NeuroNews

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Needed Innovation for Neurocritical Care

This educational supplement has been sponsored by IRRAS

IRRA*flow*®: The world's first irrigating ventricular drainage system brings intelligence to intracranial fluid management

Every two seconds, someone on earth will have a stroke. Every 10 seconds, stroke claims a life. With little respect for age, as a third of strokes occur in people below the age of 65, their aftermath can leave behind a path of devastation—for both the patient and their families (Global status report on noncummunicable diseases, 2011).[1]

WHILE THE PAST COUPLE OF YEARS have seen significant amounts of innovation within ischaemic stroke, modernisation within the haemorrhagic stroke field has been limited in comparison. Where ischaemic strokes are caused by blood clots blocking the flow of blood and oxygen to the brain, haemorrhagic strokes occur when a weakened vessel ruptures and bleeds into the brain. With the latter accounting for only 15% of all strokes, they remain responsible for 40% of all stroke deaths (Mracsko & Veltkamp, 2014).[2]

Non-surgical treatment, combined usually with invasive intracranial pressure (ICP) monitoring and passive cerebrospinal fluid (CSF) drainage, remains the standard of care for haemorrhagic events. Yet, these passive techniques are associated with a list of well-documented complications, including occlusions, infections, excessive drainage, and secondary haemorrhage (Lele AV, 2017).[3]

While the MISTIE III trial (Hanely, 2019)[4] has highlighted the relationship between clot evacuation and functional outcome, experts continue to emphasise the need for more data and refined techniques within the field.

IRRAS, a cutting-edge company focused on therapeutically treating haemorrhagic stroke, is tackling the aforementioned complications seen with the current standard of care. Indicated for ICP monitoring and drainage of intracranial fluid, IRRA*flow*®—the company's first product—is an intracranial fluid management system. Already FDA-cleared for use in the USA, this exciting new treatment option was invented by Dr. Christos Panotopoulos, who is the senior consultant neurosurgeon and head of neurosurgical research at Mediterraneo Hospital in Athens, Greece, as well as at BRAINS-Sparsh Hospital and BRAINS Advanced Institute of Neurosciences in Bangalore, India.

Previously speaking to *NeuroNews* (Panotopoulos, 2018)[5], Panotopoulos outlined the rationale behind building this intelligent fluid management system: "IRRA*flow* combines periodic, controlled irrigation and drainage of the catheter probe in order to exchange any pathological fluid collection with neutral physiological fluids. This system's fluid exchange, by design, cleans the entire inner catheter probe's surface while the fluid movement helps to disrupt a potential clot or bacteria colony formation on the catheter probe's intracranial external surface, thereby eliminating the underlying reasons for the problems associated with passive drainage: blockage and infection."

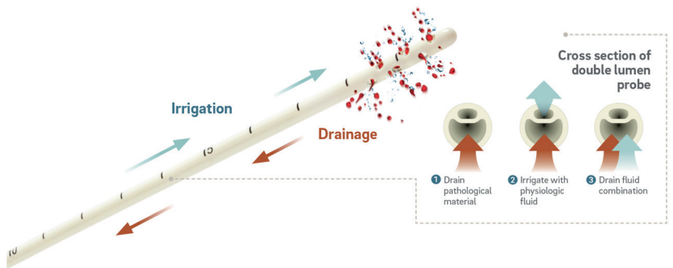
Alluding to several advantages that IRRA*flow* offers over traditional treatments, Panotopoulos said, "Active irrigation of the catheter helps to enhance the ability to dilute and remove this collected blood for a much longer period than can be performed during an open craniotomy." He further acknowledged the debilitating effects of insufficiently removed blood. "In patients with subarachnoid haemorrhage due to a ruptured intracranial aneurysm, vasospasm is a major contributor to morbidity and mortality and has been reported to occur up to 30% of the time [Ota, *et al*, 2017]."[6] In terms of external ventricular drains (EVDs), he noted that due to their reliance on gravity and intracranial pressure, they require a tremendous amount of treatment time for the evacuation of a clinically significant blood volume, even though they often leave residual blood—creating secondary adverse effects. "If an EVD cannot provide an adequate relief of pressure, rising ICP can lead to severe neurological damage or death," he added.

