Team B18: High-Flux Hemofiltration System for Toxin and Solute Removal

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Motivation

*Objective: Develop an **ECMO-hemodialysis** hybrid system to better treat acute poisoning presentations to effectively remove toxins from blood volume at a high flux rate.*

- Address limitations in current extracorporeal therapies for managing **life-threatening toxin exposures** and critical conditions.
- **Decrease strain** on ICUs due to increase in severe poisonings.
- **Increase flow rates** used in the standard of care in order **to address non-dialyzable toxins**.
- Current standard of care has blood flow rates of **only 100-500 mL/min**.

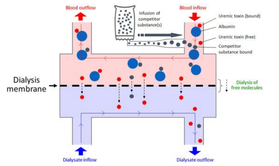


Figure 1.1: Principle of hemodialysis/hemofiltration.

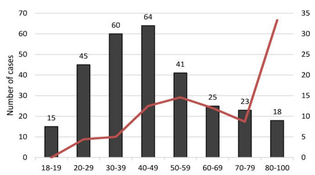


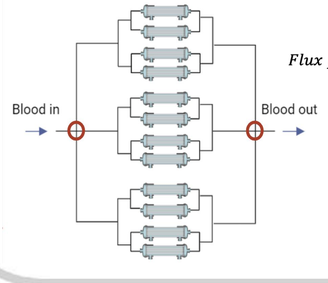
Figure 1.2: Number of acute poisoning presentations to the Emergency Dept., Jan. 2000 to Dec. 2010 (Resier et al., 2020).

Methods

Flow Through 12 Parallel Filters	• Develop 3D printed connector to align 12 filters in parallel • Achieve 3-5 L/min of flow through system with a blood viscosity mimic
Monitoring TMP	• Monitor transmembrane pressure (TMP) as flow rate is increased incrementally • Maintain adequate pressure through the system at various flow rates
Model Toxin Clearance	• Determine standard curve for various toxins using UV spectrometry • Remove dialyzable and non-dialyzable substances from the bloodstream

Design Requirements

1. Organize 12 hemofilters in parallel
2. Achieve a flow rate of 3-5 L/min
3. Maintain TMP below 600 mmHg for 15 minutes
4. Determine the optimal reading wavelength for model toxins
5. Remove model toxin greater than 200 mL/min
6. Create whole blood viscosity mimic



$$Flux\ for\ Filters\ in\ Parallel \longrightarrow Q_{Total} = \Sigma Q_i = n * Q_{Revaclear}$$

$$Q_{Total} = 5\ \text{L/min (desired total flux)}$$

$$n = 12\ \text{filters}$$

$$Q_{Revaclear} = \frac{\left(5\ \frac{\text{L}}{\text{min}}\right)}{12\ filters} = \sim 417\ mL/min$$

Final Design

- Efficient **integration of 3D printed parts** (e.g. three-way adapters) optimizing tubing system for seamless functionality at arterial and venous termini.
- Careful design preventing membrane fouling, maintaining flux rates of **3-5 L/min** in clinical settings.
- 12-filter design **promises improved efficiency** and future advancements in membrane filtration technology for clinical applications.

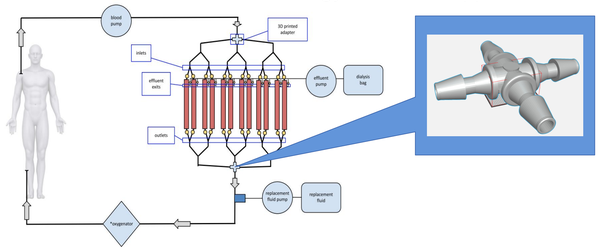


Figure 2: Schematic of the 12-filter high flux hybrid system with the 3D printed connectors.

Figure 3.1: Baxter Revaclear 300 dialyzers used in the hybrid system.

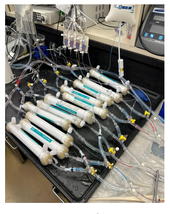


Figure 3.2: 12-filter system setup in parallel at the UMB laboratory.

