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Circular Configuration of Torcular Herophili Presenting as Childhood Headache: 2D Computational Fluid Dynamic Analysis with a Proposed Mechanism

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Abstract

This case report presents a rare anatomical variant of the torcular Herophili, characterized by a circular configuration and the absence of the left transverse sinus. A 12-year-old child presented with intermittent holocranial headaches, and imaging revealed the circular torcular Herophili along with mild ventricular enlargement. The straight sinus drained into the left side of the circular torcular Herophili. Following lumbar puncture and cerebrospinal fluid (CSF) drainage, the child experienced symptom improvement. During a 6-month follow-up, the patient remained asymptomatic, without further headaches or academic disruptions. Similar to a previously reported case, the circular torcular Herophili with unilateral absent transverse sinus may be associated with impaired CSF absorption due to altered blood flow through abnormal venous anatomy. We performed two-dimensional computational fluid dynamic analysis of simulated flow through a synthetic model and showed that this circular configuration is associated with venous stasis. The venous stasis in the sinus may impair CSF absorption through the arachnoid granulations causing hydrocephalus and explaining the headache. Close monitoring and follow-up are recommended for patients with this variant. Further investigation is needed to better understand the clinical implications and underlying mechanisms of such torcular Herophili variations.

Keywords
- childhood headache
- confluence of sinuses
- neuroanatomy
- torcula
- venous sinus anomaly

Introduction

Torcular Herophili, also known as the confluence of the sinuses, is present at the posterior end of the superior sagittal sinus. Bilateral transverse sinuses arise from it and the straight sinus and occipital sinus drain into it. Several anatomical variations in the torcular Herophili have been noted and Kobayashi et al classified variants of the torcular Herophili into nine types with type 1 being the most common.[1] Tardieu et al reported a previously unreported variant of the torcular Herophili with a circular configuration along with absent right transverse sinus. A second case was reported by Lake et al in a cadaveric case.[2] Herein, we report a case of circular torcula Herophili presenting with headache.

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Illustrative Case

A 12-year-old child presented with a history of intermittent episodes of holocranial headache not associated with any history of vomiting for 4 months. There was no history of convulsion, loss of consciousness, limb weakness, or any cranial nerve palsies. Neurological examination was unremarkable without any focal neurodeficit. Initial imaging showed mild enlargement of ventricles; however, fundoscopy did not show any papilledema. Magnetic resonance imaging of brain with magnetic resonance (MR) venography brain showed the presence of circular configuration of torcular Herophili with absent left transverse sinus without any other structural abnormality (►**Fig. 1A**). The straight sinus was draining into the left hemicircumference of the circular torcular Herophili (►**Fig. 1B**). Aqueductal stroke volume was 69 µL. There was prominence of all the ventricles noted on T2-weighted magnetic resonance imaging, but no cerebral edema was noted. Lumbar puncture was done with the opening pressure being 16 mm Hg and about 30 mL of cerebrospinal fluid (CSF) was drained. Although the child reported improvement after lumbar puncture and CSF drainage, we continued to keep the kid on conservative lines of management. On 6-month follow-up, the kid remained asymptomatic without any further episodes of headache and resumed academics. Patient is continuing close follow-up.

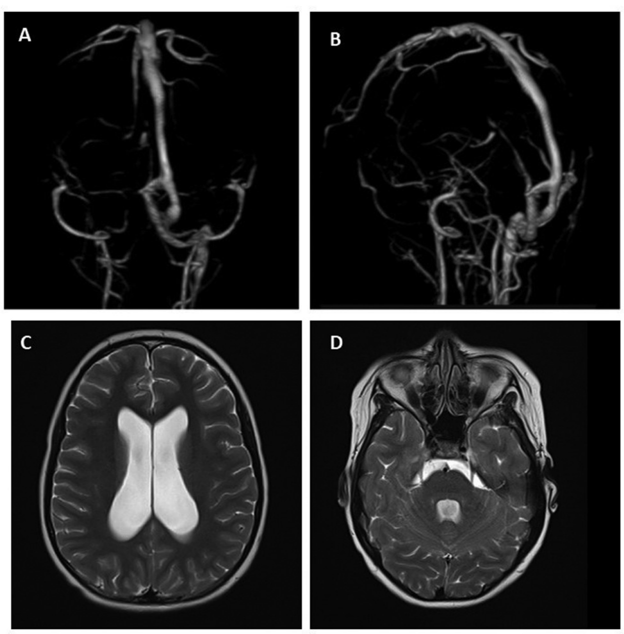

Fig. 1 (**A**) Magnetic resonance venography showing the circular configuration of the torcular Herophili with absent left transverse sinus (posterior view). (**B**) Magnetic resonance venography showing the straight sinus draining into the left half of the circular torcular Herophili (posterior view). (**C**) T2-weighted magnetic resonance imaging (MRI) showing prominent bilateral lateral ventricles with rounding of the frontal horns. (**D**) T2-weighted MRI showing prominent fourth ventricle.

