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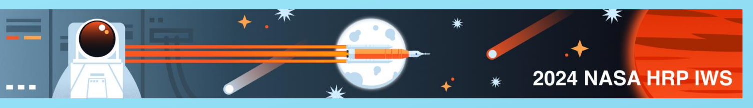
The 2024 Human Research Program (HRP) Investigators Workshop (IWS) February 13-16, 2024, Texas, U.S.A.



The 2024 NASA Human Research Program Investigators' Workshop

ELEVATED BLOOD VAPOR PRESSURE AND THE REDUCED HEAT CAPACITY OF BLOOD LEAD TO GAS EMBOLISM CAUSING FLOW CHOKING AT A CRITICAL PRESSURE RATIO IN BOTH GRAVITY AND MICROGRAVITY ENVIRONMENTS

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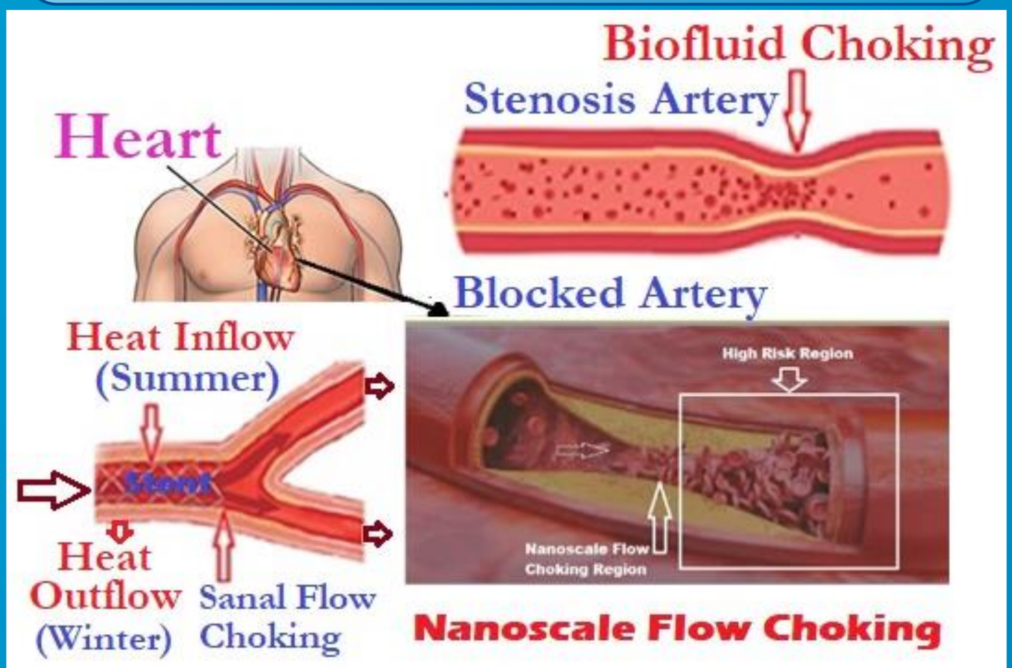
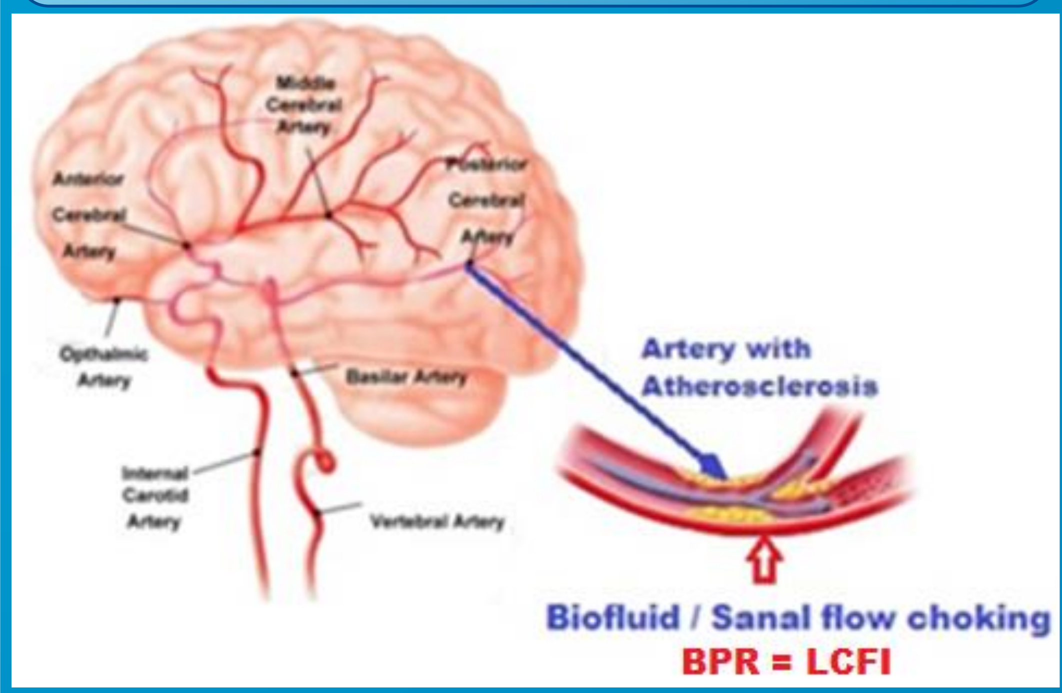
Introduction