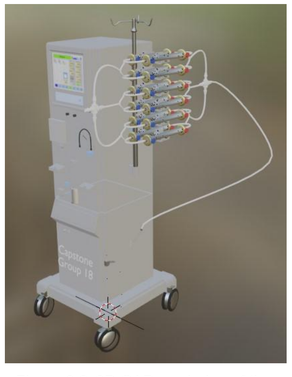
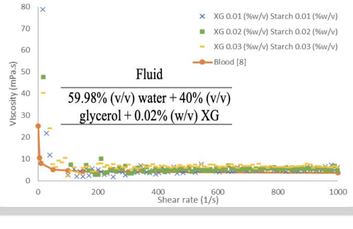


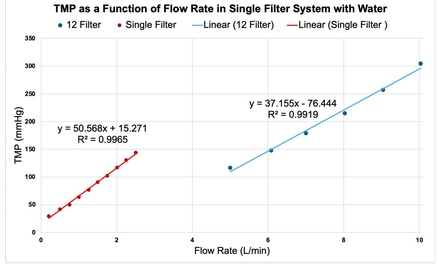
Figure 3.3: 3D CAD rendering of the 12-filter ECMO-hemodialysis hybrid system.

Results

***Table 1.* Pressure data – 12-filter system (*water*)**

Flow Rate (L/min)	Arterial Pressure (mmHg)	Venous Pressure (mmHg)	Transmembrane Pressure (mmHg)
5.00	135.00	98.00	116.50
6.08	170.00	126.00	148.00
7.00	204.00	154.00	179.00
8.03	243.00	187.00	215.00
9.04	288.00	226.00	257.00
10.03	339.00	270.00	304.50



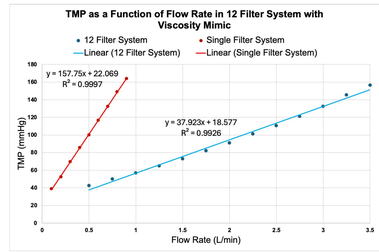


Blood Viscosity Mimic Composition:
- 300 mL dH_2O
- 200 mL Glycerin
- Xanthan Gum (0.01% [w/v])
- Soluble Starch (0.01% [w/v])

Results (cont.)

***Table 2.* Pressure data – 12-filter system (*blood viscosity mimic VI*)**

Flow Rate (L/min)	Arterial Pressure (mmHg)	Venous Pressure (mmHg)	Transmembrane Pressure (mmHg)
1.00	76.00	38.00	57.00
1.50	101.00	45.00	73.00
2.00	128.00	54.00	91.00
2.50	157.00	64.00	110.50
3.00	189.00	76.00	132.50
3.50	224.00	89.00	156.50



Observations:
- **Greater rate** of increase in TMP for single filter system versus 12-filter system.
- Effluent pressure was **0 mmHg at all points** (open to atmosphere).

Conclusions

- Successfully developed 12-filter ECMO-hemodialysis hybrid system using 12 Revaclear 300 hemofilters in a parallel configuration.
- Created a **blood viscosity mimic** that was implemented within the system.
- Maintained adequate **TMP** (**<600 mmHg**) throughout system for over 15 minutes of continuous flow.

Bioethical Considerations

Preclinical Testing	Clinical Testing	Standard of Care
Artificially pumping deceased poisoned patients' blood	Poisoned patients with no other treatment options	Weighing benefit of toxin removal against hemolysis risk and cost

Future Work

Clearance:
- Remove **dialyzable and non-dialyzable substances** from the bloodstream using the 12-filter hybrid system.

Testing:
- Optimization studies to refine testing parameters.
- Clinical testing to validate **efficacy** and **safety** of hybrid system.

Commercialization:
- Explore scalability and **integration** into current medical practices.
- **Reduce cost** of system with development of cheaper components.

References

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