Sensors Converge

Finding Flow: Noninvasive, Wireless, Wearable Fluid Sensing for the Human Body

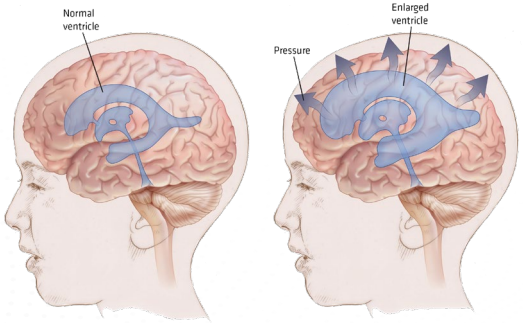
June 20–22, 2023 | Santa Clara, CA

R. Chad Webb, Ph.D.
Chief Technical Officer, Rhaeos Inc.
cwebb@rhaeos.com

#SensorsConverge

HYDROCEPHALUS

Chronic condition
with no cure caused by excess fluid in the brain



NORMAL PATIENT

HYDROCEPHALUS PATIENT

Total Patient Population in the US

1 MILLION+ patients

Population Breakdown

~4,000-8,000
infants are born each year with hydrocephalus[1]

~700,000+
seniors have hydrocephalus[1]

Cost of Care

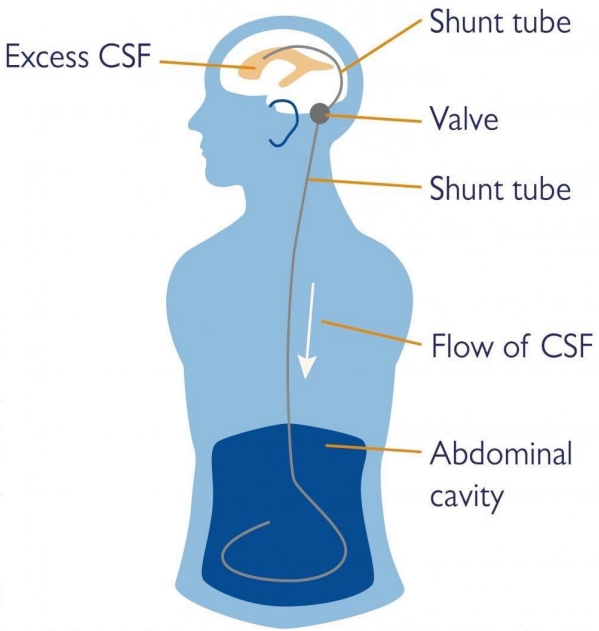
$2 billion estimated hospital charges for hydrocephalus in US hospitals

>$50k estimated cost of single hospital visit for shunt placement or repair

HYDROCEPHALUS

Standard treatment

Shunts = tubing that "drains the brain" of excess fluid



Shunt Problems

- **50%** of shunts fail within **2 years**
- Fail due to infection, obstruction, & disconnection
- Symptoms are non-specific: headache, lethargy, nausea, etc.
- Need to be revised = another neurosurgery
- High clinical costs for shunted patients

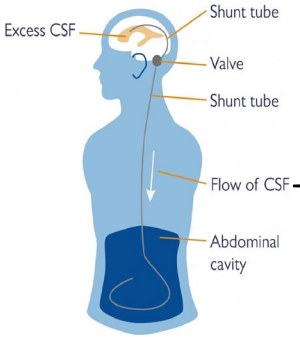
CHALLENGE: DIFFICULT SHUNT FUNCTION DIAGNOSTICS

Shunted patient presents w/ non-specific symptoms

→

Need: Diagnosis of shunt malfunction

Malfunction?



No Good Options Today
No Direct Measure of Shunt Flow or Pressure

CT Scan *65%/84% Sens./Spec.*	***Radiation*** ***Capital Equipment Scheduling*** ***Need Specialist***
Shunt Tap *31%/89% Sens./Spec.*	***Invasive*** ***OR Scheduling*** ***Need Specialist***
Shunt Series *18%/97% Sens./Spec.*	***Radiation*** ***Capital Equipment*** ***Scheduling*** ***Need Specialist***
MRI *51%/89% Sens./Spec.*	***Capital Equipment*** ***Scheduling*** ***Need Specialist***

Boyle (2014) Pediatrics
Boyle (2017) PAS
Desai (2007) Pediatric Radiology
Griffey (2007) Radiology
Lehnert (2011) Emergency Radiology
Mater (2008) CJEM
Vassilyadi (2010) J Neurosurgery Pediatrics
Zorc (2002) Pediatric Emergency Care

HOW DO WE GET A MORE DIRECT MEASURE OF IMPLANTED SHUNT PATENCY?

