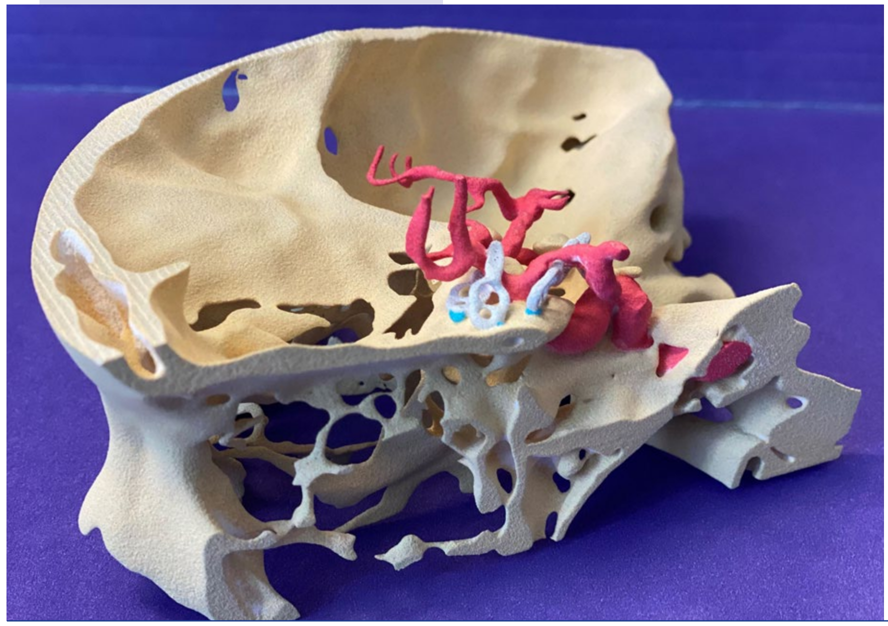
Managing paediatric aneurysms using three-dimensional stereolithographic modelling and surgical simulation

This article focuses on the current research work by Dr Michael Levy, Chief of Paediatric neurosurgery at Rady Children's Hospital-San Diego and Professor at the University of California San Diego School of Medicine. By investing in futuristic surgical simulation techniques like preoperative, 3D virtual and stereolithographic modelling, Dr Levy is paving the way for improved surgical practice outcomes for all future surgeons. Preoperative simulation modelling techniques are also valuable resources for patient education, resident training, anatomical studies, disease management and patient rehabilitation post brain surgery.

Aneurysms refer to a weakness in an artery causing a protruding, bulging bubble-like or pouch-like abnormality involving vascular complexities. The reason can be genetic, induced as a result of other primary abnormalities, infectious, or idiopathic (with unknown cause) in nature. Most aneurysms in the brain appear in the space between the brain and its surrounding tissue, known as subarachnoid space, and can cause subarachnoid haemorrhage if the aneurysm ruptures.

Surgical management of intracranial (brain) aneurysms requires in-depth technical knowledge and can have multiple complications. It thus demands a multidisciplinary team of specialists, including neurologists, cerebrovascular neurosurgeons, and neuro-interventional radiologists. Analysis of large patient databases confirms that outcomes are indeed better with high-volume centres and high-volume surgeons.