Two-Dimensional Computational Fluid Dynamics Simulation

We believe that the circular anatomy of the torcular Herophili alters the dynamics of the venous blood flow in the superficial dural venous sinuses and may impair the absorption of CSF from the arachnoid granulations leading to communicating hydrocephalus. Computational fluid dynamics (CFD) can analyze the flow of fluids through different systems in silico and provide useful information about the system. To test the above hypothesis, we performed a simplified two-dimensional CFD analysis of flow of water through a synthetic model representing the venous anatomy in question and compared it with flow through a simulated two-dimensional cross-section of a normal sigmoid sinus-transverse sinus junction. The two-dimensional models were generated using FreeCAD v. 0.21 with the dimensions obtained from the MR venography images (►**Fig. 2B**). The ends marked inlet was set at a width of 6 mm and the length was set at 3 cm, representing a segment of the superior sagittal sinus proximal to the torcular. The configuration of the torcular is modeled with an angle of 90 degrees in between the arms. The outlet representing the transverse sinus has a width of 4 mm. Similarly, for the model representing normal anatomy, width of the two transverse sinuses was set at 4 mm. The models were then imported in Simflow 4.0, a CFD software based on OpenFOAM simulation software and post-processed with Paraview software. The models were then meshed to generate a mesh with the model of abnormal anatomy having 10,150 cells and 20,992 nodes, while the normal anatomical model had 12,668 cells and 26,232 nodes. Flow simulation was then performed for three scenarios with the inlet boundary having a flow velocity of 10 cm/s, 15 cm/s, and 20 cm/s in range reported in the literature.[3] The outlet boundary was set as a pressure outlet with a pressure of 0 Pa for both the models. ►**Fig. 2** shows the results of the flow simulation. There was significant stasis of flow noted in the circular configuration of the torcular with increased pressure upstream to the torcular in circular configuration model compared to the normal torcular model. This translates to stasis of venous flow in the sagittal sinus upstream to the torcular, impairing CSF absorption from the arachnoid granulations.

Discussion

According to the classification system proposed by Kobayashi et al type 1 torcular Herophili, that is, superior sagittal sinus and two transverse sinuses forming a single point, is the most common variant.[1] The superior sagittal sinus predominantly drains into the right transverse sinus. The torcular Herophili embryologically develops from the anterior and middle dural plexus. Developmentally, the sagittal plexus arises from the caudally shifted anterior dural plexus due to the growth of the forebrain. The superior sagittal sinus arises from the sagittal plexus. The anterior dural plexus is