Moreover, Panotopoulos emphasised that both the flushing process to remove occlusions or EVD replacement can increase the risk of infection and secondary haemorrhage. Lastly, he alluded to a "major problem" with EVDs: "We do not have any safety control on pathological fluid outflow rate, other than having someone manually check the patient's ICP. As a result, underdrainage, compromising therapy, or over-drainage can occur." He noted that the latter may cause problems such as ventricular collapse, secondary intracranial bleeding, and catheter blockage.

Yet, the IRRA*flow* CNS system overcomes these practical hurdles, having demonstrated shorter treatment times and less-than-expected post-treatment residual blood volumes in over 100 patients in Greece, Sweden, Germany and Finland (Venkataramana, *et al*, 2012).[7] Panotopoulos also told *NeuroNews*, "To date, in the early European clinical experience—probably because of the underlying design elements—there have not been any documented blockages or probe-associated infections detected in any IRRA*flow* treatment. This was also the case in the previous embodiments during the development of our fluid exchange principal."

Additionally, the safety of IRRA*flow* is not to be underestimated. "IRRA*flow* automatically, reliably, and continuously monitors ICP and alerts hospital personnel with visual and sound alarms immediately when the patient's ICP is out of the pressure range set by the treating neurosurgeon, which eliminates any delay in detecting under- or over-drainage and any treatment's compromise," surmised Panotopoulos.

Given IRRA*flow* has been recently launched in the USA, *NeuroNews* sat down with three physicians to discuss their initial experience with the product, and further spoke to Dr. Andrew Carlson who explains the value of multimodal neuromonitoring through using Hummingbird.*



IRRA*flow* demonstrating active fluid exchange

*The opinions and views in this article are those of the respondents and not of IRRAS.

A shortened surgical time and length of stay for subdural haematomas

Dr. Sumeet Vadera is an associate professor of neurological surgery at the University of California, Irvine, (USA). As the first physician in the USA to use IRRA*flow* for patient care, he speaks to *NeuroNews* about his experiences using the technology so far, in the context of treating chronic subdural haematomas.

Can you tell us about the incidence of chronic subdural haematomas and the typical patient?

It is a very prevalent problem, and it is getting more common over time as society ages. As an individual gets older, their brain shrinks, and the veins that cross from the brain to the covering of the brain get stretched, meaning that even minor bumps to the head can cause them to tear and bleed. Some of the older population are also on aspirin or other blood thinning medications, which can disrupt the normal ability of blood to clot, so they are also at risk for these haematomas.

What is the current standard of care for treating chronic subdural haematomas?

There are several different methods to treat chronic subdural haematomas. One method is to do a burr hole evacuation, which means you make a small incision in the skin and a single burr hole in the bone. Then, you open the covering of the brain, and drain out as much fluid as you can. The other option is to carry out a mini-craniotomy by making a small window in the bone, open the covering of the brain and, again, try to get out as much of that blood clot as you can. Sometimes, physicians will leave drains in the cavity to continue to remove any additional fluid that remains.

Using these techniques, what are some of the issues you have experienced?

There are two downsides to the burr hole method: there is a risk of turning a chronic subdural haematoma into an acute subdural haematoma—after draining the chronic blood, you unknowingly create a new source of bleeding which can cause an acute blood clot and new symptoms. One reoccurring issue, particularly with the burr hole, is that you do not drain out enough fluid. So, at times, you might have to go back to drain out more fluid.

