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Tethered brain: disentangling unintentional brain-mesh interfaces. Illustrative case

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BACKGROUND Surgical meshes have found widespread use in neurosurgical practice. While commonly recognized risks of synthetic mesh include infection, exposure of mesh implants, and foreign body reaction, the risk of mesh tethering to neural structures is often overlooked.

OBSERVATIONS The authors presented the first case, to their knowledge, of the disentanglement of mesh interfaced to cortical tissue. The patient, a 68-year-old woman, presented with severe intractable seizure disorder and worsening left hand function and incoordination after meningioma resection and cranioplasty 9 years earlier. Magnetic resonance imaging (MRI) demonstrated interval progression of macrocystic encephalomalacia involving the right supplementary motor area, with fluid-attenuated inversion recovery signal extending posteriorly into the right primary motor cortex. Both computed tomography and MRI suggested potential tethering of the cortex to the overlying cranioplasty mesh. Because of the progressive nature of her condition, the decision was made to surgically remove the tethered mesh.

LESSONS De-tethering brain parenchyma from surgical mesh requires careful microdissection and judicious use of electrocautery to minimize further tissue damage and preserve neurological function. This inadvertent complication evinces the importance of using dural substitutes when unable to primarily repair the dura to prevent scarring and tethering of neural tissues to synthetic cranioplasty materials.

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KEYWORDS surgical mesh; tethering; cranioplasty; duraplasty

Surgical meshes have been a staple of general surgery since the early 1890s, when they were first used for hernia repair surgeries.[1] Since its inception, mesh has been adopted by a range of other surgical disciplines and has undergone multiple evolutions in terms of source material, porosity, biochemical composition, textile confirmation, stiffness, and implantation scheme.[2,3] The field of neurosurgery began to experiment with meshes and synthetic materials for cranioplasty to counter common issues found with bone grafts for wartime injuries during World Wars I and II.[4,5]

In current neurosurgical practice, titanium mesh is often used when autologous bone is either unavailable or not appropriate because of infection or resorption. Historically, infection was a major complication of titanium cranioplasty and was estimated to occur in 16% of cases.[6] However, a recent report showed a decrease in the rate of infection of titanium implants compared to the rate with polyetheretherketone-based custom cranioplasty (0.0% vs. 27.8%, respectively).[7] Whereas "risk of infection," "exposure of mesh implants," "foreign body reaction," and "mesh deformation" are commonly searched terms associated with synthetic implants, no complications involving tethering have been reported or discussed.

Although primary tethered cord syndrome is a recognized disorder with an estimated incidence of 0.25 per 1,000 births,[8,9] the incidence of abutted neural tissue tethered to artificial biomedical materials is estimated to be far lower. Despite extensive literature regarding tethered spinal cord and brain in the setting of spinal dysraphism and Chiari malformation, a limited number of reports were identified in the literature in relationship to foreign body reaction. Only two cases of unintentional interfaces of foreign bodies with neural tissue as the primary pathology for clinical symptoms were noted. One case involved a 13-year-old boy born with a myelomeningocele who experienced progressive lower-extremity pain and foot deformity. It was later discovered that terminal nerve roots had adhered to a piece of mesh lying in the intradural space initially placed during his primary surgical defect closure.[10] A second case