Various Physical Situations of Flow Choking in CVS

- **V.R.S.Kumar et al. [*Physics of Fluids*, 34(10), 2022], reported conclusively the possibilities of the occurrence of flow choking leading to shock wave generation within the cardiovascular system (CVS) at a critical ratio of blood pressure (SBP/DBP).**
- **Multi-phase flow choking, and shock waves occur at a critical pressure ratio (SBP/DBP) in CVS due to gas evolution and/or cavitation (The 2023 NASA HRP IWS).**
- **Asymptomatic gas evolution, cavitation and/or tiny bubble formation in CVS occurs due to high vapor pressure and/or low heat capacity of blood.**
- ***In vitro* study at gravity environment [V.R.S.Kumar et al., Stroke, 2021;52:AP804] revealed significant amounts of nitrogen (N_2), oxygen (O_2), and carbon dioxide (CO_2) gases within fresh-blood samples from healthy humans and Guinea pigs, observed within a temperature range of 37–40° C (98.6–104° F).**
- **Comprehensive analytical, *in vitro*, *in silico*, and small animal *in vivo* studies, authors [2018-2024], demonstrated multi-phase flow choking, shock waves, and pressure overshoot in stenotic arteries due to gas evolution, posing cardiovascular risks.**

Flow Choking and Unchoking In CVS



Unique Conditions for Prohibiting Flow Choking

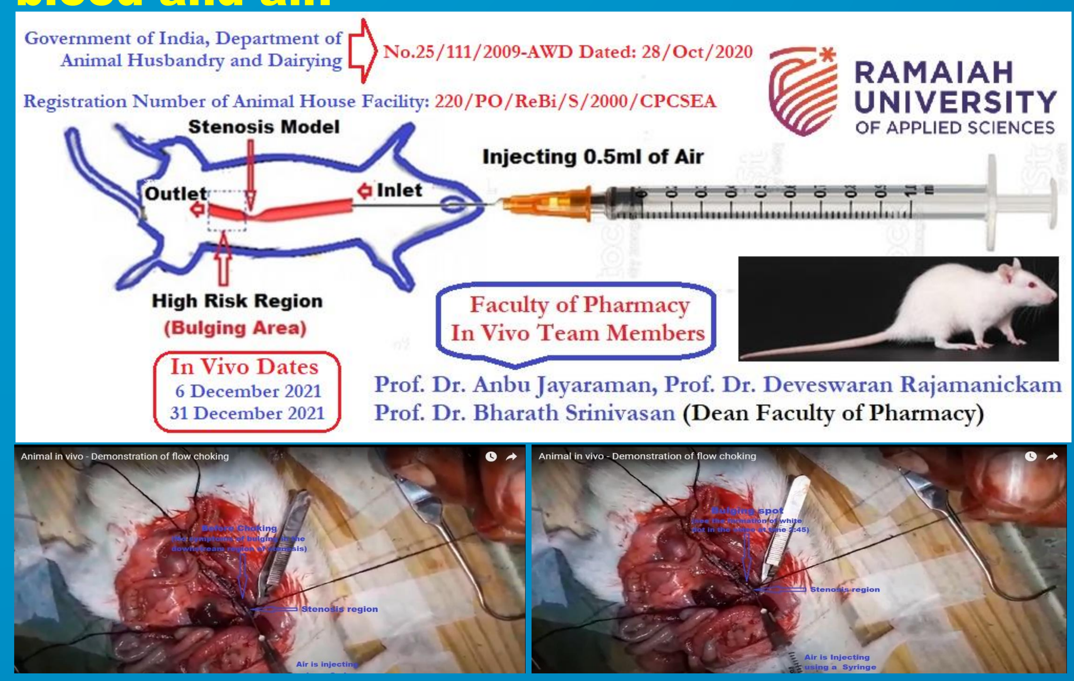
$$BPR < LCFI = \left(\frac{(BHCR)_{lowest}+1}{2}\right)^{(BHCR)_{lowest}/(BHCR)_{lowest}-1} \quad (1)$$