With an open craniotomy, you can create an acute subdural haematoma, and we have all seen these type of complications in the past. Also, there is often some residual blood following in the subdural space after surgery. But, with IRRA*flow*, you can irrigate and get even more blood out after the surgery. Even if you do get some acute bleeding, what happens is that the irrigation (IRRA*flow*) continues to wash and drain without allowing it to clot.

What caused you to want to try IRRA*flow*?

I was the first one in the country, in the USA, to try out IRRA*flow*. Part of the reason I was keen to try it was because I like trying new technology and techniques, but part of it is that it really made sense at the time. We had

Dr. Sumeet Vadera

problems following surgeries where we had created acute subdural haematomas or had not managed to drain as much fluid as we would have wanted, meaning the patient's length of stay in the intensive care unit (ICU) gets extended. So, I wanted to try it to assess if we would have any improvement. In our experience thus far, with several patients that we have used this device on, we have seen an improvement in these factors with minimal complications and a reduction in the needed treatment time.

Have you experienced any other changes?

The procedural time does tend to be a little shorter. Normally, we spend a lot of time trying to get every last drop of blood that we can see. Now, we can allow ourselves to be a little less aggressive, which then shortens the period of surgery, meaning the patient is under anaesthesia for a shorter length of time. And, by putting a catheter in, we then treat and drain the last little bit of fluid or any new fluid that occurs after the surgery. So, overall, it has been a win for us by reducing both surgical time and length of stay.

How has IRRA*flow* solved issues with the current standard of care for the treatment of chronic subdural haematomas?

In our experience, there are several benefits. First, it shortens the length of time because you can place it into any pocket where you think blood or fluid might accumulate. Second, the length of stay is shorter, on average with the five patients we have treated. And, number three, if any acute blood forms, there is a reduced risk that acute subdural haematoma may form. I think that, partly, IRRA*flow* breaks it down and drains it before that haematoma forms. We have seen in a couple of patients that this is the case. From my perspective, I have seen several improvements over our current standard of care, a traditional external ventricular drain, and the patients seem to be happy with it.

CASE REVIEW: Chronic Subdural Haematoma

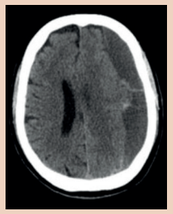
Male, 82 years old

Pathology treatment

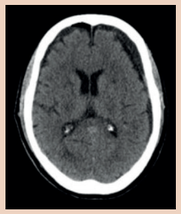
- 2.5cm left convexity mixed density extra-axial haematoma, causing a 9mm rightward midline shift and subfalcine herniation

Treatment description

- Mini craniotomy for evacuation of the subdural haematoma
- Active fluid exchange performed with the IRRA*flow* system, with an irrigation rate of 40ml/hour



Pre-IRRA*flow* Treatment



Post-IRRAflow Treatment

Treatment results

- Active irrigation and associated drainage assisted in providing controlled re-expansion of brain tissue back into the subdural space
- Complete resolution of the midline shift
- No catheter occlusion seen
- No drainage-related infection

The irrigation of antibiotics: Hope for rare infections

An infection to the ventricles in the brain, also known as ventriculitis, more often than not presents as a life threatening condition. **Dr. Behnam Rezai Jahromi**, Helsinki University Hospital (Helsinki, Finland) speaks to *NeuroNews* about how IRRA*flow* has provided needed change, and how the technology will continue to shape treatment approaches in the future.

What is the current standard of care for treating ventriculitis?

Ventriculitis is a rare reservoir of infection where the brain's ventricular system is infected by bacteria. Standard care is actually giving antibiotics and hoping that this is going to elicit a positive result, when unfortunately, most of the time this rationale does not result in good outcomes.

It is a very serious disease with a mortality rate of 80–100%. In terms of its incidence, it varies within the literature. It is fairly rare and predominantly occurs with patients that have another significant disease. So, these patients have needed critical attention many times in the past with a very long treatment period. Unfortunately, even when they undergo treatment for months in an intensive care unit, most of the time, the patients die anyway.