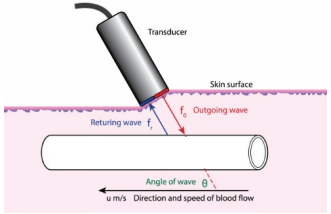
Intracranial Pressure

- Direct measure of pressure buildup
- Invasive (probe into brain)
- Ongoing research into implantable and noninvasive wearable solutions (some traction out of Brazil).

Natus Camino® 1104L Catheter

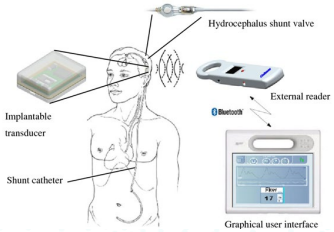
Ultrasound

- Normal CSF lacks natural Doppler scatterers
- Some research into exciting bubbles to support ultrasound use.



Direct Flow From Within the Shunt

- Implant flow sensor directly into shunt catheter (“smart shunt”)
- Ongoing research – needs to work reliably as permanent implant
- Long regulatory path



Noninvasive Thermal Flow Sensing

- Doesn’t require scatterer
- Can be applied as wearable to surface of skin over shunt
- Rhaeos FlowSense® currently in clinical trials for FDA clearance
- Must manage other physiological and environmental thermal signals

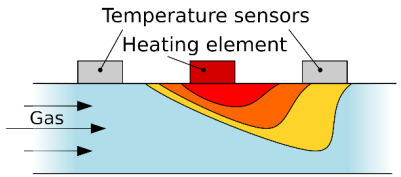
Rhaeos FlowSense®

LEVERAGING PRECISION THERMAL TRANSPORT

RHAEOS

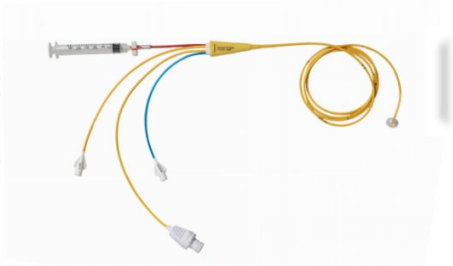
Commercial Examples of thermal flow measurements

Mass-Flow Controllers



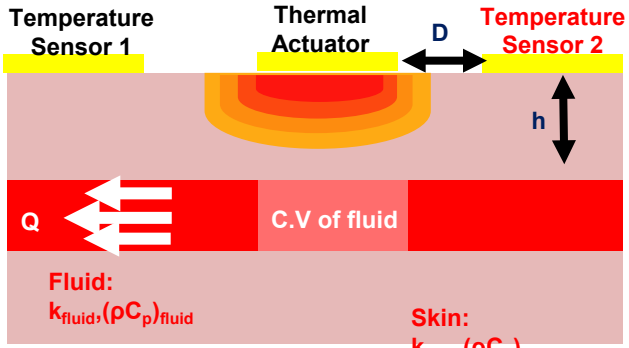
Wikimedia commons

Swan-Ganz Thermodilution Catheter

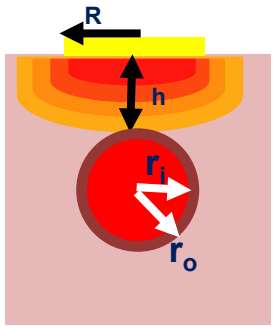


Edwards Life Sciences

Side View



Front View



Flow parameter:

$\Delta T_{sensors}/T_{actuator} \equiv \alpha$

$\alpha = \alpha(Q, P, D, h, r_i, r_o, R, k_{skin}, (\rho C_p)_{skin}, k_{fluid}, (\rho C_p)_{fluid})$

