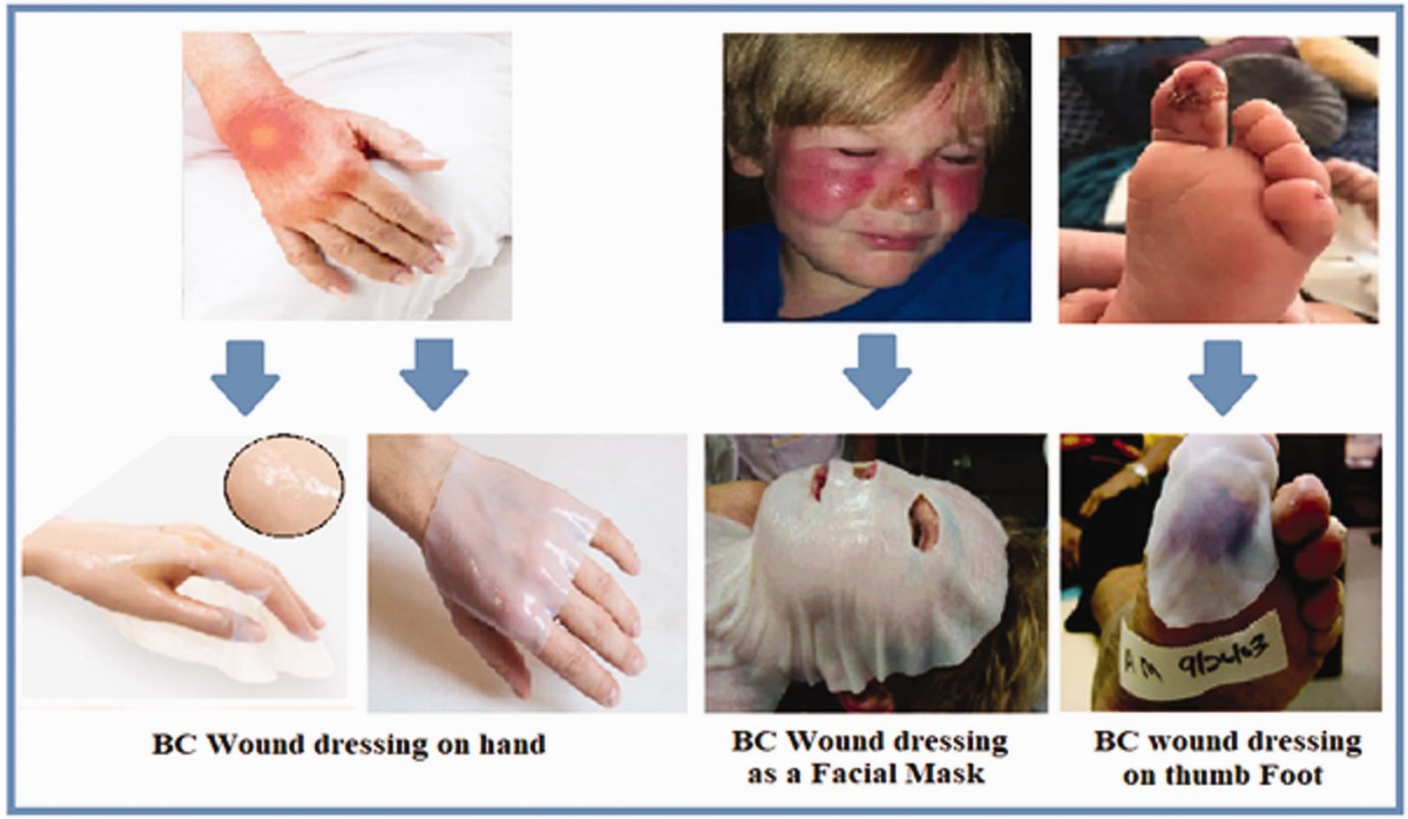
- PLLA (poly-L-lactic acid) based polymer used for fabricating stents
- Rate of resorption easily controlled
- Better outcomes that drug-eluting stents due to natural expansion of blood vessels
- Key Advantages:
  - Reducing number of procedures
  - Superior performance