$$\frac{(\text{Reynolds number})(\text{Kinematic Viscosity})}{\text{Hydraulic Diameter of the Vessel}}\left[\frac{\text{Fluid Density}}{(BHCR)_{lowest}\,(DBP)}\right]^{1/2} < 1 \quad (2)$$

- **At high systolic blood pressure (SBP), non-continuum flows experience a reduction in the Knudsen number (Kn), leading to a decreased average mean free path.**
- **Consequently, this scenario leads to Sanal flow choking [*Global Challenges* 2021] and shock wave generation due to the sonic fluid throat effect, a condition that is vulnerable to neurological disorders such as Moyamoya disease [*Physics of Fluids* 2022].**
- **Shockwaves also occur in CVS when gas-filled bubbles collapse due to the internal/external pressure ratio exceeding critical thresholds for choking.**
- **In microgravity, reduced plasma volume and higher hematocrit elevate blood viscosity, intensifying boundary layer blockage and susceptibility to Sanal flow choking, especially in astronauts.**
- **Excessive blood thinners reduce viscosity, increase Reynolds number, and promote flow turbulence, leading to early Sanal flow choking [V.R.S.Kumar et al., *Global Challenges 2021*, PMID: 33728053].**

Multi-Phase Flow Choking in CVS

- **Animal in vivo conducted at the Faculty of Pharmacy, M.S. Ramaiah University of Applied Sciences in Bangalore, India, conclusively illustrated the presence of multi-phase flow choking, involving both blood and air.**



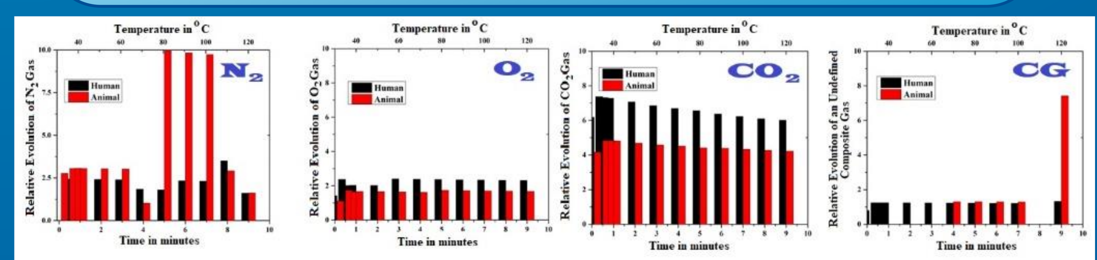
Anbu J et al., Circulation Research. 2022;131:AP3028

In vivo (6th December 2021): Multimedia view: https://youtu.be/Air3K89Gr8g. Demonstrating the bulging of the downstream region of the stenosis artery of a rat due to multi-phase (blood/air) flow choking and shock wave generation.