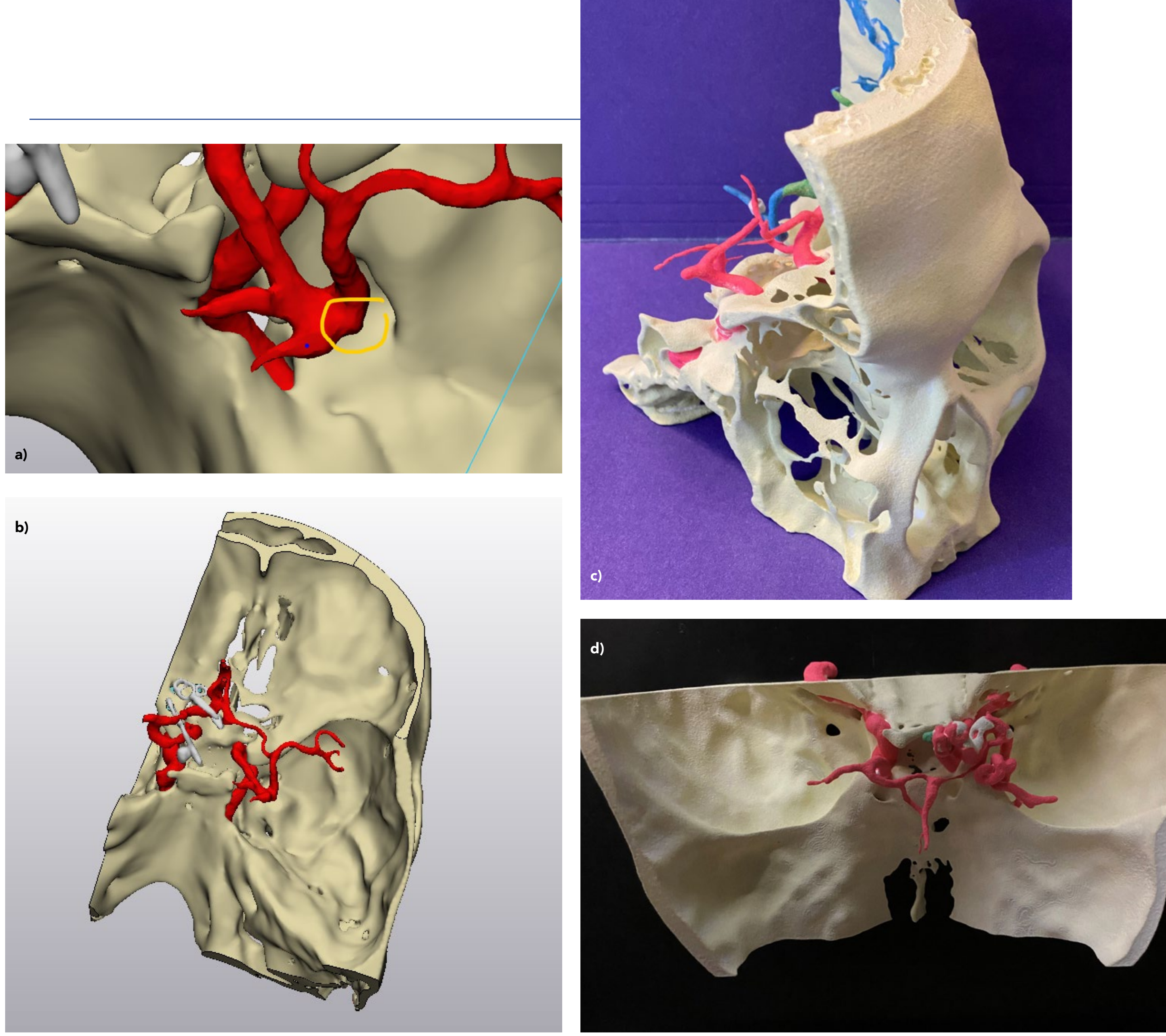
Adult patients have definable risk factors, such as smoking and hypertension. In children, however, the causes are often congenital, implying that there is inherent weakness in their blood vessels that makes these cases even more complicated and critical.

Paediatric aneurysms are rare, comprising of <5% of all aneurysms. The skillset demand becomes higher in children, as there lies a high risk of intraoperative aneurysm rupture, leading to catastrophic bleeding, haemorrhage, or stroke.

Studies show a male predominance in paediatric intracranial aneurysms which seems to reverse at puberty. Paediatric aneurysms can be saccular (berry-like bulging only on one side of the axis) in morphology, accounting for about 20% of cases, while most are dissected and fusiform (circumferential dilation, causing bulging on all sides of the blood vessel) in nature, accounting for over 50% of cases. Less common are infectious aneurysms, accounting for 15% of cases. The rarity and complex morphologies of paediatric aneurysms demand a surgeon equipped to deal with a variety of complex surgical techniques.

