Wool/Acrylic Blended Fabrics as Next-Generation Photodynamic Antimicrobial Materials

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Antibiotic Resistance

- 2.8 million antibiotic resistant infections per year
- Highest risk is staying in a health care facility
- Antimicrobial materials as alternative for antibiotic use in hospitals and health care facilities
Traditional Antimicrobial Material Methods

- Nanoparticles (silver, copper)
- Antibiotic coatings
- Quaternary Ammonium Salts
- Novel material scaffolds (hydrophobic surfaces, graphene)

- Cost and scalability
- Specificity
- Toxicity
- Cause more drug resistance
New Solution

Antimicrobial photodynamic inactivation (aPDI)

• Photosensitizers:
  • chemical compound which absorbs light energy from certain wavelengths and transfers the energy to the chosen reactant
  • Chemical compound: Rose Bengal
  • Reactant: molecular oxygen
  • Wavelengths are within the visible range (450-580nm)

- Non-toxic photosensitizer
- Visible Light
- Molecular Oxygen
Photosensitization Mechanisms

- Sensitizer
- hv
- Sens\(^{-}\) & Sub\(^{+}\)
- Type I
- \(^{3}\)O\(_{2}\)
- Oxidized Products
- Type II
- \(^{1}\)O\(_{2}\)
- Oxidized Substrate
Overall Process of aPDI
Rose Bengal
(4,5,6,7-tetrachloro-2',4',5',7'-tetraiodofluorescein)

Basic Dye Yellow 13, Cationic Yellow X-8GL dye (CY)
Why Rose Bengal?

• High quantum yield of singlet oxygen

• Intersystem Crossing
  • Singlet state non-radiatively passes to a triplet state
  • Transfers energy from excited state to the oxygen molecule

• “Heavy atom effect” increases intersystem crossing efficiency
  • Large atoms increase spin-orbit coupling
  • Allows forbidden transitions
  • Ultimately increases quantum yield of singlet oxygen
Singlet Oxygen Damage to Cells

Photosensitizer & Light → $^1\text{O}_2$ → Nucleic Acids, Lipids, Proteins
Previous Implementations

• Single photosensitizer
  • limited to a monochromatic material

• Utilize 3 main methods of incorporation
  • Covalent attachment of Photosensitizer to a polymer
  • Encapsulation of the photosensitizer
  • Scaffolding of the photosensitizer

• Novel method incorporates a photosensitizer as a dye for textiles
Creating Blended Materials

- Blended materials allow for different properties and colors
- Simultaneous vs. Sequential dying
- Electrostatic dying process
- Rose Bengal with Wool
- CY with Acrylic
Substrate Photo-oxidation studies

Production of Singlet Oxygen by Rose Bengal/Wool over time
Substrate Photo-oxidation studies

Effects of Rose Bengal concentration and singlet oxygen production
Antibacterial Photodynamic Inactivation Studies with RB-W/A Fabric

Survival of bacteria after exposure to RB dyed wool with varying RB concentrations

Survival of bacteria after exposure to RB dye wool with varying exposure times
Effect of Cationic Yellow Dyed Acrylic

### Production of singlet oxygen from RB/CY blend over time

![Graph showing production of singlet oxygen from RB/CY blend over time]

- **A**: Graph showing production of singlet oxygen from different blends over time.
  - **W/A**
  - **RB/CY1-W/A**
  - **RB/CY3-W/A**
  - **CY3-W/A**

### Survival of bacteria after exposure to RB/CY blend

![Bar chart showing survival of bacteria after exposure to RB/CY blend]

- **B**: Bar chart showing survival of bacteria after exposure to different blends.
  - **RB/CY1-W/A**
  - **RB/CY3-W/A**
  - **CY3-W/A**

Survival of bacteria after exposure to RB/CY blend
Scanning Electron Microscopy

- Scanning electron microscopy (SEM) showed membrane damage to bacteria consistent with oxidative stress
Conclusion

• Photodynamic dyed fibers can cause inactivation of microbes
• Rose Bengal/wool and cationic yellow/acrylic blends as viable microbial control
• Exploiting electrostatic interactions for cost effective and scalable dying process
• Future applications
  • Medical curtains
  • Bed sheets and pillow coverings
  • Mattress covers and linens
  • Hospital gowns and gloves
  • Gauze
Table 2. Thermodynamic parameters of photosensitized system of xanthene dyes/iodonium

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<th>( E_s ) kcal/mol</th>
<th>( E_T ) kcal/mol</th>
<th>( E_{ox} ) V</th>
<th>( E_{red} ) V</th>
<th>( \Delta G_s ) kcal/mol</th>
<th>( \Delta G_T ) kcal/mol</th>
<th>( R_b ) s(^{-1}) x 10(^2)</th>
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