Bacterial Cellulosic Wound Dressings are Superior to Traditional Strategies

- Salient Features:
  - Hydrated
  - Flexible – moldable
  - Oxygen permeability
  - Ability to load therapeutics for wound-healing

- Biodegradable alternative to traditional methods



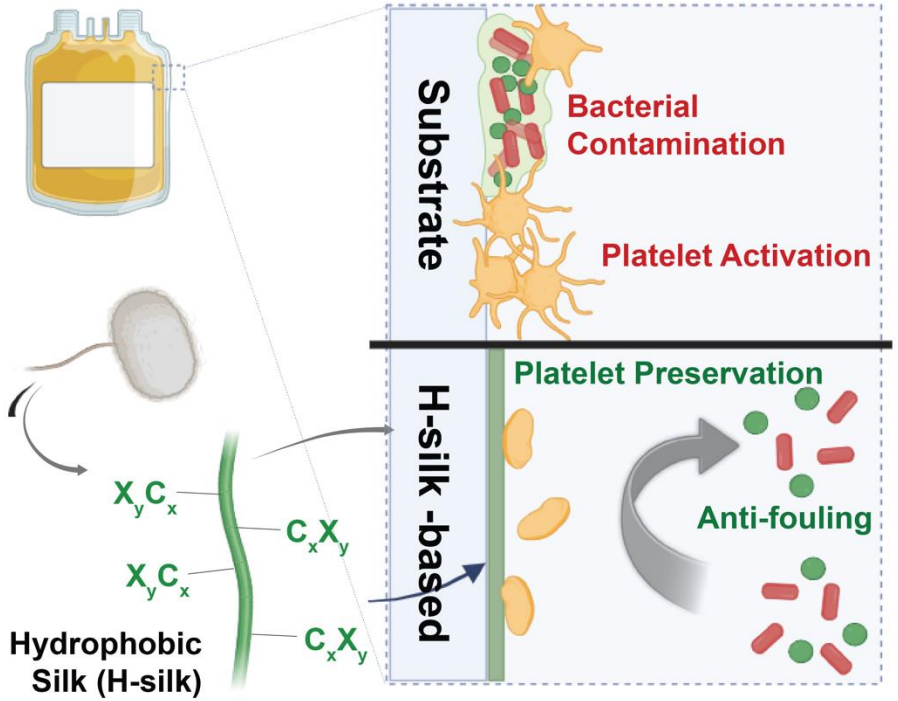
Biodegradable Packaging Materials for Medicine

- Water-resistant, paper-based packaging materials for pills
- Compostable and recyclable
- Bio-based water repellent coating
- Easy to clean