Objective

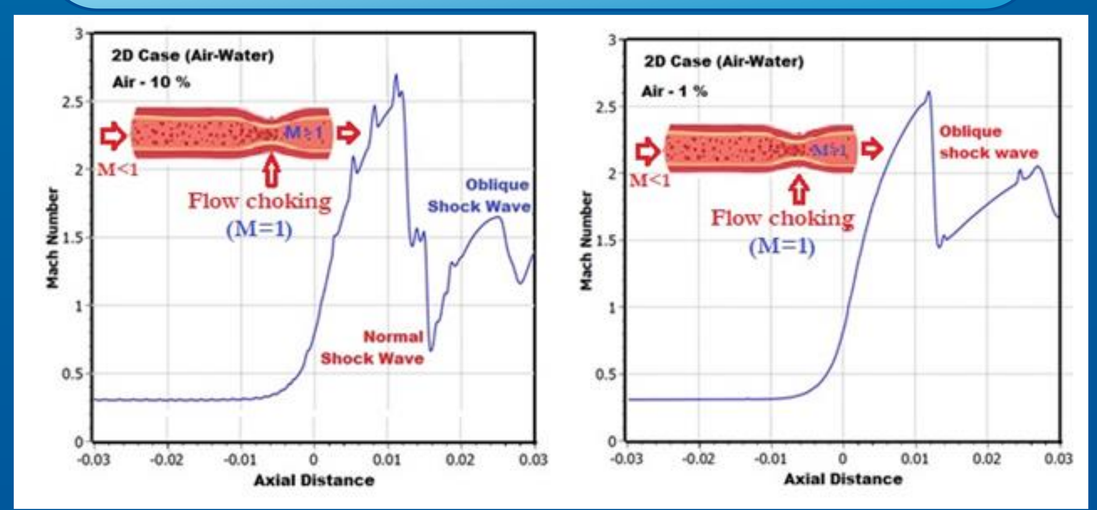
- **Investigate the cardiovascular implications of gas expulsion from blood when diastolic blood pressure (DBP) drops below blood vapor pressure (BVP), causing multi-phase flow choking at critical pressure ratios (SBP/DBP) and subsequent shock wave generation, for assessing cardiovascular risks.**

In vitro Results – A Review



Mass spectrum of N_2, O_2, CO_2 and an unknown composite gas (CG)

In Silico Results – A Review



In silico (water/air): https://youtu.be/jRtYUFvooBw

In silico simulation of two-phase flow (water/air) shows strong shock waves at high air percentages and weak shock waves at low air percentages in stenotic arteries due to air flow choking (*The 2023 NASA HRP IWS*).

Discussion

Vapor pressure of water

T, °C	T, °F	P, kPa	P, torr (mmHg)	P, atm
20	68	2.3388	17.5424	0.0231
25	77	3.1690	23.7695	0.0313
30	86	4.2455	31.8439	0.0419
35	95	5.6267	42.2037	0.0555
40	104	7.3814	55.3651	0.0728
45	113	9.5898	71.9294	0.0946
50	122	12.3440	92.5876	0.1218

Ref: Lide, David R., ed. (2004). CRC Handbook of Chemistry and Physics (85th ed.). CRC Press.

- **Blood temperature typically exceeds core body temperature by 0.5° F - 1.5° F (0.3° C - 0.8° C) and at low DBP its phase changes.**
- **Low heat capacity of blood contribute to conditions where vapor pressure might increase more rapidly with temperature.**
- **Maintaining BPR (SBP/DBP) consistently below one's Critical Pressure Ratio (CPR) for choking and ensuring DBP surpasses vapor pressure are paramount, mitigating tiny gas bubbles and flow choking risks.**
- **CPR is regulated by heat capacity ratio.**
- **A case with air evolution, the flow choking occurs at a CPR (SBP/DBP) of 1.8929.**
- **Astronauts can wear ambulatory measuring devices, monitoring BPR and countering risks before reaching CPR.**
- **Herein, we unveil the fundamental cause of asymptomatic gas evolution/tiny bubble formation or cavitation in both gravity and microgravity conditions leading to cardiovascular risk due to multi-phase flow choking and shock wave generation.**
- **This breakthrough significantly extends the lifespan of individuals in both gravity and microgravity environments.**

Conclusions

- **Boosting blood's heat capacity is crucial, lowering vapor pressure, delaying/negating multi-phase flow choking and shock waves, and reducing cardiovascular risks in gravity and microgravity settings.**

Acknowledgment

- **Department of Science and Technology, SERB, Gov. of India. Dr. W. Selvamurthy, Amity University.**

Exhibit Hall A / Poster 040

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