3D PRINTING AND VR-BASED SIMULATIONS

Conventional vascular imaging techniques include magnetic resonance angiography (MRA) and computed tomography angiography (CTA). Surgical simulation has been used for neuro-interventionalists successfully for a long time as it gives surgeons an area to practice and prepare themselves with the nuances of different pathologies.



a) A 3D computer model demonstrating an abnormal bulge in the artery and the artery's relationship to the surrounding bone. **b)** When planning a reoperation on a complex, previously treated aneurysm, perfect visualisation of the aneurysm, the existing aneurysm clips, and their relationship to the bone anatomy is essential. **c)** Printing the models allows the surgeon to rotate the skull and visualise the actual orientation they will see during the operation. **d)** A printed cut-out of the anterior and middle skull base nicely demonstrates the complex clinoidal aneurysm.

The advent of 3D printing has ensured that neuro-interventionalists get a better idea of the angiographic roadmaps and projections and come up with preoperative and post-operative plans accordingly. Stereolithographic imaging is a comparatively newer technique that is being adapted for its realistic simulation of aneurysms. Using updated visualising and image-analysis software along with stereolithographic imaging coupled with 3D printing can help get a clear surgical roadmap and prepare surgeons better for the procedure.

Levy's study demonstrated the use of such advanced 3D modelling and imaging techniques, harnessing the power of virtual reality, to explore the affected vasculature and plan treatment interventions accordingly. A set of five patient images were collected from the Digital Imaging and Communication in Medicine (DICOM) dataset, and retrospectively viewed using a technology called SuRgical planner (SRP) – a Surgical Theatre VR system. The pathologies presented in these five cases included three fusiform/dysplastic (short, longitudinal aneurysms caused by non-saccular dilatations), M1 (proximal segment of the middle cerebral artery) aneurysms, two MCA (middle cerebral artery, one of the three major arteries supplying blood to the cerebrum) arteriovenous (AV) fistulas (formed as abnormal connections between arteries and veins due to any injury, causing blood to flow from an artery to a vein) with an associated aneurysm, and an

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MCA bifurcation aneurysm (aneurysms arising from major bifurcations in the middle cerebral artery) with an associated blister lesion. The system used CTA and MRA images, processed them into 3D models to view them on an Oculus Rift VR headset preoperatively and on a computer workstation intraoperatively.

The high level of preoperative detailing using the SRP ensured focus on individual structures and their relationship with the surrounding structures as well, which could be manipulated as per the surgeon's convenience. The surgeons were able to shift focus from the skin, bone, brain parenchyma, nerves, angioarchitecture, veins, sinuses, and other neurological structures, both as a whole and individually in 3D.

The 3D detailing of aneurysms made it easier to manoeuvre digitally over any structure, at any angle, measure aneurysm size and neck dimensions, detect presence of a thrombus, arterio-venous fistulas and their location, flow, and drainage patterns. It further enabled surgeons to study and assess complex relationships between the affected vessel and the surrounding perforated vessels as well as normal ones, the extent of dysplastic (abnormal cell development) involvement in affected vessels, and bifurcations between parent and daughter blood-vessels. 3D detailing also made it easy to scan through layers of tissues wherever necessary.

The utility of this technique was highlighted specifically in the last case, with the MCA bifurcation aneurysm. It was anticipated that the neck on a laterally projecting gigantic aneurysm (one half of the bifurcation) with the blister-lesion would be difficult to visualise and explore intraoperatively. Since the aneurysm was located in a way that was coinciding with the angle of approach, the aneurysm dome needed to be mobilised or a temporary clip placed. However, visualising the neck of the aneurysm preoperatively with the 3D-printed and VR-based SRP system ensured that surgeons could avoid the otherwise initial wide dissection of the aneurysm to understand the anatomy. This process also effectively minimised blood loss, highlighting the utility of the technique in cases of open surgeries due to decreased exposure needs.

the SRP technique influenced better treatment decisions for all patients besides boosting the confidence of surgeons. This also led to fewer post-operative complications.

The increased complexity of paediatric aneurysms needs skilled surgeons to carefully dissect aneurysm pathology and understand its anatomy and vascular complexity. This also increases the indications for open surgeries. Modern techniques like the SRP would be useful in conducting safe, well-planned, and more effective surgeries in future. Further down the line, outcomes-based research would be useful to analyse the impact of VR-based preoperative imaging on surgical outcomes.

