iBioMed 2024

Investigation of the effect of shell shape on flow rate in roller pumps for small dialysis systems

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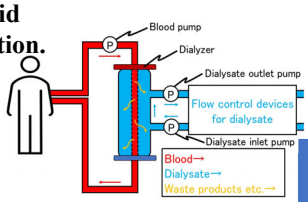
Background and Purpose

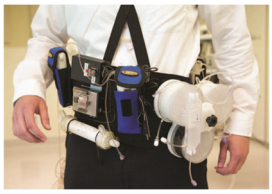
Hemodialysis treatment removes excess fluid and waste products in place of kidney function.

General hemodialysis treatment concerns

Dialysis patients are required to visit the hospital three times a week for 3–5 hours each time [1], the patient's own QOL may decrease.



Developing wearable artificial kidney (WAK) for a long period time treatment could reduce hospital visits for dialysis patients and improve their QOL.

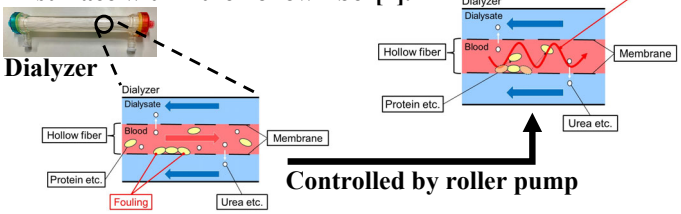


Wearable Artificial Kidney (WAK)[2]

Development of wearable dialysis system concerns

WAK is operated continuously for a long period of time, resulting in clogging (fouling) of the dialysis membrane over time.
→ Decrease in dialysis efficiency

To prevent fouling, pulsatile flow in one study showed excellent clearance [3], and pulsatile blood flow also tended to inhibit adsorption of blood components to the membrane surface within the hollow fiber[4].



Controlled by roller pump

Compact dialysis system with fouling prevention by pulsating flow

To design a compact dialysis system, we aimed to develop a new roller pump by changing the shape of the pump shell to expand the pulsating pressure fluctuation range and prevent the dialyzer filter from becoming dirty.

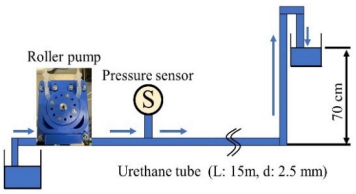
[1] Watanabe, Yuzo, et al. "Japanese society for dialysis therapy clinical guideline for Maintenance hemodialysis: hemodialysis prescriptions." Therapeutic apheresis and dialysis: official peer-reviewed journal of the International Society for Apheresis, the Japanese Society for Apheresis, the Japanese Society for Dialysis Therapy 19 (2015): 67-92.
[2] Leigh-Ann Topfer, Wearable artificial kidneys for end-stage kidney disease, CADTH issues in emerging health technologies, pp5, 2017
[3] Lee, Kyungsoo, et al. "Hemodialysis using a valveless pulsatile blood pump." ASAIO Journal 54.2 (2008): 191-196.
[4] Lee, Kyungsoo, et al. "Pulse push/pull hemodialysis: in vitro study on new dialysis modality with higher convective efficiency." Artificial organs 32.5 (2008): 406-411.

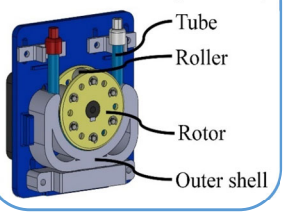
Experiment Method

To investigate the optimal pump geometry, we determined various conditions for a roller pump, including the number of rollers, the type of outer shell, and the flow rate.

The design parameters of the roller pump prototype

- **Tube were constructed from silicone rubber.**
  Tube dimensions: outer diameter 12 mm, inner diameter 8 mm
- **Rollers were crafted from a polyacetal spacer.**
- **Rotor and outer shell were produced using PLA with a 3D printer (ANYCUBIC MEGA X, ANYCUBIC).**
  Radius of the rotor and roller were 29 mm and 10 mm, respectively.
- **Rotor speed was adjusted to 25-200 rpm.**

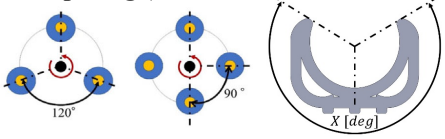




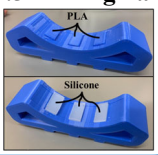
Pressure standard deviation (P_{SD}) and Pressure coefficient of variation (P_{VC}) were calculated using pressure sensor data.
Reynolds number (Re) was calculated based on the average of three measured flow rate at room temperature 20° C.

Shell & roller conditions

Rotor were made for three and four rollers.
The angle X of the shell was designed to cover at least one roller-to-roller spacing (120° for 3-rollers, 90° for 4-rollers).



To compare the effects of surface elasticity and outer shell shape, two outer shells with bosses 2.5 mm high and 10 mm wide were prepared.

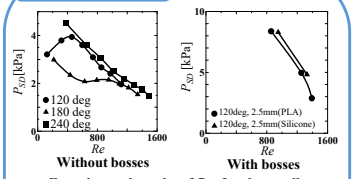


The durometer hardness of the silicone bosses is A48.

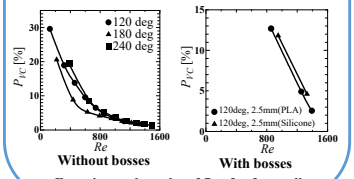
Three rollers: 120-degrees, 180-degrees, 240-degrees, 120-degrees with PLA bosses, 120-degrees with silicone bosses
Four rollers: 90-degrees, 180-degrees, 240-degrees, 90-degrees with PLA bosses, 90-degrees with silicone bosses

Result

Roller 3

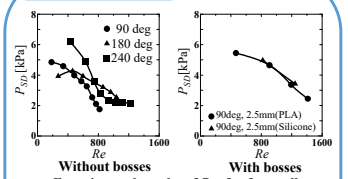


Experimental results of P_{SD} for three rollers

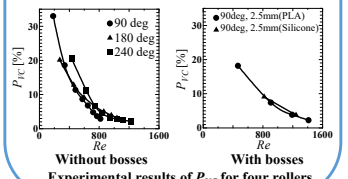


Experimental results of P_{VC} for four rollers

Roller 4



Experimental results of P_{SD} for four rollers



Experimental results of P_{VC} for four rollers

Discussion

- **All flows were assumed to exhibit laminar behavior because Re was below 1600.**
- **The effect of the material of the bosses has not been clear.**

Without bosses

- **The larger the area covered by the roller, the smaller P_{VC} was indicated.**

With bosses

- **Pressure fluctuations tend to increase even under the same motor operating conditions.**

Conclusion

We found that the shell without bosses had small pressure fluctuations, making pulsation difficult. In contrast, adding bosses increased pressure fluctuations even under the same motor conditions.

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