ABBREVIATIONS AED = antiepileptic drug; CT = computed tomography; MRI = magnetic resonance imaging.
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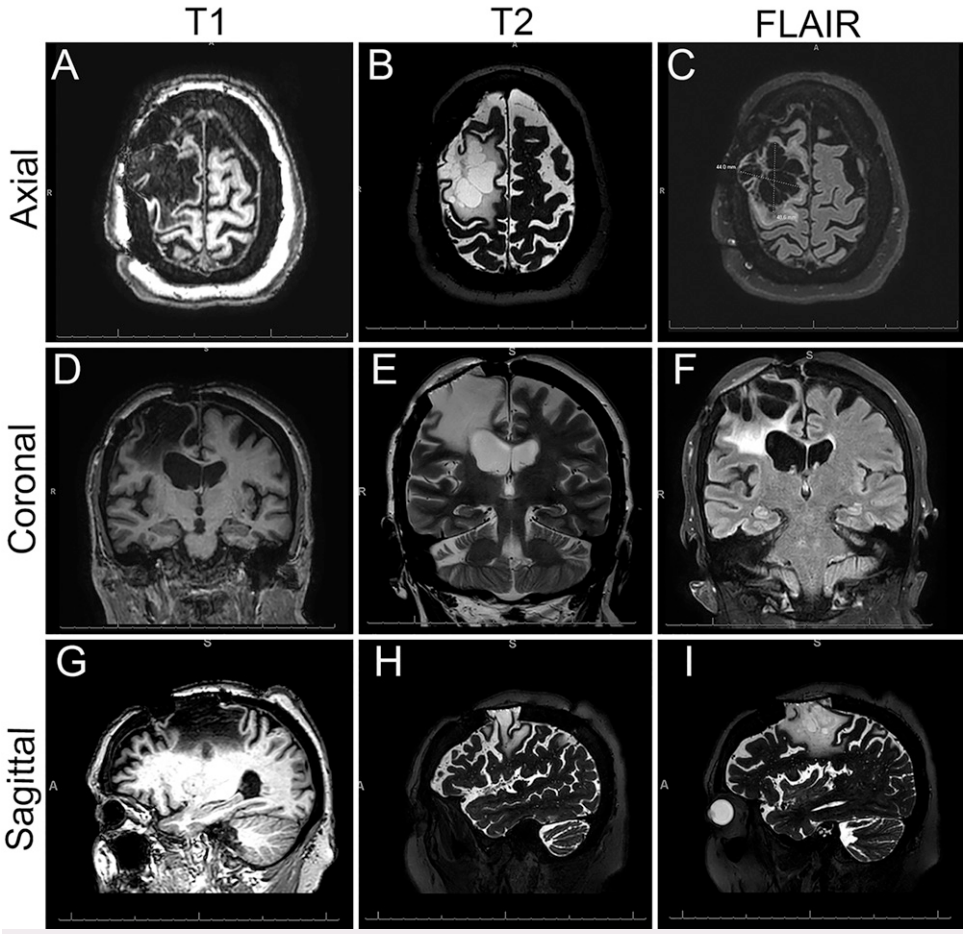

FIG. 1. Preoperative MRI sequences reveal tethering of posterior right frontal cortex to previously implanted surgical mesh. Axial (**A–C**), coronal (**D–F**), and sagittal (**G–I**) MRI in T1-weighted (**A, D, G**), T2-weighted (**B, E, H**), and fluid-attenuated inversion recovery (**C, F, I**) sequences demonstrating macrocystic encephalomalacia involving the posterior right frontal lobe and measuring approximately 4.9 cm anteriorly to posteriorly by 4.4 cm transversely.

of spinal cord tethering was reported in a 15-year-old girl 15 years after primary lipomeningocele surgery when she was 3 months old, in which a lyophilized dural graft implant caused a fibrotic tethered scar.[11] Although these two cases of spinal cord tethering to foreign bodies were described, no case documented intracranial neural tethering to mesh implants. To our knowledge, we present the first case of tethered brain, or unintentional interfacing of mesh with cortical tissue.

Illustrative Case

History and Presentation

A 68-year-old right-handed woman presented with severe intractable seizure disorder and worsening left hand gross and fine motor weakness and incoordination. Typical seizure started with a left hand aura described as a floating feeling, which progressed to tonic flexion and clonic jerking of the left hand and face intermittently followed by postictal Todd's paresis. Multiple antiepileptic drugs (AEDs) had failed. Her past surgical history was notable for a prior right frontal craniotomy for World Health Organization grade I meningioma resection with mesh cranioplasty in 2011 at an out-of-state institution, from which limited operative records were available. This case was complicated by a cerebrospinal fluid leak and a suspected postoperative wound infection. Her situation had been managed conservatively with oral antibiotics and application of silver nitrate to the leaking spot.

Six years after her surgery, she presented to our comprehensive epilepsy center with medically resistant epilepsy. Video electroencephalograph demonstrated right frontocentral seizure activity. Initial imaging demonstrated no evidence of tumor recurrence, a skull defect with mesh cranioplasty, and macrocystic encephalomalacia along the posterior right frontal lobe. At presentation, referral was made to functional neurosurgery to discuss closure and repair of the skull defect; however, the patient declined. Subsequent magnetic resonance imaging (MRI) revealed progression of the macrocystic encephalomalacia involving the posterior right frontal lobe and measuring approximately 4.9 cm anteriorly to posteriorly by 4.4 cm transversely (Fig. 1). There was also evidence of brain parenchyma herniation (encephalocele) through the right frontoparietal craniectomy defect with likely tethering to the mesh cranioplasty on preoperative computed tomography (CT) (Fig. 2).