Dr. Behnam Rezai Jahromi

What are some of the issues that you have experienced with the current standard?

The care of ventriculitis is through the delivery of either IV or intrathecal antibiotics, which means they are delivered straight to the brain via an external ventricular drainage system.

The current standard is not enough to actually save the patients' lives and their neural tissue. It is very heartbreaking to see patients dying in the 21st century because of an infection. Even though we have antibiotics that should work on that particular bacteria, unfortunately, it is very hard to get those antibiotics into the system of the brain and to treat the infection. The problem is that the antibiotic is not penetrating to the place that we want.

However, with this IRRA*flow* system, we had the ability to actually deliver the antibiotics and treat the infection in a way that was not previously possible. We have had two cases that we have treated here in Helsinki, and we have been successful. We were able to wash the bacterial mass away and were able to deliver those antibiotics to the ventricular system, which eliminated the infection.

If you were to design a product to assist in treating ventriculitis, what would that look like?

If I had to innovate something, I hope that I, myself, would have the same idea that IRRA*flow* encompasses. The idea is that you are able to dynamically change the cerebrospinal fluid, to deliver the drug needed at the same time, and check the intracranial pressure, which are all of the factors that are needed when treating these ill patients. So, we were happy to have the device available to take care of this rare disease. [Without treatment with IRRA*flow*, those two] patients' mortality would have been extremely high, probably 100% in both cases.

How did you come to find out about IRRA*flow* and what caused you to want to try it?

I had heard about it when IRRA*flow* was demonstrated to us in Helsinki previously. When we had the first ventriculitis patient in our intensive care unit with this very severe disease, we were certain that the patient would die if we did not take any action, so it came to mind that we should try this IRRA*flow* device. So I contacted IRRAS, and they were kind enough to quickly respond and provide us with the system and needed training. We then implanted the device and started our journey with the device.

What has been your experience with IRRA*flow* to date, and how has it provided needed change?

If the patient is in a good condition before developing ventriculitis, they would typically struggle with the infection in the intensive care unit for months. But, in our cases using IRRA*flow*, we were able to treat ventriculitis in a matter of weeks, and they actually survived, with one of the patients able to go back to his normal life.

When it comes to ventriculitis, it has changed the idea that we are able to proactively take care of the infection mass in the brain. We are working now to publish this early experience, and I hope that, after our publication becomes public, other experiences are also published on the device so that we continue to collect more data.

It seems to me that, with our experience, IRRA*flow* will become a standard of treatment in these types of case. If you think about it, it is actually a very classic way of thinking to treat infection. With bacteria, you want to irrigate to prevent colonisation, deliver a drug, and take steps to remove the mass. Previously, this was not possible, but, with IRRA*flow*, it is.

> **"We were certain these patients would die if we did not take action."**

Can you see any other indications for it?

The device has many potential applications. For example, drug delivery straight to the brain might be one of the future uses of the device. There will need to be many scientific studies done, which will enable us to see how effective it will be, but it is very promising. It has a good future, not only in these rare ventriculitis cases, but also in more common intracerebral haemorrhage and also intraventricular haemorrhage cases.

The message is quite clear. We have to get the publications out so everybody can see them and start to use the device themselves, to get their own data published, to stimulate discussions about it.

An innovative approach to treating intraventricular haemorrhage

Speaking to *NeuroNews*, **Dr. Gregory Fautheree** from The NeuroMedical Center, Baton Rouge, USA said he was "extremely intrigued" by IRRA*flow*, and in the context of treating intraventricular haemorrhage, outlines his latest experience with the device.

Why and how do haemorrhagic events occur?

The most common reason to bleed into the ventricles is high blood pressure. Other reasons for ventricular blood are ruptured aneurysms, trauma, and blood vessel malformations that rupture. When blood gets into the ventricles, it starts off very solid—much like a scab. But overtime, it slowly liquefies and washes away with that spinal fluid circulation. Unfortunately, because the spinal fluid circulation is like plumbing a pipe, that solid blood can enter the pipes, the ventricles, and can cause pressure build up, or hydrocephalus.