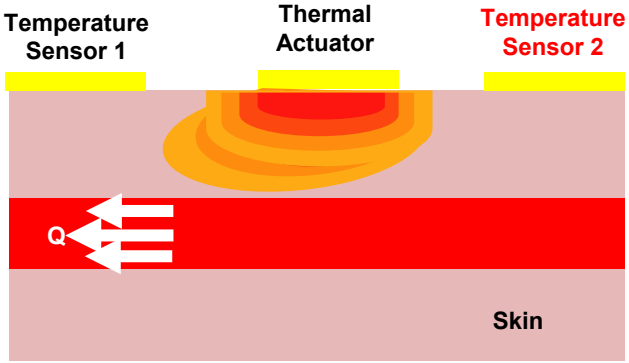
Geometrical parameters

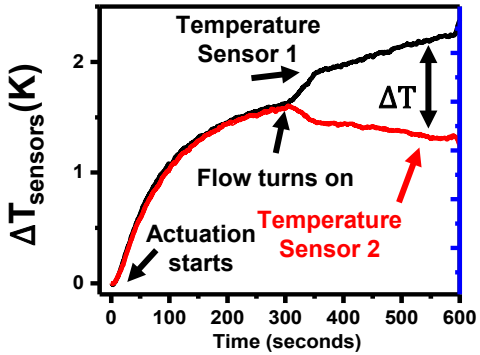
Thermal parameters

Diffusion through skin: $h \sim \sqrt{\frac{k_{skin} t}{(\rho C_p)_{skin}}}$

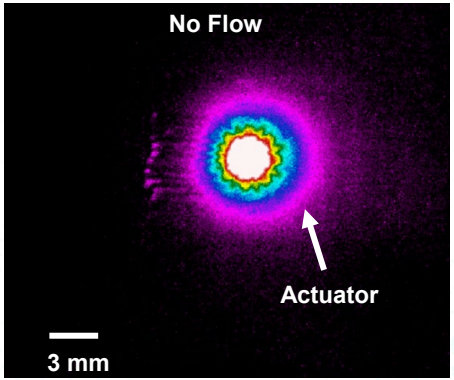
Thermal mass of flowing fluid: $C_{th} \sim \dot{m} C_p$