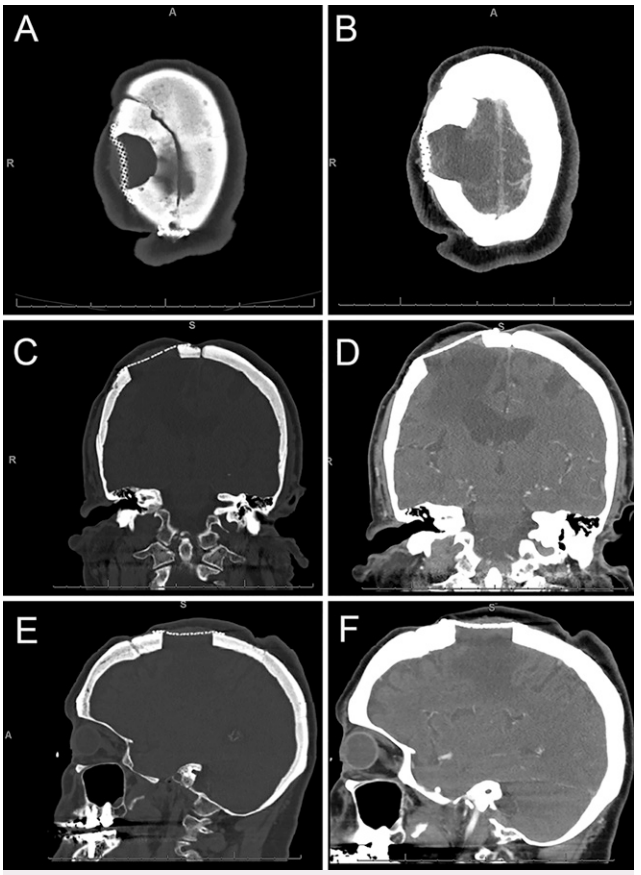

FIG. 2. Preoperative CT and CT angiography support tethering of posterior frontal cortex to surgical mesh. Axial (**A and B**), coronal (**C and D**), and sagittal (**E and F**) CT (**A, C, E**) and CT angiography (**B, D, F**) images demonstrating tethering of cortical tissue to surgical mesh. Macrocystic encephalomalacia is also evident, involving the right posterior frontal lobe, with parenchymal herniation through the right frontoparietal craniectomy defect.

Operation and Postoperative Course

Because of the progressive nature of her clinical and radiographic condition and worsening seizure disorder, after careful consideration and thorough discussion with the patient and her family, the decision was made to proceed with surgical removal of the mesh, including brain de-tethering, duraplasty, and custom-made cranioplasty. A calcium phosphate composition in combination with a supporting titanium skeleton (OssDsign, Sweden) bone flap was used to decrease the rate of infection.[12]

Image-guided redo right frontoparietal craniotomy was performed to repair the skull defect with reparative brain surgery to release the brain cortical tissue. The previous skin incision was opened in the usual fashion. A plane between the mesh and galea was dissected using sharp and blunt dissection. No electrocautery was used during this part of the procedure to avoid cortical injury and spread of current. Eventually, posterior and anterior margins of the previous bone flap, which was partially fused, were exposed and the previous mesh was identified. All screws were removed from the circular mesh that was located in the center of the craniotomy flap. The mesh was then carefully lifted and freed of adhesions using microdissection techniques, and cotton patties were used to gently displace the adherent brain parenchyma from the undersurface of the

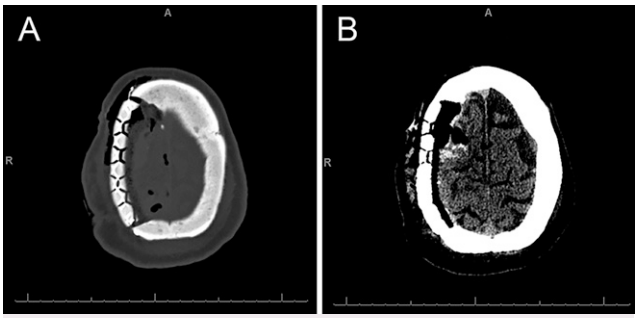

FIG. 3. Postoperative axial CT demonstrates resolution of tethered cortex to surgical mesh. **A and B:** Axial images without contrast reveal successful placement of calcium phosphate custom-made cranioplasty (OssDsign) and detachment and preservation of previously adhered cortical tissue. Postoperative pneumocephalus and a small amount of subarachnoid hemorrhage are demonstrated.

mesh. A #1 Penfield dissector was then used to dissect the brain or thin layer of dura from the undersurface of the inner table of the skull circumferentially around the craniectomy defect, which was exposed by removal of the mesh. The brain surface was continually irrigated with cold saline during dissection.