Parcel HEALTH

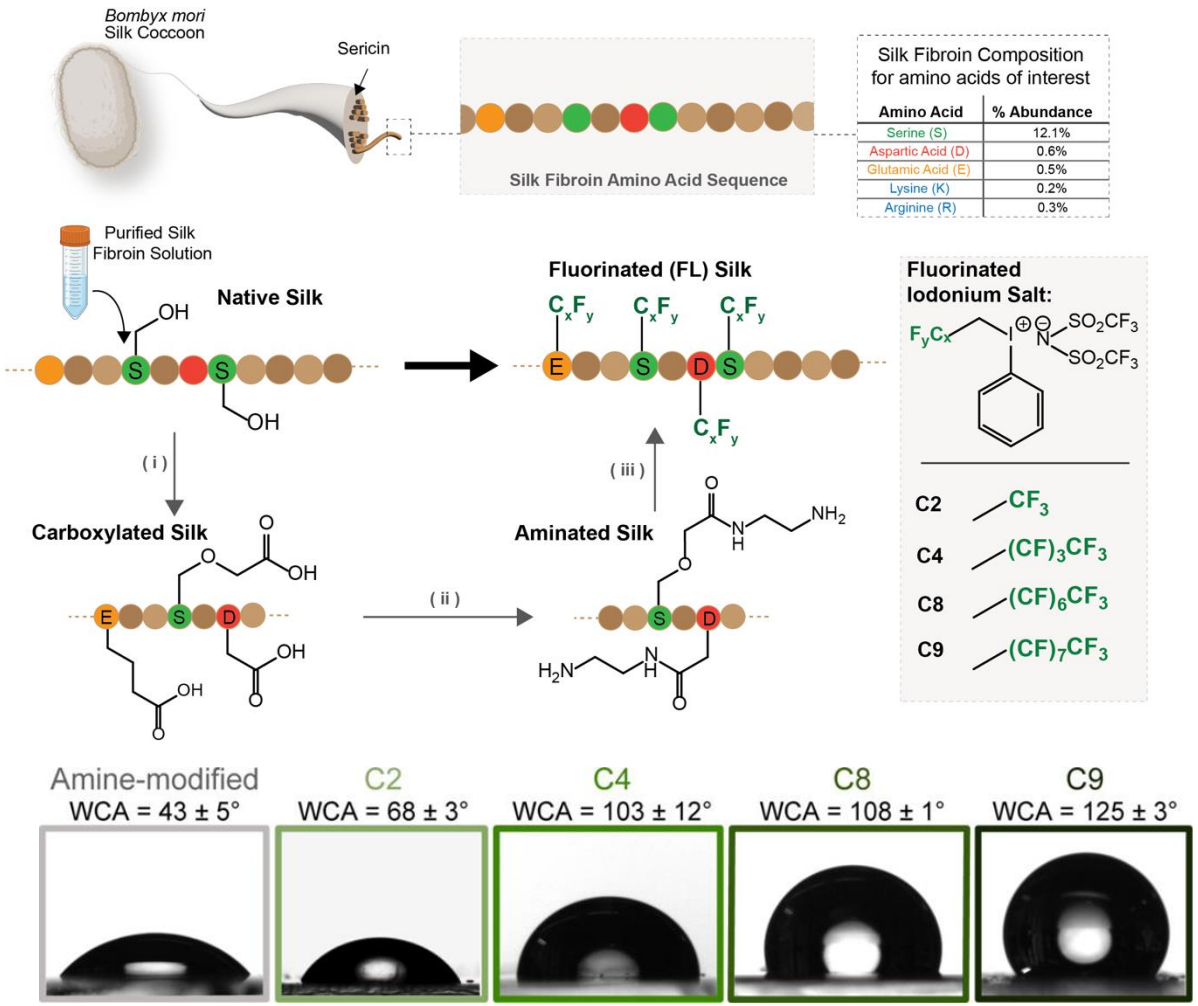
Fluorinated Silk as an Alternative for Storing Platelets

- Hydrophobic silk coating prepared by chemically modifying perfluorocarbons onto silk
- Coating is anti-fouling
- Prevents bacterial contamination and platelet adhesion and aggregation