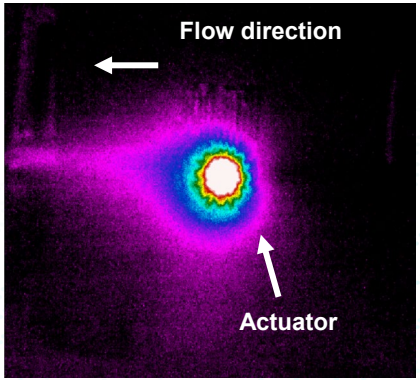
LEVERAGING PRECISION THERMAL TRANSPORT

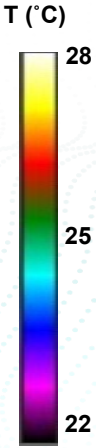




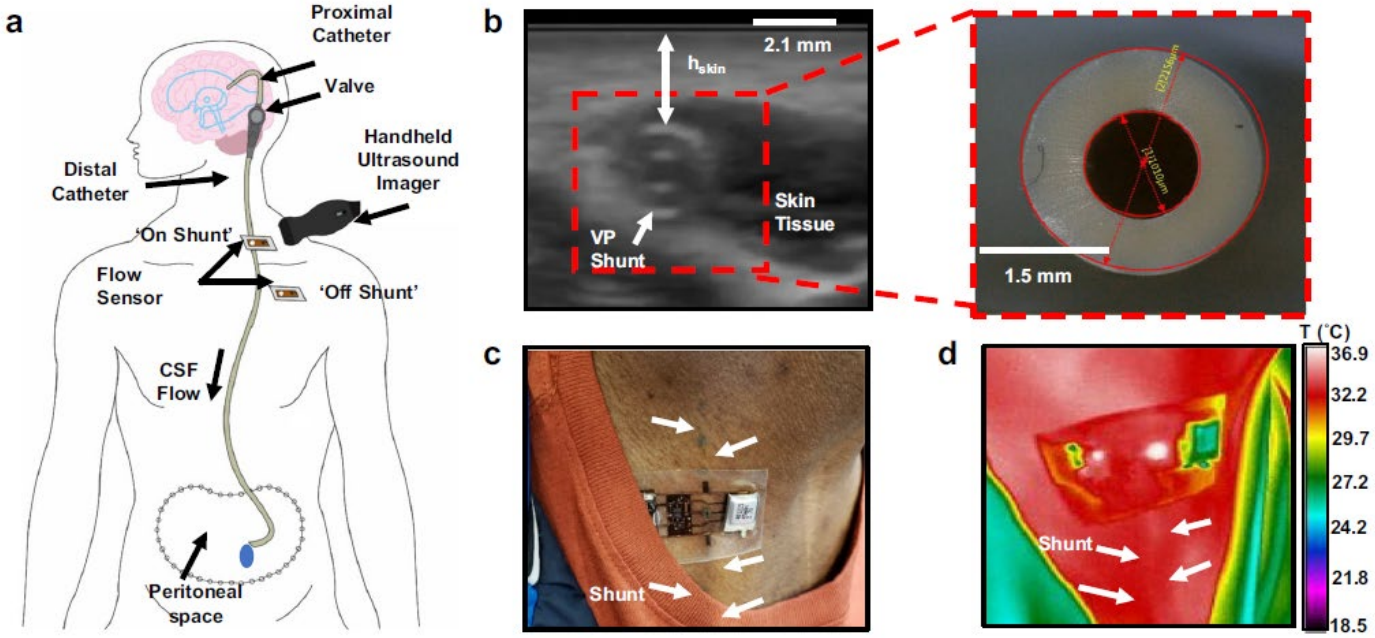
IR Image, Top View







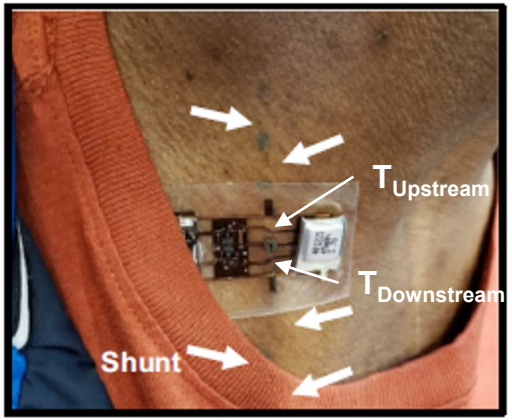
APPLICATIONS TO SHUNTS



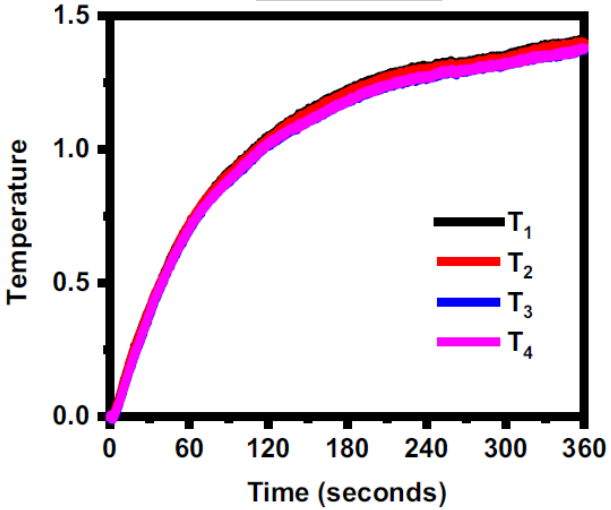
Krishnan, et. al., npj Digital Medicine (2020).