To treat intraventricular haemorrhage, we traditionally use a ventriculostomy, which is a drain placed into a ventricle that works by gravity drainage. That is where this product comes in, as (IRRA*flow*) not only works from gravity draining, but it also has an irrigating port and can measure intracranial pressure (ICP) at the same time. By irrigating the ventricle as well as draining it, it helps the blood dissolve, and the movement helps to keep the solid blood in solution instead of settling and clogging the circulation.

What are some of the issues that you have experienced with the current standard?

The drain sits in the ventricle, connected to a sterile system at the bedside that can be raised or lowered to drain as much or little as you want. The problem with this is that it is much like siphoning gas from a gas tank—reliant on gravity alone. If there is solid clot in the ventricle, it is very prone to clogging. Sometimes, we administer a clot-busting drug, such as tPA, to try and resolve the clot. But, the main challenge in these patients is having to change the drain out multiple times, which can lead to higher rates of infection and longer duration of the drain being in. The longer you stay in the hospital, the higher the cost. Having to replace the drain over and over is not only expensive, but that manual manipulation increases the likelihood of infection. Most patients need at least one week of IV antibiotics followed by oral antibiotics, and their ICU stay may be increased by at least a week, if not longer.

Dr. Gregory Fautheree

If you were to design a product to assist in the treatment of haemorrhagic events, what would it look like?

Much like IRRA*flow*. I think anything that irrigates but also monitors pressure while it is irrigating is a necessity. In the ventricles, stagnation leads in this case to clots and bacteria growth. So anything that has forward pressure in a pipe is going to result in less infection.

How did you come to hear about IRRA*flow*?

I was contacted by the company as they knew that I had treated a lot of strokes as well as cranial work and ran it by me to see if it was a product that I would have some use for. I was extremely intrigued by it as there is nothing on the market like it. There was recent European data on its efficacy, and all of it made good sense. As a result, I thought that it made sense to give it a try.

Could you tell me more about your personal experience using this technology?

The patients that I have used it in had extensive intraventricular haemorrhage with a large volume of blood. These patients would have likely required multiple ventriculostomies or drains, due to clot. With IRRA*flow,* they did not require changing.

This product is very difficult to clog as it is self-irrigating, and it continuously tells you what the ICP is. If it were to clog up, the pressure would rise, and it will tell you. And, on top of that, one of the ways that we treat these haemorrhages is to administer a clot-busting drug, tPA. When we do that, we inject it and clamp the drain, let it sit for an hour, and then open [the drain] to gravity.

But the beauty of IRRA*flow* is that, if you want to give that clot-busting drug, you are already irrigating fluid through the system. So you add the tPA to the fluid, and it slowly irrigates it, which I found works much better than the bolus technique. With IRRA*flow*'s continuous fluid introduction, I have found that the drug can be introduced over a longer period at a smaller, safer amount with better results.*

Do you see the patient's clinical outcome improving with IRRA*flow* compared to the current standard of care?

I hope so. Our experience is too early so there is not enough data out there to know. I do know that, without a doubt, it is going to improve ICU length of stay, and I expect it to improve infection rates. So, from that standpoint, yes, there will be an improvement in outcome.