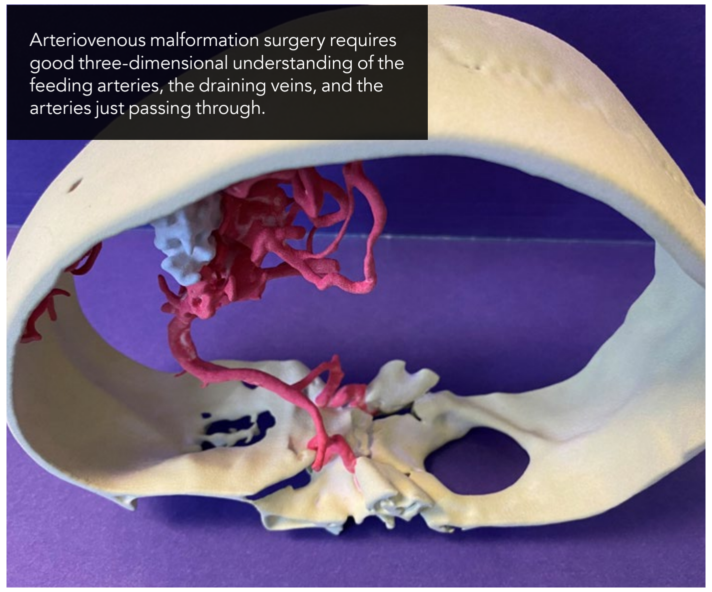
SRP technique influenced better treatment decisions for all patients, leading to fewer post-operative complications.

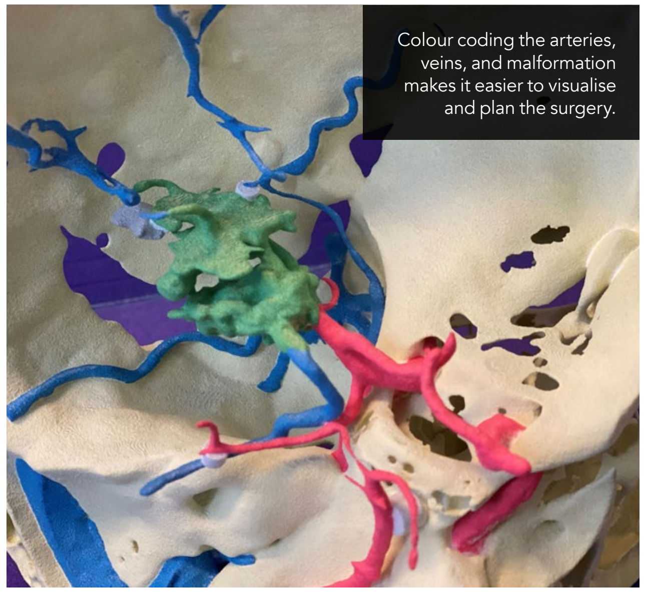
KEY TAKEAWAYS

The SRP technique was shown to improve preoperative review of standard imaging and enhance the surgeon's knowledge of complex neuropathologic spatial relationships. Prior studies had reported thus far that 3D-printed, VR-based simulation was instrumental in altering the surgical plan in nearly 25% of cases, and it was no different in this study as well.

Since much of the anticipated open surgical procedures were avoided, the SRP technique influenced better treatment decisions for all patients besides boosting the confidence of surgeons.

The advent of more modern and advanced imaging systems like the intraoperative Surgical Navigation Advanced Platform (SNAP; Surgical Theater, Inc.) can further improve surgical outcomes. The SNAP technology uses the 3D navigation files from the SRP and synchronises a surgical probe for real-time neuro-navigation using stereotactic localisation. This technique can help the surgeon better visualise anatomic nuances by using improved 3D visualisations, and hence lead to a better understanding of the tissues.


Arteriovenous malformation surgery requires good three-dimensional understanding of the feeding arteries, the draining veins, and the arteries just passing through.


Colour coding the arteries, veins, and malformation makes it easier to visualise and plan the surgery.