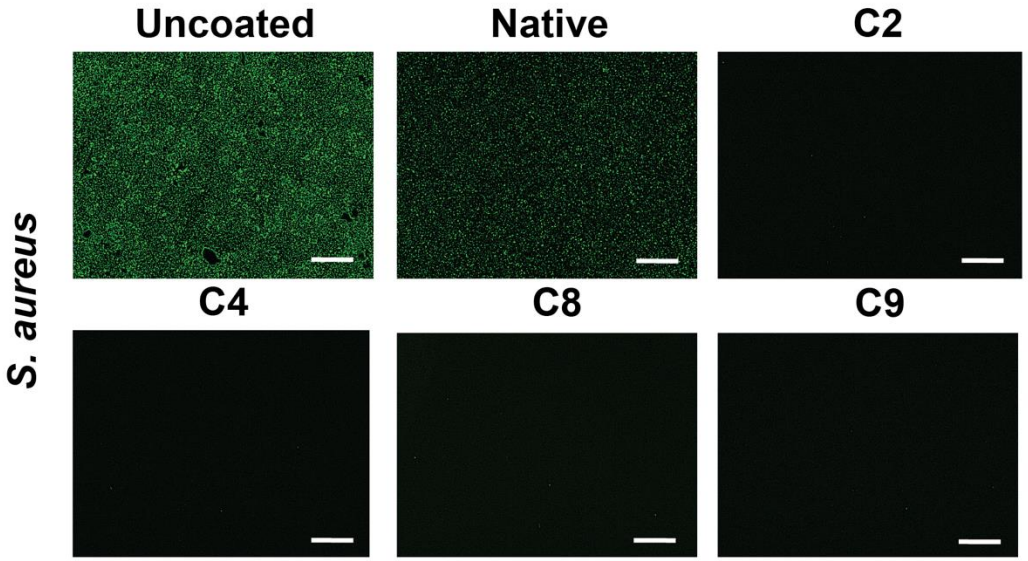


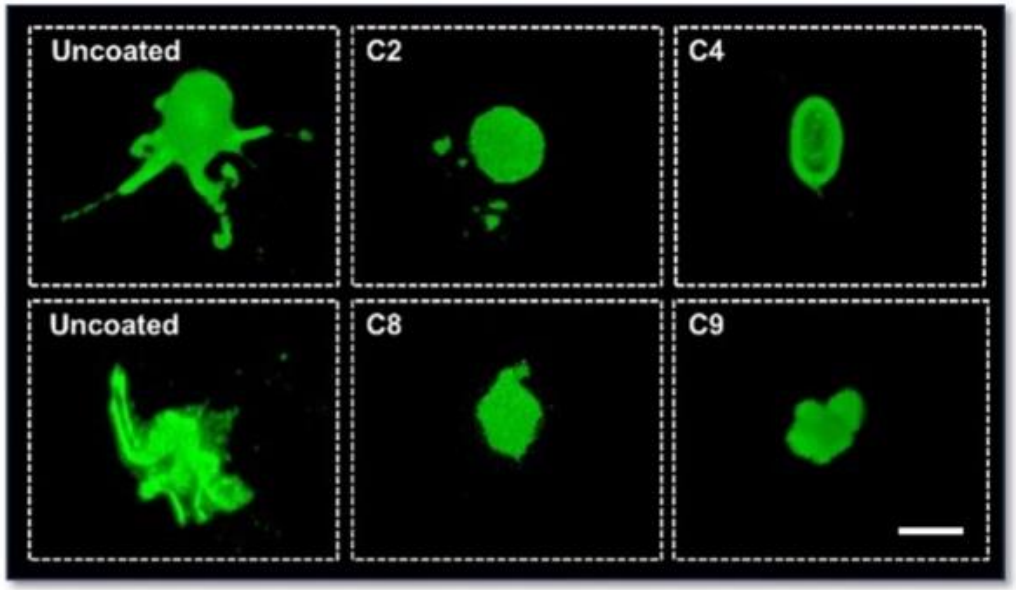
Hydrophobic Silk is Prepared by Chemical Modification

- Hydrophobic silk coating prepared by chemically modifying perfluorocarbons onto silk
- Hydrophobicity comparable to Teflon
- Teflon is widely used in blood-contacting devices due to hydrophobicity



H-Silk Prevents Microbial Contamination and Platelet Activation





- No microbes adhered to Hsilk indicating anti-fouling behavior
- Platelets preserve discoid morphology indicating low activation
- Improved shelf-life of platelets stored in ambient conditions with low risk of contamination

Conclusions

- There is a need for sustainability in healthcare
- Challenges are associated with cost, biocompatibility, sterility and material properties
- Biopolymer-based materials are emerging alternatives

Biopolymer Metropolis: The Living City
Artwork made using Gemini, a Large Language Model by Google.
Generated June 4, 2024.