CASE REVIEW: Intraventricular Haemorrhage

Female, late 60's

Pathology treated

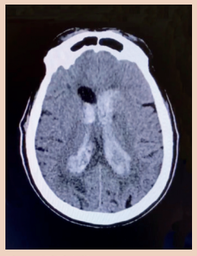
Hypertensive basal ganglia intraventricular hemorrhage with bilateral ventricle involvement

Treatment description

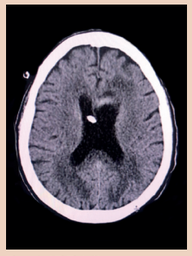
- Active fluid exchange performed with the IRRA*flow* system
- 2mg tPA in 200mL NS infusions was utilised to help breakup clot

Treatment results

- Active irrigation and associated drainage cleared clot in ventricles and reduced cranial swelling
- No catheter occlusion seen
- No drainage-related infection



Pre-IRRA*flow* Treatment



Post-IRRA*flow* Treatment

*Currently, the use of the IRRAflow® CNS System is indicated when Intracranial Pressure monitoring is required, and for externally draining intracranial fluid as a means of reducing intracranial pressure. IRRAS makes no claims as to the ability, safety and efficacy of infusing a thrombolytic or other pharmaceutical agent through the system.

Hummingbird: Bringing multimodal management to neurocritical care

Just recently, IRRAS completed an asset acquisition of the Hummingbird product line from InnerSpace. The Hummingbird product line is an innovative means of performing advanced neuromonitoring. After the acquisition, *NeuroNews* interviewed **Dr. Andrew Carlson** from University of New Mexico (Albuquerque, USA) to discuss his thoughts on the value of multimodal monitoring and how Hummingbird addresses current shortcomings of existing technology.*

Dr. Andrew Carlson

What is multimodal monitoring?

The idea of multimodal monitoring is to try to measure various functions of the brain, in order to better direct our therapy to what that individual patient needs, as each patient is not the same.

A certain intervention might be helpful in one patient, for example, raising the blood pressure. But this might actually be harmful in another patient as it may cause the pressure in the brain to go up too high. So, by using multimodal monitoring, the idea is that we can get a snapshot into various different brain systems. We can understand the pressure in the brain; we can understand more about the blood flow, oxygen to the brain, [as well as] more about the physiology of the brain, like whether there are seizures. And, even the metabolism of the brain, like how well the brain tissue itself is functioning.

To what extent does it help to individualise care?

The most obvious is the management of intracranial pressure as that is the parameter that is most commonly measured. We know that treatment directed at lowering the pressure is better. Since we are actually able to monitor that, how can we confirm that, on a patient-by-patient basis, we are actually having a beneficial effect for that individual?

When we add in additional parameters, such as blood flow or oxygen to the brain, then we can start going beyond just a simple pressure. We can start understanding more about the physiology. In other words, pressure may or may not mean anything, but, if high pressure is related to lower blood flow or lower oxygenation, that might be a problem. Then, we could better tailor our treatment specifically to that patient.

> **“It gives us an insight into what is going on with that patient, and how we can do a better job [and] generate more generalisable knowledge.”**

What are some of the disadvantages of current technology?

I would say that there are basically two different kinds of standard of care. One is a more minimalist approach where very few of these parameters are monitored. In that situation, we just cannot get the same information about what is happening in the brain with regards to brain tissue oxygen, metabolism, or pressure that we can with invasive monitoring.

Even in centres where multimodal monitoring is used to direct patient care, the challenge is to try to figure out how we can place multiple probes that allow us to get these different pieces of information in a way that is safe for the patient, does not require drilling [burr] holes all over the head, and can also give us reliable and consistent results.

With other systems that are available, you often have to at least drill several holes in the head to be able to put the monitors in. They may not all be in the exact same place, or have the same relationship. They might be in a different part of the brain, from one patient to the next. This creates additional variability that can make the data harder to interpret and can also affect the reliability of the data.

Why is Hummingbird different, and what advantages does it offer you?

There are two big advantages of the Hummingbird system. One is that it allows for placement of whichever probes you would like to place; an oxygen probe, a blood flow probe, a microdialysis probe, or a seizure detection electrode. Any of these probes can be placed through the side ports. Also, these additional access lumens are structured with a slight angulation at the bottom of the port, so the position of the tip of your desired probe will always be the same within the frontal lobe of the brain. This ensures that you do not have to worry about the possibility that the probe is going to be positioned at various depths or within different parts of the brain.