EARLY SHUNT FLOW DATA

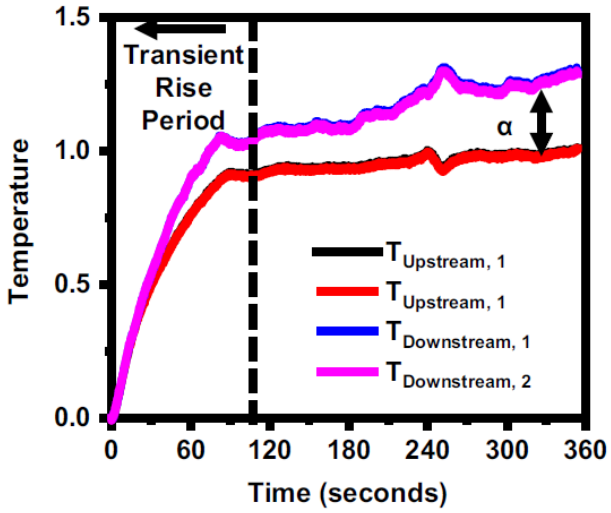
Early Flow Measurements



No Flow



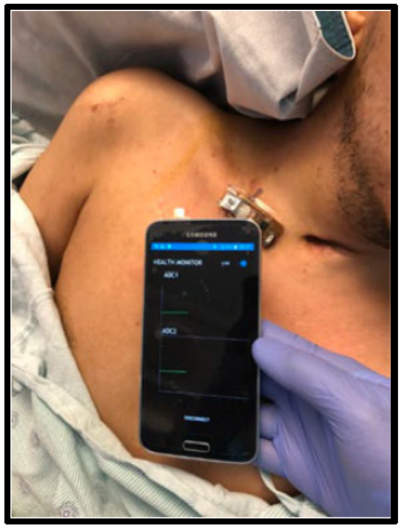
CSF Flow

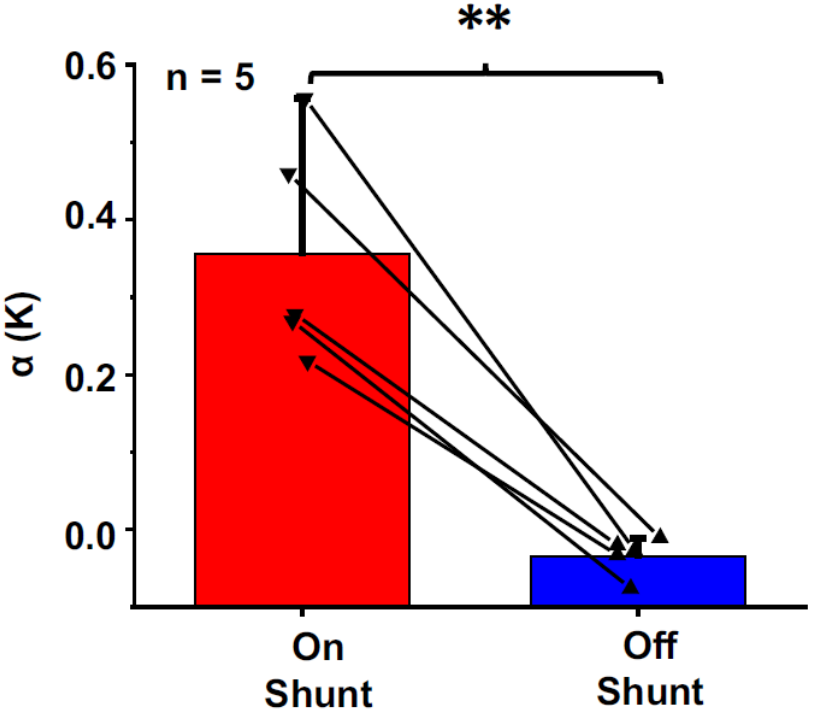


Krishnan, et. al., npj Digital Medicine (2020).

EARLY SHUNT FLOW DATA

Noninvasively assessing presence of flow in implanted CSF shunts





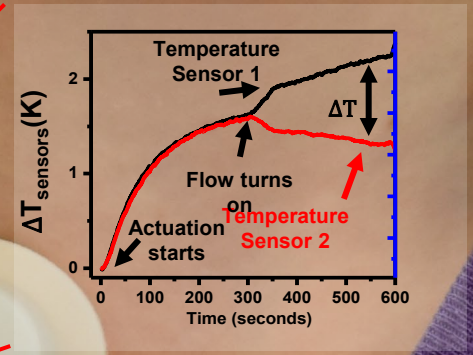
Krishnan, et. al., npj Digital Medicine (2020).