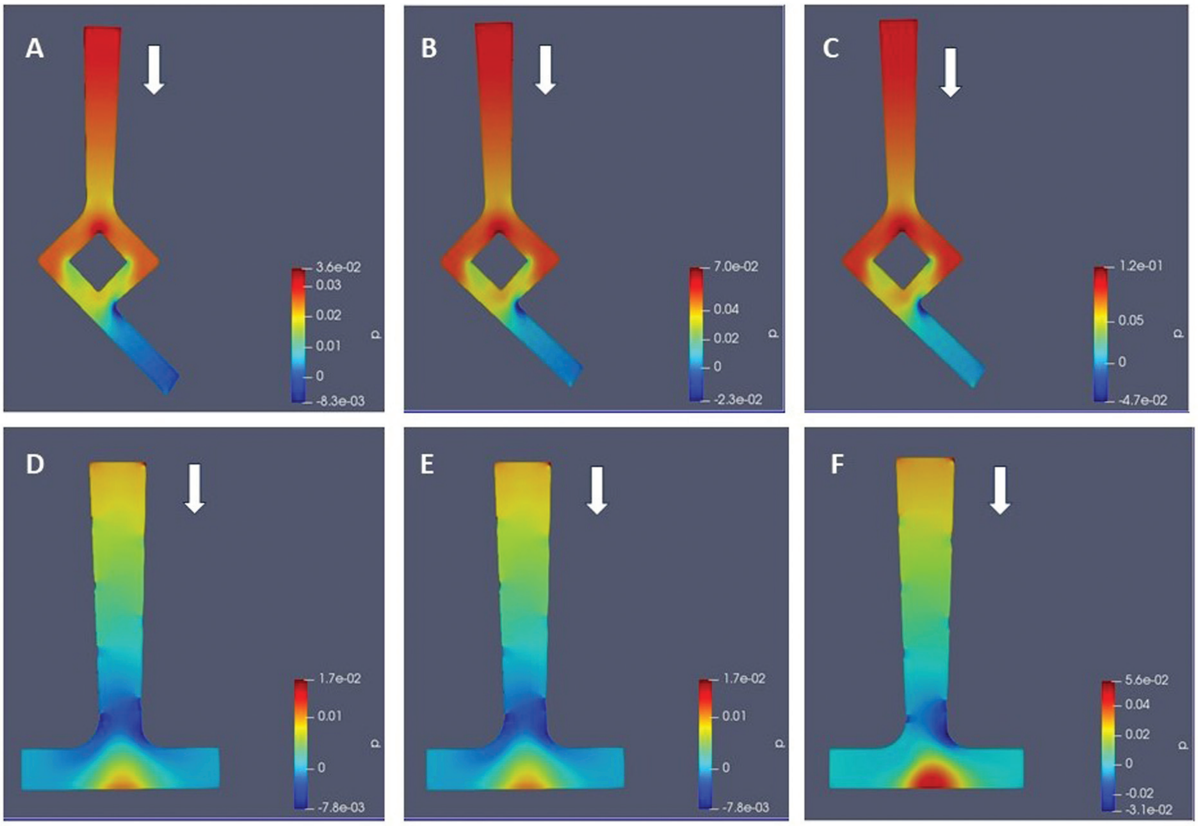

Fig. 2 (**A**) Distribution of pressure across segment of the simulated model of circular torcular with constant inlet velocity of water at 10 cm/s. Increased pressure is indicated by deeper shades of red, and decreased pressure indicated by deeper shades of blue. Direction of flow indicated by arrow. (**B**)Distribution of pressure across segment of the simulated model of circular torcular with constant inlet velocity of water at 15 cm/s. Increased pressure is indicated by deeper shades of red, and decreased pressure indicated by deeper shades of blue. Direction of flow indicated by arrow. (**C**) Distribution of pressure across segment of the simulated model of circular torcular with constant inlet velocity of water at 20 cm/s. Increased pressure is indicated by deeper shades of red, and decreased pressure indicated by deeper shades of blue. Direction of flow indicated by arrow. (**D**) Distribution of pressure across segment of the simulated model of normal torcular Herophili with constant inlet velocity of water at 10 cm/s. Increased pressure is indicated by deeper shades of red, and decreased pressure indicated by deeper shades of blue. Direction of flow indicated by arrow. (**E**) Distribution of pressure across segment of the simulated model of normal torcular Herophili with constant inlet velocity of water at 15 cm/s. Increased pressure is indicated by deeper shades of red, and decreased pressure indicated by deeper shades of blue. Direction of flow indicated by arrow. (**F**) Distribution of pressure across segment of the simulated model of normal torcular Herophili with constant inlet velocity of water at 20 cm/s. Increased pressure is indicated by deeper shades of red, and decreased pressure indicated by deeper shades of blue. Direction of flow indicated by arrow.

joined posteriorly by the middle dural plexus forming the junctional area of the drainage of superior sagittal sinus, straight sinus, and bilateral transverse sinus, thereby forming the primitive torcular Herophili.[4]

The present case has clinical similarity with that reported by Tardieu et al.[4] In both cases, headache was the presentation presumably due to raised intracranial pressure and had a unilateral absent transverse sinus. Tardieu et al have proposed that circular configuration of the torcular Herophili along with unilateral absence of transverse sinus may impair venous drainage causing cerebral edema explaining the clinical symptom of the patient.[4] We propose that the association of circular torcular Herophili with unilateral absent transverse sinus predisposes the patients to altered flow through the sagittal sinus upstream to it and impairs CSF absorption through the arachnoid granulations and can cause a communicating hydrocephalus. This is in accordance with the simulated flow through the synthetic model as observed in the CFD simulation. Further clinical evidence in support of this hypothesis is the presence of prominence of all the ventricles and the relief of symptoms obtained after a lumbar puncture that provided an alternative pathway of CSF drainage. We are closely following the child for recurrence of symptoms and occurrence of hydrocephalus and will consider shunting if repeat lumbar puncture and CSF drainage show improvement in symptoms.

Authors' Contributions

A.S. was involved in patient care and review of the article. D.D helped in manuscript preparation.

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Conflict of Interest

None declared.

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