The other big advantage is that the Hummingbird multimodal bolt allows all of these monitors, as well as an integrated external ventricular drain to drain extra spinal fluid if the pressure increases, to be placed through one burr hole. You no longer have to drill multiple access sites, and your probes are all in the same relationship to each other. The especially nice thing about the pressure measurement is that, even if the ventricular catheter with Hummingbird does not go into the ventricle (if there is a clot or the ventricle has collapsed), you can measure the intracranial pressure (ICP) using the parenchymal monitor built into the catheter. With a normal external ventricular drain system, you would not be able to measure pressure [if these events occur].

So I think those are the big advantages: having the ventricular drain built in to the same delivery system as all the bolts, having the ability to measure pressure independent of the ventricles, and having the multiple side ports integrated into one bolt. Also, Hummingbird is completely a bolt-based system, which allows for a much simpler placement and set-up because you do not have to do any tunnelling. All of the aiming and positioning is done upfront when you first drill the hole. Our experience is that, overall, the risk of infection is lower using this bolt-based system. A lot of the potential headaches, such as drains pulling out, have really improved with the use of a bolt-based multimodal monitoring system like Hummingbird.

Do you see Hummingbird changing procedural time?

I think certainly, when compared to placing multiple different systems, it improves time, efficiency and reliability in terms of where you are placing the probes. In a shorter period of time, you can place multiple probes with the exact same orientation to each other, rather than trying to fit in several bolts or external ventricular drains with other systems.

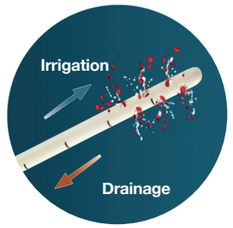
Does Hummingbird advance our understanding of neurocritical care in ways we have not explored before?

Yes, it definitely does. I think it does on two levels. It gives us insight into what is going on with that patient and how we, as a neurocritical care team, can do a better job. For example, do we need more oxygen or more blood flow, or do we need to lower the intracranial pressure? All of these decisions are things that we would just be doing blindly if we did not have this kind of monitoring.

Secondly, from a larger perspective, it really is giving us a better insight into generating more generalisable knowledge. Here at the University of New Mexico (Albuquerque, USA), we now have a database of well over 300 patients whose treatment has been guided by this same Hummingbird monitoring system set-up. We are now able to examine this data to look at correlations with outcomes and treatments that we carry out in order to try to confirm overall what are the things we are doing that are helpful versus what might not be helpful. The data can also help guide us toward the topics that should be focused upon for the next big studies.*

*The opinions and views in this article are those of the respondents and not of IRRAS.

IRRA*flow*



IRRA*flow* Dual-lumen Catheter
Dual-lumen catheter that combines active irrigation with CSF drainage.

IRRA*flow* Tube Set
Intelligent digital pump enables communication between control unit and catheter to provide automated irrigation, fluid drainage, and ICP monitoring.

IRRA*flow* Control Unit
Active fluid exchange via an intuitive touch-screen with personalized alarm settings that provide control when managing ICP and CSF.

Hummingbird

Hummingbird Multimodal Monitoring System with Drainage
Multimodal monitoring system that combines access through a single twist-drill hole, providing CSF drainage, parenchymal ICP monitoring, and your choice of two probes.

Hummingbird ICP Control Module
Control module that transmits needed ICP data from Hummingbird catheter to patient monitor.

Hummingbird Bolt Based Monitoring System
Bolt-based system that combines both access and parenchymal ICP measurements.