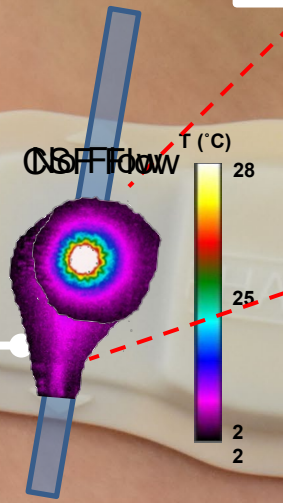
Bluetooth data transmission

Silicone, skin-safe adhesive

Soft, skin-like electronics

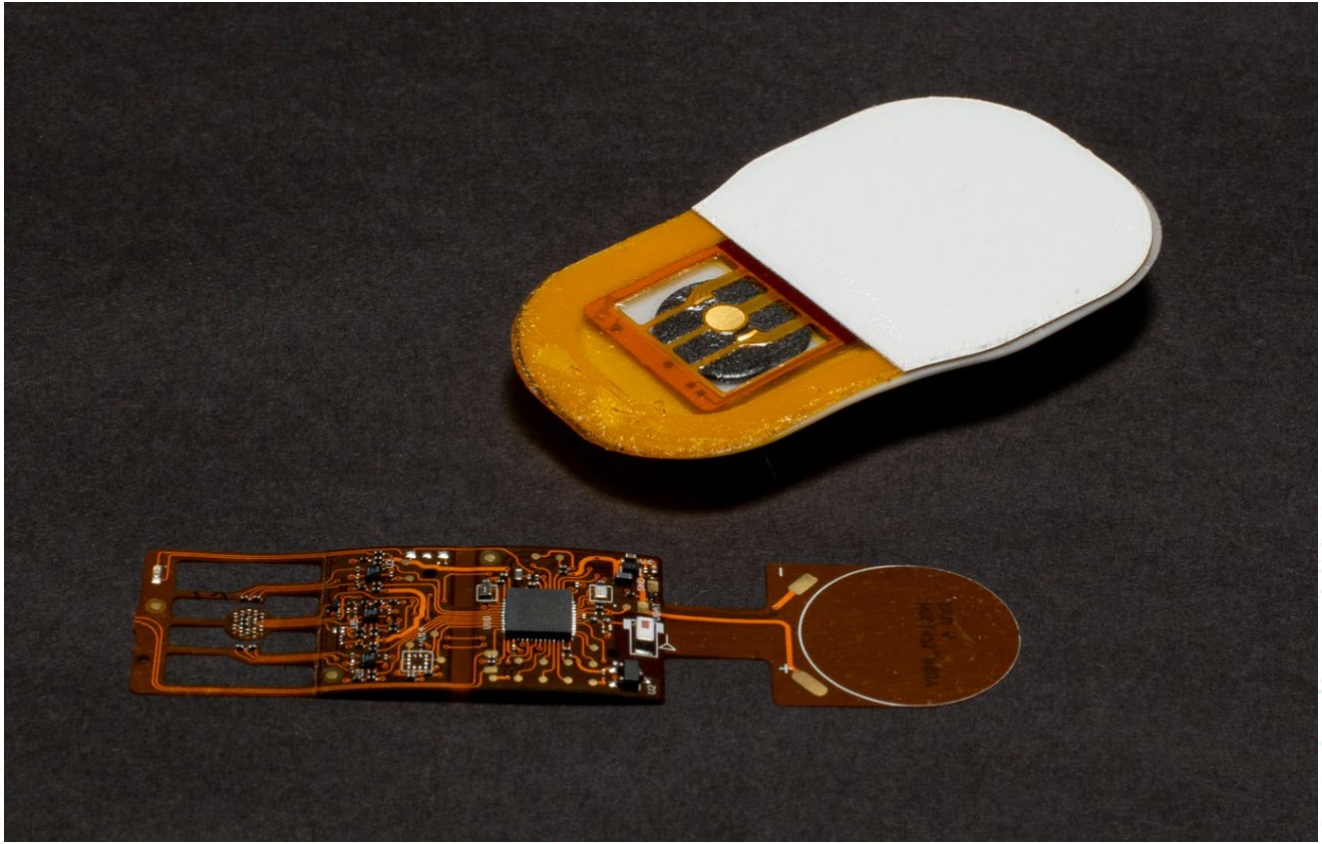
Shunt flow readout via iPad





RHAEOS

FLEX ELECTRONICS FOR CONFORMAL CONTACT



BENEFITS OF NONINVASIVE SHUNT ASSESSMENTS

Patients
>50% imaging reduction
>$500 reduction in out-of-pocket expenses

REDUCED

ER visit length

radiation exposure

diagnostic testing

unnecessary surgeries

readmissions

Providers
Saves >1hr of diagnostic testing time

Payors
>30% reduction in diagnostic testing
>40% reduction in unnecessary admission

Hospitals
Readmissions: up to $200K/pt

*Numerical assumptions are based on US healthcare data

SUMMARY

- Leverage thermal physics + wearable mechanics for noninvasive fluid flow sensing
- Enables new generation of diagnostics for conditions which impact near surface biological fluid flow
- Applications across numerous biological fluids
- Clinical studies in progress for applications in hydrocephalus shunts

RHAEOS®

CONTACT:

R. Chad Webb | CTO

cwebb@rhaeos.com