Behind the Research

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Research Objectives

Dr Levy is using preoperative three-dimensional virtual and stereolithographic modelling for infants and children with giant aneurysms and other complex cerebral vascular malformations.

Detail

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Bio
Michael L Levy, MD PhD, is the chief of paediatric neurosurgery at Rady Children's Hospital in San Diego and is a professor at UC San Diego School of Medicine. Dr Levy has particular expertise in complex paediatric brain tumours and treatment of vascular malformations. He has incorporated endoscopy and three-dimensional modelling imaging technologies into surgical planning and management of these diseases.

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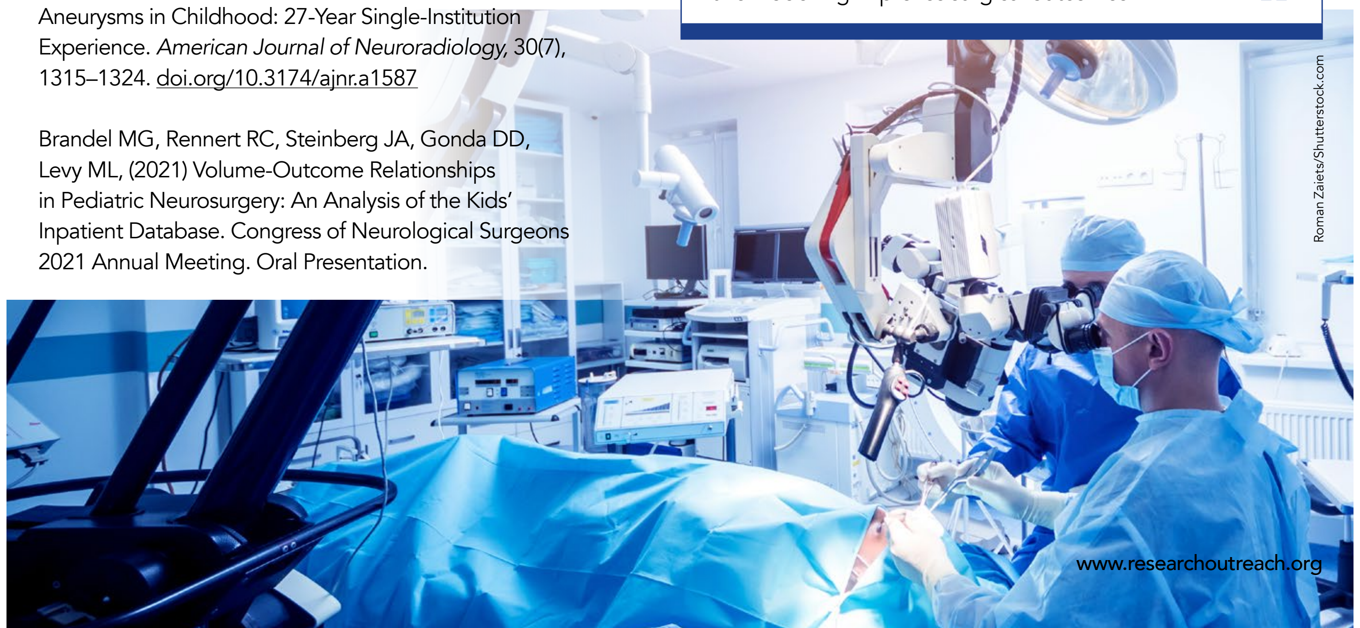
Personal Response

Complex cases can only be solved by a well-experienced surgeon. In these cases, will it be useful to introduce simulation studies and 3D, VR-based modelling studies in the academic curriculum of surgeons as well? Is there already any such module in surgery courses?

" VR modelling is relatively new and access to this technology is institution dependent. Neurosurgical trainees are therefore exposed as part of the normal workflow when available. It is for this reason that complex cases should be referred to hospitals that manage a high volume of paediatric vascular cases and are adequately equipped with the newest technology. "

What are you planning to study next?

" We hope to continue to integrate VR platforms and 3D printing into our perioperative workflow to create a seamless surgeon experience, and continue to study how this modelling improves surgical outcomes. "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