A large skull defect was exposed after mesh removal, and a single layer of Surgicel (Ethicon) was applied for hemostasis. A high-speed drill was used to place burr holes in the two previous anterior burr hole locations, and the dura was dissected carefully to remove the anterior half of the previous bone flap. Posterior burr holes were redrilled, and the posterior half of the remaining old craniotomy flap was removed. Dura was exposed and an adequate plane between the brain and the epidural space was obtained. Upon visual inspection, the brain looked discolored from scar tissue formation and tethering. Intraoperative cultures were obtained and found to be negative. A 5 $\times$ 4–cm dural substitute, nonsuturable collagen matrix (DuraGen), was placed in the epidural space. A custom-made 4 $\times$ 7–cm bone flap was used and secured in place in the usual fashion. The wound was irrigated with antibiotic solution. Adequate cosmetic correction and hemostasis were achieved. The skin was partially rotated anteriorly and clockwise to adequately cover the craniotomy site, and galea was approximated using interrupted, inverted 3-0 Vicryl. Skin was approximated with interrupted vertical mattress sutures using 2-0 nylon, and no drains were used.

The patient was admitted to the neurosurgery intensive care unit for monitoring and seizure precautions. Postoperative head CT without contrast demonstrated expected postoperative changes, including a small amount of pneumocephalus with trace subarachnoid hemorrhage without mass effect or midline shift (Fig. 3). On postoperative day 1, the patient expressed improvement of left hand function, noting her hand was unclenched upon waking from surgery. She was able to keep the fourth and fifth digits of her left hand in extension at rest, which she had been unable to do preoperatively. She admitted to residual issues with grip and control of her left hand, however. Her self-reported left hand strength and control continued to improve until discharge 3 days postoperatively. At the last follow-up, she was seizure free (on AEDs), her neurological exam continued to improve, and the wound was well healed.

Discussion

Recent research advances have pushed the boundaries of brain and hardware interfaces. Syringe-injectable mesh electronics with

stimulatory capacity have been shown to seamlessly integrate with neural tissue in rodent models,[13] and brain machine interfaces for neuroprosthesis and neurorehabilitation are nearing clinical application.[14] Before the clinical implementation of these forward-looking devices, attention first must focus on cases of unintentional integration of biomedical materials with neural tissue and the downstream ramifications of those interactions. Namely, consideration must be given to long-term effects of these implants, with specific attention paid to resulting gliosis and neuronal scarring provoking functional deficits. Also, techniques for successful neural disentanglement of such devices must be investigated in the event of necessitated removal.

Observations

Here, we present the first case, to our knowledge, of cortical entanglement with postcranioplasty mesh. On presentation, the patient had diminished functional control of her left hand, which had progressively worsened since her original meningioma resection 10 years earlier. Upon surgical exposure of the mesh, the degree of mesh and cortical adherence was fully appreciated. Careful microdissection was performed to free the adhered cortex from the undersurface of the mesh during its removal while continuous irrigation of the brain was performed with cold saline to decrease the risk of intraoperative seizure. Because of apposition of the titanium mesh with cortical tissue, care was taken to avoid inadvertent contact of electrocautery tools with the mesh. De-tethering was safely achieved while preserving preexisting neurological function, and the patient was ultimately able to regain an encouraging amount of function in her left hand after surgical mesh removal, demonstrating the safety of this surgical approach.

Lessons

This case provides an account of the progressive functional damage that tethering of surgical mesh and cerebral cortex can cause. Care must be taken during cranioplasty when using surgical mesh to ensure proper placement and using dural substitutes to prevent tethering of cortical tissue to synthetic biomedical materials. We hypothesized that cerebral pulsations in the setting of an absent or incomplete dural coverage can lead to delayed adhesions to a titanium surgical mesh and result in progressive cystic encephalomalacia with a resultant neurological deficit. Attached cortex can be successfully separated without unnecessary sacrifice of the adhered tissue, with the goal of preserving functional control of the left hand and upper extremity. A sound surgical approach to the management of this rare complication and a clear understanding of the potential intraoperative complications are necessary for the safe de-tethering of brain parenchyma–mesh interfaces.

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Disclosures

The authors report no conflict of interest concerning the materials or methods used in this study or the findings specified in this paper.

Author Contributions

Conception and design: Vale, Spellicy, Moore-Hill. Acquisition of data: Kilianski, Poston, Moore-Hill. Analysis and interpretation of data: Vale, Spellicy. Drafting the article: Spellicy, Kilianski, Moore-Hill. Critically revising the article: all authors. Reviewed submitted version of manuscript: Vale, Spellicy, Kilianski, Moore-Hill. Approved the final version of the manuscript on behalf of all authors: Vale. Administrative/technical/material support: Kilianski, Poston. Study supervision: Vale, Moore-Hill. Senior/lead resident surgeon: Kilianski.

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