References

1. (2011). Global status report on noncummunicable diseases. Geneva: World Health Organization.
2. Mracsko, E., & Veltkamp, R. (2014). Neuroinflammation after Intracerebral hemorrhage. *Frontiers in Cellular Science*, 1-13.
3. Lele AV, e. a. (2017). Perioperative Management of Adult Patients With External Ventricular and Lumbar Drains: Guidelines From the Society for Neuroscience in Anesthesiology and Critical Care. . *J Neurosurg Anesthesiology*, 191-210.
4. Hanely, e. a. (2019). Efficacy and safety of minimally invasive surgery with thrombolysis in intracerebral haemorrhage evacuation (MISTIE III): a randomised, controlled, open-label, blinded endpoint phase 3 trial. *Lancet*, 1021-1032.
5. Panotopoulos, C. (2018, December 31). IRRA*flow*: A new innovative fluid management, A Conversation with Dr. Christos Panotopoulos. (*NeuroNews*, Interviewer)
6. Ota, N., Matsukawa, H., Kamiyama, H., Tsuboi, T., Noda, K., Hashimoto, A., . . . Tanikawa, R. (2017). Preventing Cerebral Vasospasm After Aneurysmal Subarachnoid Hemorrhage with Aggressive Cisternal Clot Removal and Nicardipine. *World Neurosurgery*, 630-640.
7. Venkataramana, N., Rao, S., Naik, A., Shetty, K., Murthy, P., Bansal, A., & Panotopoulos, C. (2012). Innovative approach for prevention and treatment of post subarachnoid hemmorhage vasospasm: A preliminary report. *Asian Journal of Neurosurgery,* 77-80.

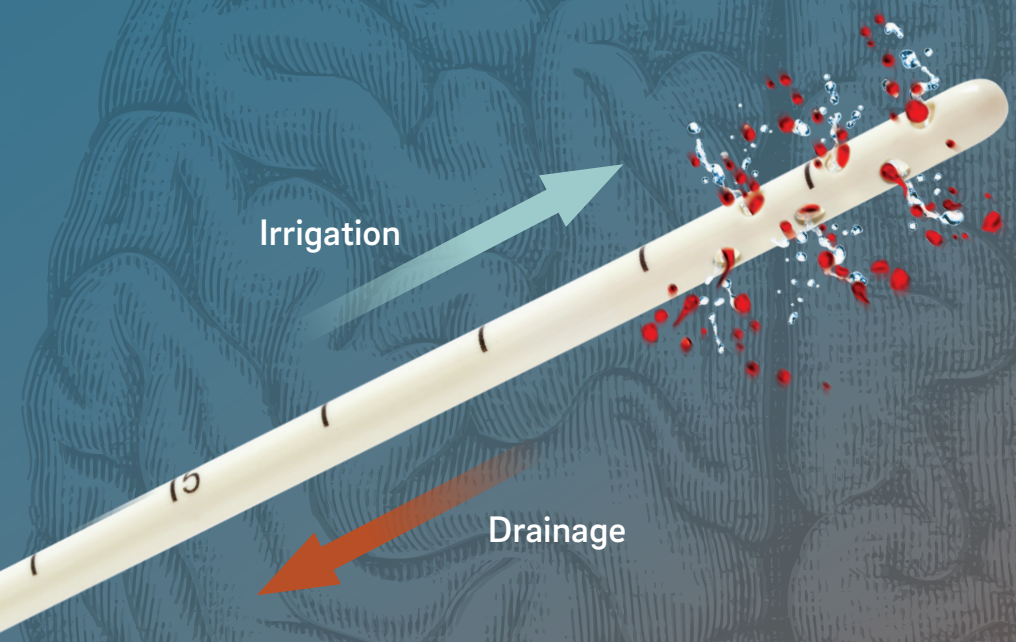
IRRAS

Bringing Needed Innovation to Neurocritical Care

Offering a full product portfolio from the IRRAflow and Hummingbird product lines

IRRAflow® + Hummingbird® neuromonitoring

The world's first irrigating ventricular drainage system!



Bolt-based Parenchymal ICP Monitoring

Parenchymal ICP Control Module

Single Access Multimodal Monitoring System with Drainage

For more information, visit IRRAS.com.